Gustafsson, Åsa., Vessby, J., Rask, L-O. (2012)
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Lean Construction Journal pp. 61-71
www.leanconstrutionjournal.org

Identification of potential improvement areas in industrial housing: A case study of waste

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Abstract

Purpose: The purpose of this paper is to categorize waste in the construction industry for a specific building system (using wood as the load-bearing elements).

Research method: This case study consists of the following three parts: 1) current state maps of the supply chain; 2) identification of waste appearing at the construction site; and 3) a time study of the installation process.

Findings: This paper proposes that waste in the construction supply chain for the current case can be categorized as follows: Defects and Controls, Logistics, Utilization of Resources, Health and Safety, and System and Structure.

Limitations: The current paper is based on a single case study; and hence, its results need to be replicated in further studies.

Implications: This study contributes to previous knowledge with regards to lean construction and waste (as it specifies the waste concept with regard to the construction industry).

Value for practitioners: This paper provides a categorization of waste in the construction industry in which the categories are inherent from the same source. Hence, elimination of the waste is facilitated by identifying an overall solution for each category rather than for individual types of waste.

Key words: Logistics, Value Stream Mapping, Waste, Wooden Residential Buildings

Paper type: Case study

Introduction

Between 1968 and 1998, the production costs for multi-family houses in Sweden doubled, while those for single-family houses increased by only about 70% (Lutz and Gabrielsson, 2002), suggesting that small single-family houses are produced in a more efficient way than are large multi-family houses. Utilizing wood for load-bearing structures is completely dominant in the construction of private single-family homes in Sweden (Näringsdepartementet, 2004). There is a rebirth of the interest in the use of wood as a

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structural load-bearing material for multi-story buildings in Sweden. This increasing interest in high-rise, multi-family housing is opening up a new segment of the market for multi-family housing. Companies in the wood-mechanical sector, mainly sawmills, have developed building systems (consisting of load-bearing elements) for wooden housing. There are business opportunities in the market, but the market is still in its early life cycle phase, with technology, business models and manufacturing building systems are developing.

Building systems are developing in different directions under the influence of general philosophies for competitive construction. An example of construction and management concepts being introduced is that of lean construction. Lean construction is seen as a paradigm for project management (Ballard and Howell, 2004), as it emphasizes the need simultaneously to design a facility and its production process while minimizing waste and maximizing value to the owners (Howell, 1999). The introduction of lean thinking in the construction industry was triggered by the need for reduced waste and improved efficiency (e.g., Koskela, 1992). The introduction of Lean Construction was inspired, but not only, by successful applications in industrial manufacturing i.e. lean manufacturing (c.f. Björnfot and Stehn, 2005; Lessing et al., 2005; Björnfot and Sardén, 2006; Mastroianni and Abdelhamid, 2003). In comparison with the manufacturing industry, in which these concepts evolved, the construction industry is a project-based industry with an environment characterized by a high level of uncertainty and complexity due to such factors as short-term relationships and a fragmented structure of the supply chain.

The development of lean processes in the construction industry has been elaborated on by Koskela (2004) assessing the principles of lean thinking as well as justification of these. The author concludes that the application of lean principles is limited to mass production excluding the construction industry. Therefore, a study applying lean to the construction industry ought to be needed. Research that has been performed indicates that construction is ineffective, and many problems have been observed. An analysis of the perceived problems shows that many of them are what can be called supply chain problems stemming from the interfaces between the actors (Vrijhoef et al., 2001). In their research they find that higher levels of commitment and trust bring efficiency gains. Such findings could be confirmed in a case study. Previous research indicates that much of the waste in the construction industry has a considerable value and is avoidable (Teo and Loosemore, 2001), implying that there is a need for further research focusing on identification and categorization of waste in the construction industry in order to be able to reduce it. A construction industry study revealed that waste accounts for up to 30 to 35% of the total cost of the projects in Sweden (Josephson and Saukkoriipi, 2005). This indicates the great potential for improving the effectiveness in the Swedish construction industry. In addition, activities in the construction industry are normally measured in days or weeks, rather than in minutes or hours in which most manufacturing operations are measured (Fearne and Fowler, 2006). Time is treated with less respect in the building industry as compared to other industries. However, in order for the lean philosophy to further be developed in the construction industry, a categorization of waste is needed in which the categories are related to the origin of the waste as well as it is related to the chosen building system in order to enable the actors to eliminate each type of waste.

This paper provides a categorization of waste that allows the actors to identify waste related to a specific building system, with similar origins in order to enable them to take appropriate actions in order to eliminate the waste. Some preliminary suggestions for reducing the waste are given in the conclusions, although a detailed analysis of how to eliminate each of the sources for waste is beyond the scope of the current study. The empirical data from the studied case consists of the following three parts: 1) current state maps of the supply chain; 2) identification of waste appearing at the construction site; and 3) a time study of the installation process aimed at identifying changes of time consumed during installation of the load-bearing elements. For actors entering the market, it is necessary to make attractive offers to their customers, and it is therefore necessary to continuously improve the building system and eliminate waste in the processes and supply chain.

Literature review

In general, lean is a practice that considers the use of resources for purposes other than creation of value for the end customer to be wasteful, and hence this use of resources should come to an end. According to Mossman (2009), there are several benefits of lean in construction such as more satisfied customers, productivity gains, and greater predictability. Alves and Tsao (2007), as well as Bertelsen (2004), have reported on the development of the concept of lean construction.

