CONSTRUCTION SITE OPERATIONS MADE LEANER AND STANDARDIZED: A CASE STUDY

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ABSTRACT

This paper tests a method for analysing and improving construction site operations to standardize them as the common way of performing the operation. Analysis tools are used to identify improvement potential and alterations based on Lean Construction principles are implemented to fulfil this potential.

Reducing waste and optimizing production methods are some of the key elements in Lean thinking. Waste and low productivity can be products of several factors, e.g. poor material flow, suboptimal operation design or poor production control. By finding good practices for operations and standardizing the work by this norm, variability can be reduced and production reliability increased.

With thorough analysis and continuous improvement towards better practice, both time and cost expenditures could be greatly reduced both for the single unit and the project, but also throughout an entire organization over time. A field study was conducted to investigate how a traditional production unit's productivity and work flow would be affected by altering its operation according to Lean principles.

The production unit was initially analysed with its traditional practice "as is". The analysis clarified where there was potential for improvement, and alterations were suggested by the crew. Those with foundation in Lean Construction principles were implemented and performance reassessed.

Analysis showed little room for improvement within several of the tasks, as they had no waiting for tools, materials or preceding tasks to finish. On a higher level, the operation was greatly improved by eliminating entire tasks, rearranging the work sequence, increasing visualization and increasing the number of crew members.

KEYWORDS

Lean Construction, standardization, operation design, productivity analysis, workflow

INTRODUCTION

Contemporary construction industry has much room for improvement (Koskela 1992; Olsen 2010). A Norwegian data envelopment study of 122 comparable apartment block projects showed that the average project had an improvement potential of 21% compared to the most efficient projects in the study (Ingvaldsen & Edvardsen 2007), showing a lot of variation in productivity in the industry. But even in the most efficient projects in this study we can expect to find a lot of waste. Swedish studies

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have found that 10-20% of total project cost on projects were from changes and rework (Cnudde 1991; Jonsson 1996), and several Norwegian analyses have found that the amount of time spent on transformation work is only 41-59% (Bølviken and Kalsaas 2011; Kalsaas and Bølviken 2010, Kalsaas 2010, 2011, 2012, 2013).

Furthermore, construction costs are increasing at a more rapid pace than the Consumer Price Index, indicating that construction is constantly getting more expensive compared to other goods and services (Statistics Norway 2014). This is further motivation for looking for ways of making projects more cost-efficient.

Many in the industry acknowledge that the prevalent project delivery models are directly related to the mediocre performances observed (Byggekostnadsprogrammet 2010), and encourage looking at new ways of conducting projects. Lean Construction is a philosophy that offers such an alternative approach, and with its core values from the Toyota Production System (Koskela 1992), has proven effective in reducing waste and improving productivity (Alves et al. 2012). In Norway, Lean Construction is growing in popularity and is by several industry professionals viewed as the project model of tomorrow (Byggekostnadsprogrammet 2010).

However, the industry is conservative and hard to change (Alves et al. 2012), and convincing companies how Lean Construction is superior to the traditional approach can be laborious without scientific evidence. This paper presents a study of a limited implementation of Lean Construction tools and principles, investigating if performance can be improved by applying these to one single production unit.

The field study was conducted as constructive research, which according to Lukka (2003) means that instead of merely observing, the researcher first observes and analyses the problem, then in cooperation with the organization involved constructs a solution, and finally tests this solution. What is really tested in this paper is the method for improving the work operation, thus basing the method's success on the improvement of the operation it is applied to in the field study.

An inner wall production crew was studied, aiming to improve their operation in collaboration with them. If the revised performance was convincing, this could be the standardized way of performing this operation, both on this project and on all of the contractor's projects in the country.

THEORETICAL PERSPECTIVE AND METHOD

OPERATION RELIABILITY AND IMPROVEMENT OF WORKFLOW

Achieving less variation and greater predictability is central in Lean Construction and in the Last Planner System (LPS). Initially, LPS was inspired by the quality management and productivity initiatives dominating the improvement works in the industry in the 80's (Ballard, 2000). It thereafter changed conceptually to focus on predictable workflow, reflected by Ballard (2000) and the flow part of Koskela's (2000) works on production theory, the so-called TFV-theory (transformation, flow, value). Productivity seen as input in relation to output is often associated to transformation, while flow addresses the processes occurring between the work operations. Koskela (1992) claims that the greatest potential for improvement for in construction site operations is related to flow.

Analysis As First Step In Standardization

According to Moore (2011), it is desirable to achieve reliability by first analysing the operation to find the best way of performing it with the current prerequisites. This is then set as the standardized way of performing the operation, either for the specific team or for the entire organization. The process of analysis, improvement and standardization is then continuously repeated.

The empirical analysis in this paper is conducted once, as the first iteration of this repetitive process. The operation is analysed with reference to tools presented in *"Productivity Improvements in Construction"* by Oglesby et al. (1989) as well as common Lean Construction tools such as process mapping. The tools used in the case study have strong focus on both transformation and flow as defined by Koskela (1992), and a strong process orientation, which is a clear trait of the Lean approach.