Several authors have studied the application of lean philosophy to the construction industry and to supply chain management related to the construction industry (e.g., Vrijhoef and Koskela, 2000; 1999; Mossman, 2009; Arbulu and Ballard, 2004; Childerhouse et al., 2000). Johansen and Walter (2007) conducted a survey among German construction companies in order to ascertain the current understanding of lean principles, perceptions of lean, and future trends in lean development. In addition, Johansen et al. (2002) reported on published material on lean in the UK and the Netherlands regarding the construction industry. Velarde et al. (2009) provided process flow improvements in a modular home manufacturer. Applications of Value Stream Mapping and identification of waste is well established in dozens of studies concerning the construction industry (see for instance IGLC conferences and journals) Examples being Arbulu et al. (2003) and Fontanini and Picchi (2004). Arbulu et al. (2003) performed a value stream analysis based on the supply chain for pipe supports, while Fontanini and Picchi (2004) conducted a case study focusing on value stream micro-mapping of aluminum windows. More recently, Melo and Alves (2010) carried out an investigation of the supply chain of prefabricated wooden doors, based on Value Stream Mapping. Further, Arbulu and Tommelein (2002) conducted a study focusing on elimination of waste in order to improve total delivery lead-time of pipe supports, while waste in terms of value drivers has been studied by Taylor and Björnsson (2002).

An important part of lean construction is the concept of waste. A Swedish construction industry study conducted by Josephson and Saukkoriipi (2005) classifies waste into the following four categories:

- **Defects and Controls**. Costs for visible and invisible defects are significant and inspection costs, insurance, thefts, and damage are also substantial. Waste of this kind accounts for more than 10% of the total production cost of a project.
- **Utilization of Resources**. Value mappings show that a surprisingly large share of waste is a result of waiting time, idle machines, and material spillage. This kind of waste also accounts for more than 10% of a project's total production cost.

- **Health and Safety**. Job-site related injuries and sicknesses are so significant that they need to be categorized in a separate group. The greatest costs are connected to rehabilitation and early retirement pensions, and indirectly load the project through taxes. Waste from this group accounts for approximately 12 % of total project production cost.
- **System and Structures**. Waste in this category such as transaction and documentation costs, and represents 5% of total project production costs. This category of waste is the most under-reported of the different types of waste.

The study provided by Josephson and Saukkoriipi (2005) classifies waste in the Swedish construction industry into four categories; and this study will hence be used (and developed) for classification of wastes identified in the non-compliance reports.

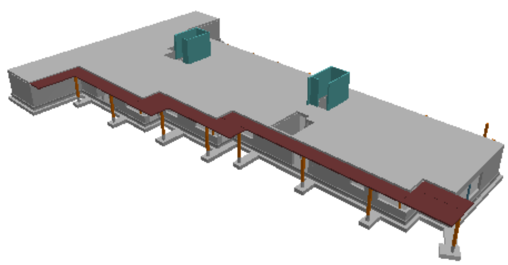
Method

Industrialized housing is part of the Swedish construction industry. When producing timber building systems different levels of on-site and off-site activities are involved. Industrialized housing can be divided into the following three parts: 1) off-site prefabrication of materials and parts; 2) prefabrication of components and sub-assemblies; and 3) prefabrication where 80% of the work is completed in a factory environment (Höök and Stehn, 2008). The basis for the current case study is the Limnologen block in Växjö, the highest recently built multi-story residential house using wood in the load-bearing structure in Sweden. The supplier is a so-called system supplier implying that they take responsibility for the whole building rather than individual components only. Four eight-story houses provide a total of 134 apartments. The apartments are of different sizes, ranging from one room to five rooms. The design of the apartments is similar between stories 2 and 6: the top floor plan differs, with only three apartments, each of two stories. In general, the case study research method is used for exploratory research, in which no specific hypotheses are proposed; rather, a basic understanding is sought of how and why different phenomena occur. The case study research method is particularly useful when the object of the study is a contemporary phenomenon occurring in a real-life setting over which the researcher has little control (Yin, 2003). The use of a single case over which the researcher has little control, thereby complies with Yin´s criteria for selecting the method. A general concern regarding case studies is the quality of the empirical research. The following four tests are commonly used to establish the quality of empirical research: 1) construct validity, which refers to using measuring methods that captures the problem in a correct way; 2) internal validity, which refers to explaining relations between variables; 3) external validity, which refers to generalization of a case study results to other cases; and 4) reliability, which aims at minimizing errors and biases in a study in order for another researcher, following the same procedures, to arrive with the same findings.

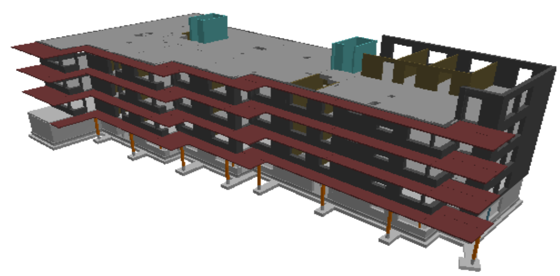
In order to be able to identify and remove non-value-added activities, value stream mapping (hereinafter referred to as VSM) is a helpful tool, as it provides graphical illustrations of the flow of material and information and all activities (value-added and non-value-added) that are involved in bringing a product from raw material to the customer. The goal of VSM is to identify all types of waste and to take the necessary actions in order to eliminate them (Hines and Rich, 1997). The first step in VSM is to identify the product or a product family that comprises a group of product variants that pass through comparable processing steps and use common resources (Womack and Jones, 2003). The second step is to draw a current state map that is mainly a snapshot of how things are currently being done. The next step is to draw a future state map that depicts what the system should look like after all the inefficiencies have been eliminated. This map then becomes the basis for making the required changes (Abdulmalek and Rajgopal, 2007). According to VSM, different types of common waste include overproduction, waiting, transportation, inappropriate processing (processing itself), unnecessary inventory (stock on hand), unnecessary transport (movement), and defects (making defective products) (Ohno, 1988; Hines et al., 1998; Hines and Rich, 1997). In order to acquire a proper understanding of how and where waste is generated, different state maps have been formed. These are based on field visits, observations at manufacturers' premises, and interviews with involved personnel. VSM has been used for mapping the process before the elements reach the site where they are built into the actual building. The lead-times collected at the manufacturer were checked with the project engineer on site in order to secure correctness and also that potential misunderstandings would be cleared up.

At the building site, data with the purpose to identify waste have been gathered from daily non-compliance reports generated by managers on site, workshops with the different teams of workers, and a meeting where contractors and suppliers discussed experiences from the building process. In addition, the site has been visited 2-4 times a week for ten months by at least one of the authors, and photos documenting the process have been taken and organized. The identified waste at the installation site has been categorized in two stages: firstly, according to the categories proposed by Josephson and Saukkoriipi (2005); and secondly, one of the groups was divided into two depending on their origin (i.e., the physical product or logistics) of the waste. The main reason for using the categorization suggested by Josephson and Saukkoriipi is that they have previously worked with the national construction industry contradictory to many others that worked mainly with other industries. The current study concentrates on the *number of observations*, rather than on *costs* (such as Josephson and Saukkoriipi, 2005), as the authors sought a basic understanding of the phenomena (waste) and hence prioritized a variety of actual observations (which those involved need to take action on) in order to conduct an overall survey in the appearance of different types of waste aligned with the studied building system. In this study, Defects and Controls have been defined as defects on the products as well as the control that has been done in order to secure the quality of the products; Utilization of Resources regards the need for resources to do additional work on the products; Health and Safety ensures that of construction workers, and System and Structures regards the administration of construction work and products as well as the problems regarding the chosen building system. To guarantee as valid results as possible a number of different sources have been used during the data collection phase including interviews of various informants (employees at the manufacturer, employees at the transport company, and construction workers) in the supply chain.

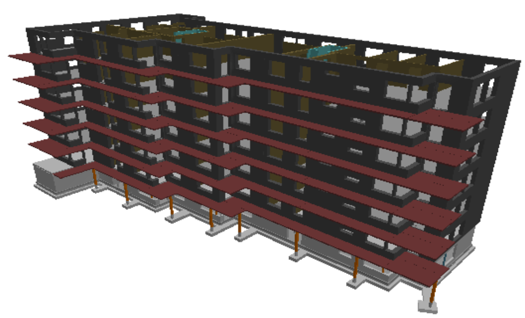
A time study has been conducted in order to identify and describe if there are systematic changes over time of the time required for installation of the elements. This study is based on all four buildings. However, the times needed for installing the prefabricated elements were recorded for two of the four buildings (Building 1 and Building 3); the two buildings differed in the methods used for collecting this data. In Building 1, the time needed for installing each of the wall and floor elements was timed from when installation began, or the moment when the element was hooked to the gantry crane, to the point in time when installation of the element was completed and unhooked from the crane. Altogether, the installation of approximately 500 elements was timed in this way, since 27 floor elements and 60 wall elements were installed on each of the six stories. In Building 3, on the other hand, measurements were made - for days on which construction was in progress and the installation of building elements took place - of the time that elapsed between when the first installation of a building element began and when the last installation of a building element was finished. The number of elements installed during that time was also noted. Lead times at the installation process were checked with the installation team. A visualization of the installation process is presented in Figure 1.



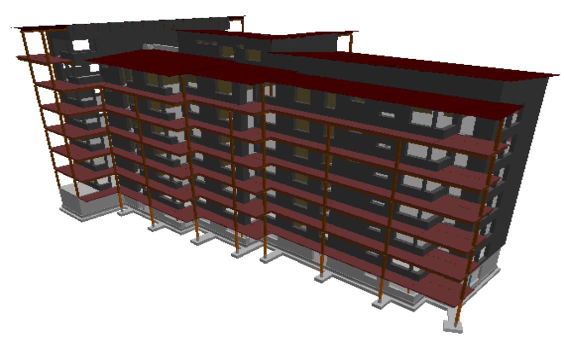
Stage 1. Only a few of the first timber elements are installed.



Stage 2. Some of the wall elements on the fifth story are being installed.



Stage 3. Only installation of the penthouse and roof remain.



Stage 4. The house is completed with respect to installation of elements.

Figure 1: Illustration of four installation stages of one building in the Limnologen development.

A three-dimensional building-information model was created in order to visualize the instantaneous state of the installation processes. Connections between the geometric model and the times taken for installation of the separate building elements were assessed by use of visualization software. This program shows how the building was constructed element-by-element in the order of installation of the different elements. In the visualization stage, the fourth dimension is that of time. This enables installation to be studied in a virtual sense, element-by-element, before, during, and after completion of the construction process. Figure 1 shows four different installation stages with progressively higher degree of completion of the structure.

Regarding external validity, the results from this case study may be generalized to other construction cases with a similar building system as the research design is well-described and allows for other researchers to pursue. Additionally, the results from this study can be seen as an example of industrialized construction backed up by lean construction theory. Considering reliability, the possibility to replicate the study is high since there is thorough documentation on how data was collected and analyzed as the procedures have been documented in case study protocols (containing an overview of the case study project, field procedures, case study questions and a guide for the case study report) and the material for the time study stems from a database. Sources of evidence used for the study are documentation, interviews, direct observations, and participant observations.

Empirical data and analysis

Current state maps

Floor elements and apartment separating walls are produced at the system supplier's facility, while the assembly of exterior and solid internal walls takes place at a sub-supplier[4]. Raw material is supplied from two of the system suppliers' sawmills and the elements are, after production, transported to the installation site. A general overview of the process is provided in Figure 2.

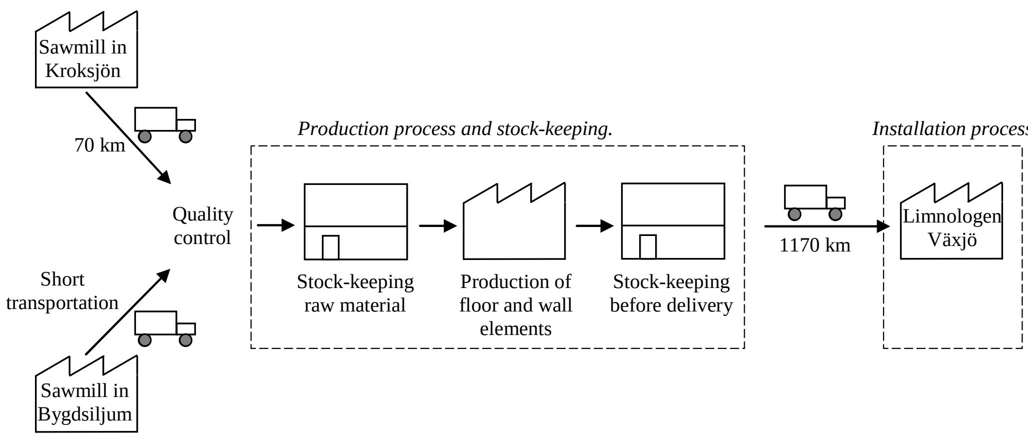


Figure 2. General process overview of production and installation of the timber-based building elements.

Incoming material comes from one of the system supplier's sawmills and from the system supplier's sawmill located closely to the production facility. The boards are quality-inspected, after which production of the cross-laminated timber panels (CLT) begins. After production, the CLTs are transferred to another conveyor belt for trimming. The boards are sawn to correct dimensions and are prepared for installation of under-floor heating. As the trimming is finished, the CLT is moved with the help of a gantry crane to another moving platform, where processing of floor elements takes place including installation of webs and flanges, sewer pipes, insulation, ceilings, and sprinklers. The floor elements are

4 A system supplier supplies the structural load-bearing system consisting of floors and walls (exterior, solid internal, and apartment-separating) elements.

then turned over, stacked and packed, and wrapped together into packages before moving to the stock site for delivery to the construction site. The process is illustrated in Figure 3.

The production of the different types of wall elements, either at the system supplier's or at sub-supplier's premises, corresponds to working stations at which the builders take the CLTs and cut them to size, etc. as specified on the respective drawings. In the case of exterior and solid internal walls, the material is transported to the sub-supplier's working stations where the same procedures take place.

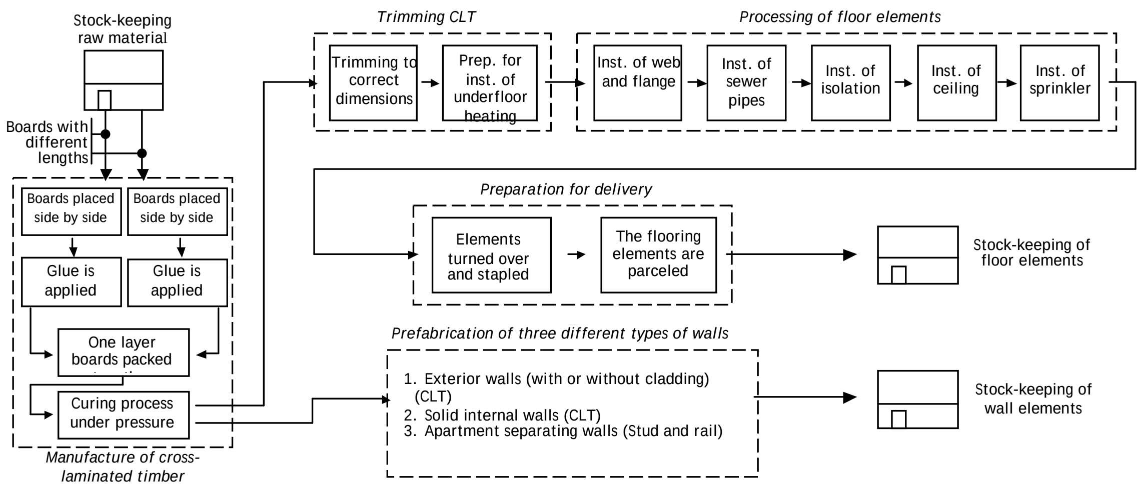


Figure 3. Process overview of the production of floor and wall elements.

At the installation site (i.e., construction site), the elements are offloaded and placed at the construction site. From ground level, they are lifted to the installation level by gantry crane to be fitted to the previously installed elements. Floor elements are fastened to the wall, while wall elements are fitted with tie-down rods and fastened to the bottom rail. The installation process is illustrated in Figure 4.

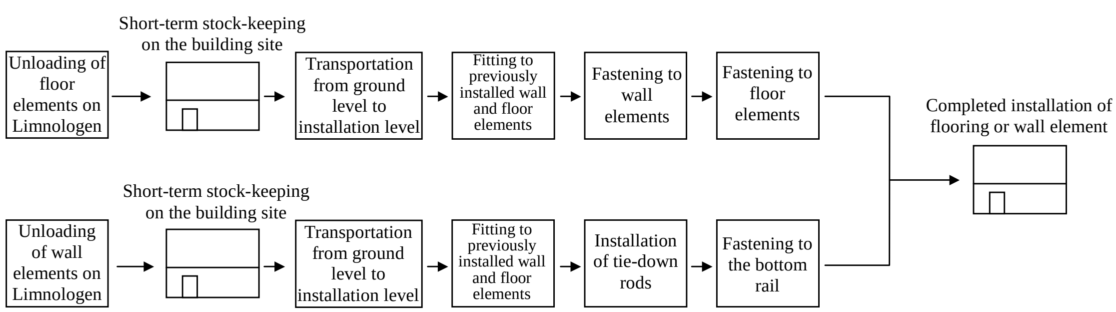


Figure 4. Process overview of installation of floor and wall elements.

Identification of waste

The total time for production and preparation for delivery of a single floor element to be later installed at the building site is 182 minutes. The dominating waste encountered with respect to time can be classified as either Waiting Time (stock-keeping before delivery, 4320 min) or Transportation Time (transport to construction site, 2880 min).

These two types of wastes are largest since the since the elements transported take quite a long time to get transported and are delivered to the site and stored there for approximately 24 hours. Regarding the other types of waste previously defined as Overproduction, Inappropriate processing, Unnecessary inventory and motion, Defects and overall structure (see Hines et al., 1998) also exist but are not as large as the two first mentioned.

One large source of waste is that of Waiting Time. Waiting time evolves due to storage of elements before and after delivery. There might be a number of reasons for storing elements at the manufacturing site. One is that the production pace is faster than the pace of assembly, another that deliveries take place only with full trucks. In order to reduce the waiting time, a manufacture might take place closer to the installation site. However, this would reduce the benefit from economies of scale in production. Reducing the transport volume and increasing the frequency of deliveries is dependent on changes to transport systems. In addition, a 24-hour storage time at the installation site is also dubious. However, a decision needs to be made between having the elements stored for one day and ready for installation as soon as they are needed or not having any elements and risking waiting times in installation. Since the elements are produced in advance and stored at the producer this 24-hour storage at the building site serves only as a buffer reducing the risk of mistakes in deliverance.

As far as Transportation Time is concerned, firstly, the long wooden boards are transported to the manufacturing site; and secondly, elements are fabricated and transported to the building site. Waste associated with Transportation Time can be tracked to two sources. The first of these is transportation of the sawn boards from sawmill to the manufacturing site. Sawing these boards more closely to the manufacturing site could decrease the time wasted during construction. The second source of waste coupled to transportation time is that the load-bearing elements are manufactured 1170 km north of the building site. This waste could in theory be eliminated by production at the installation site.

According to Josephson and Saukkoriipi (2005), waste in the Swedish construction industry can be divided in Defects and Controls, Utilization of Resources, Health and Safety, and System and Structures. Since their classification was made for the same market (with different building systems) as this study, their categorization was used. Utilization of Resources, i.e., identification of waste based on value maps, has been included in current state maps but is not included in Table 1. Table 1 provides a specification of the 177 observations stated in the non-compliance reports. The table identifies the waste category, source, number of observations, and type of observations. The categories are shown in Figure 5. Note that Defects and Controls account for 75% of the observations.

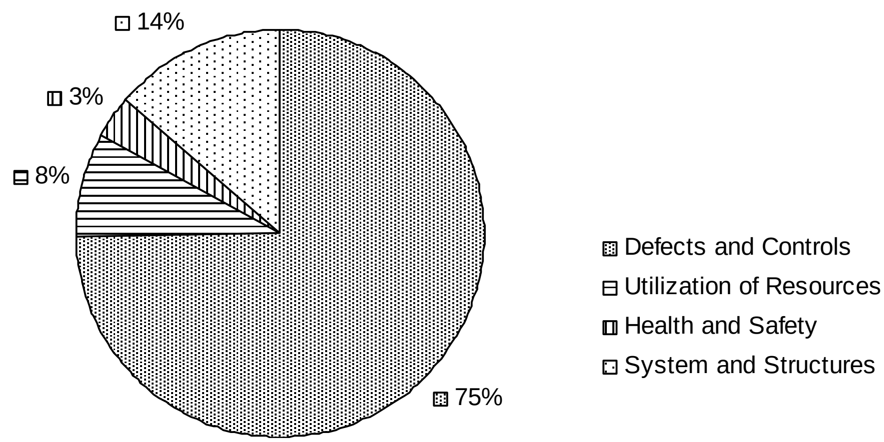


Figure 5: Overview of each waste category's relative share of observations based on the daily reports from the workers on the installation site.

Table 1: Specification of waste categories and observations

Waste	Sources	No. of remarks	Type of remark
Defects and Controls	Elements and installation – Floor elements	27	Not manufactured correctly (i.e., drilling), which needs to be fixed before assembly
	Dimensional error – Wall elements	15	The dimensions vary
	Construction errors from factory – Wall elements	32	Missing parts in wall assembly, e.g., tie down rods and window fasteners
	Supply of material – Logistics	32	Missed important delivery service elements such as contents (elements have been missing, staple missing, and elements have not been loaded in assembly order), time accuracy, and missing wrapping
	Damage from transportation and lifting – Logistics	13	Transport damage (such as broken window frames), e.g., on walls and windows
	Balconies - Others	10	Minor misses in production and cracks in flooring
	Elevators and stairs – Others	3	Minor defects
Total D&C		*132*	
Utilization of Resources	Installation – Floor elements	15	Work needed for installation of drains
Total U of R		**15**	
Health and Safety	Safety issues	6	There is an open area *for reloading* (risk for falling), an *open shaft in the floor elements* (risk for falling), and *personal protective equipment is complicated (*difficult to use)
Total H&S		*6*	
System and Structures	Concept - Floor elements	6	*Load-bearing elements*: major bolting work required during assembly *Non-load-bearing elements*: insulation, under floor heating, drains *General*: placement of lifting device
	Concept – Wall elements	6	*Major bolting work required* during assembly *Assembly of plaster,* due to either the fact that the measures are not satisfactory or the thickness of the insulation
	Weather protection – Others	12	*Overhead crane*: capacity and problems caused by the weather The weather protection *concept* implies wind tunnels (affecting the working environment, rain & snow on the assembly floor) *Geometric shaping* implies that some elements need to be pushed into place by the assemblers
Total S&S		*24*	
	Grand Total	**177**	

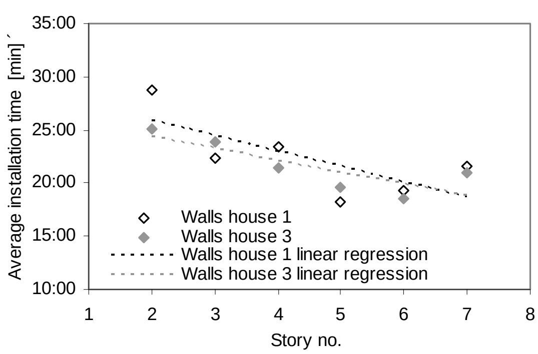
Identification of time consumed

In two of the four buildings, the time consumed for installing the 60 wall elements and the 27 floor elements per story was investigated. This was done for the second and the seventh stories. The aim of this time study was to find out whether installation time changed in a systematic manner during erection of the buildings. It also enabled the proportion of working time spent on installing elements to be determined. The following pages describe the results and potential improvement areas that could be identified.

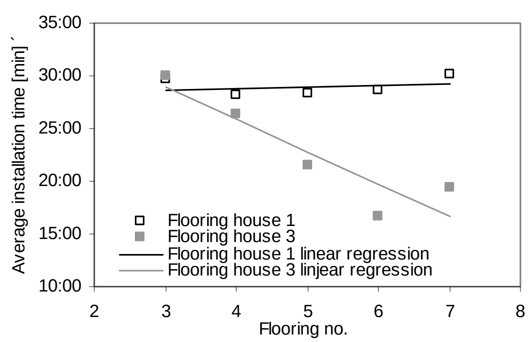
Installing the wall elements took about 2.5 working days per story, and installing the floor elements took approximately 1.5 working days per story. In terms of a 40-hour working week, installation of the wall elements took approximately 55% of the working time (in each of the two buildings). The corresponding results for the floor elements were that installation took about 33% of the working time in Building 1 and about 26% of the working time in Building 3. The seven percentage-points reduction in installation time for the flooring in Building 3 indicates that the floor installation procedures in that building were more effective. The remainder of the time in both weeks was taken up by the installation of beams, columns, and access balconies, by complementary work around stairs and elevators, by safety work, and by the work of installing rails on the flooring for the walls that were later to be installed.

For the wall elements as a whole, the average installation time per piece was found to be approximately 22 minutes. The corresponding figure for installation of the floor elements was found to be about 26 minutes. This means that, under normal circumstances, the floor elements appear to be slightly more time-consuming to install than the wall elements. This may partly be due to difficulties in fitting the more complex flooring elements to each other.

A detailed description of the average installation times is presented in Figure 6, the average times there being shown as a function of which floor element was involved. It was found that the highest and the lowest average time per story for installing a wall element, both of these being for Building 1, were approximately 29 minutes and 18 minutes respectively. The corresponding figures for floor elements were 30 and 17 minutes respectively – the first of these being for each of the two buildings and the latter for the third building. Such differences suggests that the installation process is very susceptible to disturbances, and that it is possible to reduce the installation times for both flooring elements and wall elements appreciably.



(a)

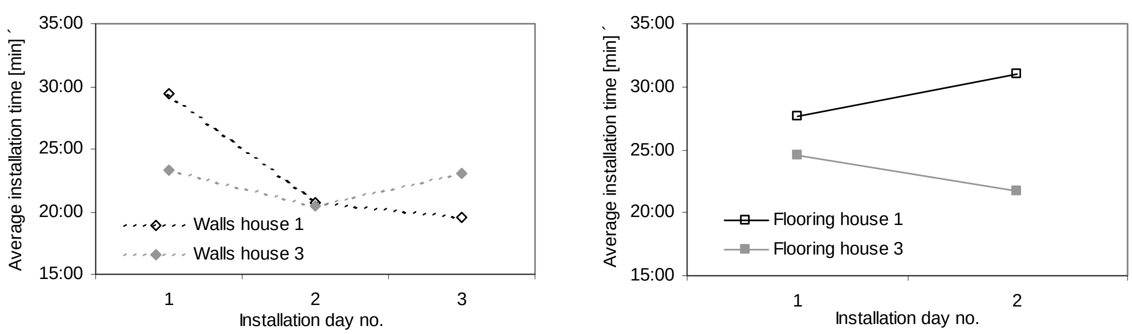


(b)

Figure 6. Average installation times in Buildings 1 and 3 respectively, for (a) wall elements and (b) floor elements. The figure indicates that, with the exception of the floors in Building 1, less time was required for installations that were carried out higher up in the buildings.

A linear regression analysis utilizing the least square method showed that for installation of the wall elements there was a tendency in both buildings for installation to take a shorter time higher up in the building, despite the fact that the time required for transportation of each element from the ground level to the story on which it was to be installed obviously increased with height above the ground. The situation differed for the floor elements in Building 1, for which the linear regression results indicate a marginal increase in the time required for installation of the flooring higher up in the house. Two explanations of the time required being lower at higher levels (apart from the floor elements in Building 1) above the ground could be that more adjustments were being made to improve the fit of the separate elements as the site of the work moved upwards in the building, and that the builders were becoming increasingly familiar with the use of the system and in the recurring operations to be carried out. The latter of these indicates the effect of a progressive learning curve for the workers on-site.

In the same way, there was a decrease in installation time required for floor elements at higher levels in Building 3. However, the situation differed for the flooring elements in Building 1, for which the linear regression results indicated a marginal increase in the time required for installation of the flooring higher up in the house. This result can be seen as reflecting the difficulties associated generally with the installation of flooring.



(a) *(b)*

Figure 7. Average installation times for (a) walls and (b) floors on separate days of installation.

Figure 7 shows the average installation time per installation day. Two observations can be made, each being very different from the assumption that one might otherwise make, that the time required for installing a particular element should be independent of the day on which installation occurs. The first observation is that, in Building 1, the average time needed for installing a wall element was considerably higher on the first day than on the other two days. An analysis of how this average came about shows that the high average value was largely a function of the time taken for installation of wall elements on the second story on that particular day. The second observation is that, on the second day, the average time needed for installing flooring elements was nine minutes longer in Building 1 than in Building 3. This difference is not due to the results for any particular story or the like, but appears rather to be an indication both of the installation of floor elements being considerably more effective in Building 3, and of the fitting together of the floor elements there being better.

Modified categorization of waste

The remarks identified in the empirical study (i.e., daily non-compliance reports) have been categorized according to Josephson and Saukkoriipi (2005). However, according to their categorization Defect and Controls accounts for 75% of the total observations. There is therefore a need to divide Defect and Control into sub-groups or to separate the group into two individual groups: one covering the physical products and one covering the logistics associated with the product. The remarks belonging to the Logistics category is to be considered as remarks that are caused during transportation of the produced product.

According to this study, one category to single out would be Logistics, so that a new grouping would be a modified category of Defect and Control (before putting the individual load-bearing elements into storage) and Logistics (from storage to installation of the individual load-bearing elements). This division of the category Defect and Control has been suggested due to the considerable share of logistics. One reason for the large share of logistics is explained by the high prefabrication level of the elements and thereby their sensitivity to handling and transports. In addition, the categories of waste identified with VSM are either Transportation Time or Waiting Time, and these would be inherited with the Logistics category.

By separating Logistics from Defect and Controls, each category's relative share of the observations is as shown in Figure 8. As shown in the figure, separated Logistics makes up 18% of the identified observations, and the illustrated damage and shortages appearing on elements that were manufactured correctly.

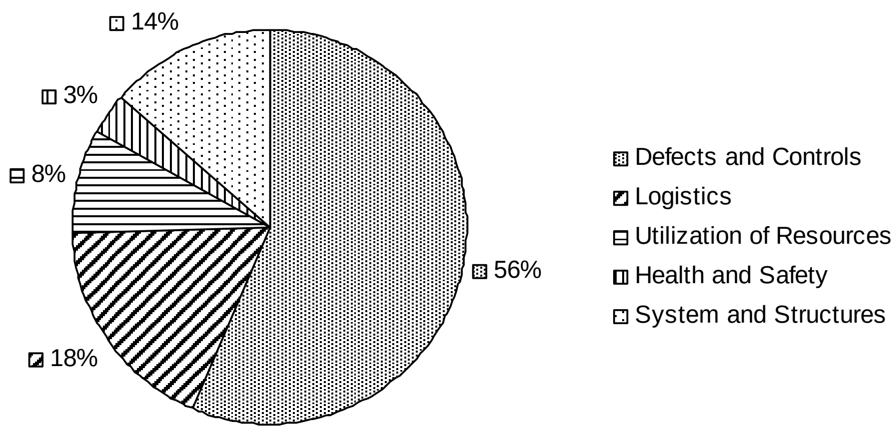


Figure 8. Practical implication of each waste category's relative share of observations based on the suggested categorization of waste.

The time study indicates that there is a waste in terms of Utilization of Resources, as the average installation time for an element of a given type was found generally to be lower higher up in the building, keeping in mind that there is an effect of learning. Studies on learning curve models have been provided by Thomas et al. (1986), and they conclude that the learning rate is not necessarily a constant value and that the different models need to be elaborated further on. Despite the focus of this study, it can be concluded that the learning curve exists in this case and that future studies need to be done.

The current study is based on a case using a specific building system in which new components and concepts have been developed by Swedish actors and delivered to the

Swedish market. The previously used categorization of waste (Josephsson and Saukkoriipi, 2005) has been complemented with the category, Logistics.

Conclusions

Elimination of waste is fundamental for all parties involved in the construction industry and its supply chain. This paper proposes that waste in the construction industry can be categorized as follows: Defects and Controls, Logistics, Utilization of Resources, Health and Safety, and System and Structures[5]. Elimination of these individual categories requires the parties to take appropriate action to each of them individually. For example the largest category, Defects and Controls, representing 56% of the observations, consists of problems related to the production of the building elements, and much of this may be eliminated already at the factory by such means as introduction of standardized routines and control of the elements before deliverance. Hence, a potential improvement area would be to improve the procedures at the production site. Waste in respect of Logistics is mainly inherent in the fact that production takes place 1170 km north of the installation site (both with regards to transportation and waiting time as well as with damage). However, there are several concerns with this set-up; the total cost for the current set-up regarding economies of scale through centralized production and large batch sizes has to be set against manufacturing close to the installation site. The other types of waste are to be considered as a result of choosing the specific building system and hence these ought to be reduced or eliminated, as the building system will be further developed[6]. Waste with regards to System and Structures are in line with Vrijhoef and Koskela (2000) in which it is indicated that waste that appears is related to decisions made before the building even started to be built. This study shows that it is possible to apply lean (as in terms of VSM) to the construction industry (focusing on this case). The actors involved in the supply chain were unknown for each other and the current way of working at the start of the building project. However, as the actors in the supply chain got to know each other and the products, higher levels of commitment and trust evolved and the distinct effects of the learning curve are a fruit of such development.

This study indicates a possibility for further increasing speed and accuracy in the process of installing timber-based flooring and wall elements (based on a learning curve). This can be concluded from the fact that the average installation time for an element of a given type was found generally to be lower higher up in the building. This can be seen as being due to increasing familiarity on the part of the workers, who learn to carry out their tasks in an increasingly efficient way. It also indicates that there is considerable potential for further improvement in the speed of installation by engaging building workers who are familiar with previous similar construction tasks (focusing on the team of construction workers skilled in the specific building system). In addition, several of the problems and efficiency losses stem from previous steps in the supply chain, which means that there is potential for improvement from other parties further back along the supply chain. System and Structure is concerned with the load-bearing system, which is continuously being developed. There is immense potential to eliminate waste and develop an efficient

[5] This categorization is based on the appearance of the types of waste identified from the non-conformance reports; hence, their importance in terms of costs has not been focused (which limits the study).

[6] How to handle the individual remarks are beyond the scope for the study.

building system based on the current technique. However, factors such as the quality of the prefabricated elements and the skills and experience of the builders are both key factors in arriving at high-speed installation of the elements.

References

Abdulmalek, Fawaz A & Rajgopal, Jayant (2007) Analysing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. *International Journal of Production Economics*, 223-236

Alves Thais da C.L & Tsao Cynthia C.Y. Tsao (2007) Lean Construction - 2000 to 2006. *Lean Construction Journal*, 3, 4, 46-70

Arbulu, Roberto & Ballard, Glenn (2004) Lean Supply Systems in Construction. IGLC -04 Copenhagen, Denmark

Arbulu, Roberto & Tommelein, Iris D (2002) Value Stream Analysis of construction supply chains: Case study on pipe supports used in power plants. *IGLC-10.* Gramado, Brazil

Arbulu, Roberto, Tommelein, Iris D, Walsh, Kenneth D, & Hershauer, James C (2003) Value Stream Analysis of a re-engineered construction supply chain. Building Research & Information, 31, 2, 161-171

Ballard, Glenn & Howell, Gregory A (2004) Competing Construction Management Paradigms. *Lean Construction Journal,* 1, 38-45

Bertelsen, Sven (2004) Lean Construction: Where are we and how to proceed? *Lean Construction journal,* 1,1, 46-69

Björnfot, Anders & Sardén Ylva (2006) Prefabrication: a lean strategy for value generation in construction. *IGLC-14.* Santiago, Chile

Björnfot, Anders & Stehn, Lars (2005) Product design for improved material flow - A multistory timber housing project. *IGLC-10* Sydney, Australia

Chilerhouse, Paul, Hong-Minh, Séverine & Naim, Mohammed (2000) House Building Supply Chain strategies: Selecting the right strategy to meet customer requirements. IGLC-00 Brighton, UK

Fearne, Andrew & Fowler, Nicholas (2006) Efficiency versus effectiveness in construction supply chains: the danger of "lean" thinking in isolation. *Supply Chain Management: An International Journal,* 11, 283-287

Fontanini, Patricia & Picchi, Flavio (2004) Value Stream Mapping – a case study of aluminium windows for construction supply chains. IGLC -04 Copenhagen, Denmark

http://mpd.midroc.se/sv/Referenser/Vaxjo-Limnologen.aspx 25nov10

Hines, Peter & Rich, Nick (1997) The seven value stream mapping tools. *International Journal of Operations & Production Management* 17, 1, 46-64

Hines, Peter, Rich, Nick., Bicheno, John, Brunt, David & Taylor, David (1998) Value Stream Management. *The International Journal of Logistics Management,* 9, 25-42

Howell, Greg (1999) What is lean construction?. Proceedings of the 7th conference of the International Group for Lean Construction, Berkely , CA, USA

Höök, Matilda & Stehn, Lars (2008) Lean principles in industrialized housing production: the need for cultural change. *Lean Construction Journal,* 20-33

Johansen, Eric, Glimmerveen, Henk & Vrijhoef, Ruben (2002) Understanding lean construction and how it penetrates the industry: A comparison of the dissemination of lean within the UK and the Netherlands. *IGLC-10.* Gramado, Brazil

Johansen, Eric & Walter, Lorentz (2007) Lean Construction: Prospect for the German construction industry. *Lean Construction Journal,* 3, 19-32

Josephson, Per-Erik & Saukkoriipi, Lasse (2005) Slöseri i byggprojekt: behov av förändrat synsätt. FoU-Väst, 1402-7410;0507 (in Swedish)

Koskela, Lauri (1992) Application of the new production philosophy to construction. CIFE Technical report #74, Stanford University

Koskela, Lauri (2004) Moving on - beyond lean thinking. *Lean Construction Journal*, 1, 1, 24-37

Lessing, Jerker, Stehn, Lars & Ekholm, Anders (2005) Industrial housing: Definition and categorization of the concept. *IGLC-10.* Sydney, Australia

Lutz, Johan & Gabrielsson, Erik (2002) Byggsektorns struktur och utvecklingsbehov. *Byggkommissionen.* Göteborg, Stockholm

Mastroianni, Remo. & Abdelhamid, Tariq (2003) The Challenge: The Impetus for Change to Lean Project Delivery. *IGLC-03. Blacksburg, Virginia*

Melo, R.S.S. & Alves, T.C.L. (2010) Investigation of the supply chain of prefabricated wooden doors. *Lean Construction Journal, pp30-42*

Mossman, Alan (2009) Why isn´t the UK construction industry going lean with gusto? *Lean Construction Journal*, Forum essay

Näringsdepartementet (2004) Mer trä i byggandet: underlag för en nationell strategi att främja användning av trä i byggandet. *Stockholm: Fritzes offentliga publikationer:*

Ohno, T. (1988). *Toyota Production System – Beyond large scale production*. CRC Press, USA

Teo, M. & Loosemore, M. (2001) A theory of waste behaviour in the construction industry. Construction Management and Economic, 19,741-751

Taylor, John & Björnsson, Hans (2002) Identification and Classification of value drivers for a new production home building supply chain. *IGLC-10.* Gramado, Brazil

Thomas, Randolph, Mathews Cody & James, Ward. (1986) Learning Curve Models of Construction Prodoctivity. Journal of Construction Engineering and Management, 112, 2, 245-258

Womack, James & Jones, Daniel (2003) *Lean Thinking; Banish waste and create wealth in your corporation*, Simon and Schuster.

Verlarde, Guillermo J, Saloni, Daniel E, Dyk van Herman & Giunta, Maximiliano (2009) Process flow improvement using lean manufacturing philosophy and simulation techniques on a modular home manufacturer. *Lean Construction Journal, 77-93*

Vrijhoef, Ruben & Koskela, Lauri (1999) Roles of Supply Chain Management in Construction. *IGLC-7.* University of California

Vrijhoef, Ruben. & Koskela, Lauri (2000) The four roles of supply chain management in construction. *European Journal of Purchasing & Supply Management,* 6**,** 169-178

Vrijhoef, Ruben, Koskela, Lauri & Howell, Glenn (2001) Understanding Construction Supply Chains: an alternative interpretation. *IGLC-9.* Singapura, CH

Yin, Robert (2003) *Case study research; Design and Method*, Sage