Lean Construction Principles to fulfil improvement potential

The productivity analysis was used with a Lean Construction setting as theoretical foundation. Several principles were used in the improvement work of the operation:

Principles from Koskela (1992, p. 16):

- *Reduce the share of non-value adding activity*
- *Reduce variability*
- *Simplify by minimizing the number of steps, parts and linkages*
- *Increase process transparency*
- *Build continuous improvement into the process*

Other Lean principles:

- *Better batching of materials (Ōno 1988)*
- *Better sequencing of tasks (Ballard & Howell 1998)*
- *Smoother production (Ballard & Howell 1998; Rosenthal 2008)*
- *Just In Time delivery (Moore 2011)*
- *Establishing a Lean culture for further improvement (Womack et al. 1990)*

Productivity And Workflow Analysis

To identify waste and potential for improvement, the operation was analysed both initially and after the alterations. To gather data, video recording was conducted with the workers' approval. The aim of the study was presented up front, and they were given the opportunity to review the video material and corresponding results.

Information was also gathered by a log-system developed for this study (example in table 1). This log was based on forms filled out by the workers and served as a source of information about the tasks and their progress. Also, the forms encouraged them to set realistic goal for how much they anticipated produce the next session, enabling us to measure PPC and track root causes for non-completion.

Table 1: Form filled out for progress tracking

Session 1	Morning to lunch		
Initials:	TK	Start:	5-3M
Task:	Sills	End:	5-3F
Time spent:	4	Goal:	5-3F
		Met?:	YES
		If not, reason for non-completion:	
		Start:	5-1M
Initials:	BU	End:	5-1M/F
Task:	Studding	Goal:	5-1F
Time spent:	3,5	Met?:	NO
		If not, reason for non-completion:	Plumbers and equipment in my way

Three stages of task completion were defined: S, M and F (start, mid, finish). This is specific to the task performed, not for the progress of an apartment's inner walls as a whole. So if an apartment is marked and silled, the condition for each of these is F, but for the studding operation entering the apartment, the condition is S. The workers were given some room for interpretation, so notations like S/M or M/F were allowed.

In the example in table 1 the workers have documented one work session from morning to lunch. One worker has installed sills in apartment 5-3 (5^{th} floor, 3^{rd} apartment). When he started, the apartment had approximately half of the sills already installed (therefore M). He expected to complete the apartment (therefore F), and did so. The other worker installed studs in apartment 5-1. Half of the studs were installed when he started (therefore M), and he expected to finish it, but did not reach this goal due to coordination problems with other trades.

CASE STUDY – INTERIOR WALL PRODUCTION

Background For The Study

The study looked at a residential construction project by a well-known contractor, both nationally and internationally. It was the third block being produced in the last stage of a large residential block contract. Floors two through five were identical, with seven apartments per floor, varying between $55m^2$ and $139m^2$ in size. Inner wall production had just commenced on the 5^{th} floor at the start of the study, and took about a week and a half per floor. The block consisted of 36 apartments over 6 floors.

Although the apartments varied notably in size, it took approximately the same amount of time to produce each of them, as the process time of a few more meters wall was just a matter of minutes and therefore not decisive. Hence, it proved reasonable in the study to use "apartments" as the standard unit of quantities produced.

Description Of Initial Operation

By inner walls we refer only to the walls *within* one single apartment, excluding the walls *separating* the apartments. However, a gap is left in the separating walls for the following work to move between the apartments, and *closing* this gap is part of *this* operation.

The inner wall production comes fairly early in the production process of the interior work of each floor. The following operation is plastering. Most trades are scheduled to work from the top down, while some, e.g. electricians, work the opposite way.

The operation of producing the inner walls can be divided into 5 tasks: (1) Marking wall location on the concrete floor, (2) cutting and placing sills according to the marking, (3) installing sills where they are placed, (4) cutting studs and finally (5) installing studs in the installed sills.

Marking is a two man job in which, according to the drawings, wall locations are marked on the floor with a red-chalked string. During the marking, gypsum wallboards for plastering the inner walls will arrive on site and are transported inside. This is done by the markers and considered part of the "marking"-task due to the coinciding time frame and crew. The gypsum is ordered and delivered per floor, approximately once a week, and allocated to the respective apartments.

After marking, one worker cuts sills and places them out on the floor according to the marking, while another worker installs them. The sills in the ceiling are identical in length and placement and the steel sills are manufactured so that the top and the bottom are attached in one detachable piece for easy instalment. Instalment in the concrete floor is done by drilling through the sills and into the floor before nailing into the drilled hole. In the ceiling the sills are installed by nailing with a nail gun.

Once sills in an apartment are installed, studs can be installed. First, a worker cuts the studs in the correct height and places them in their respective apartments for installation. A steel stud system is used, compatible with the sills, with a centre-to-centre distance of 60 centimetres. The studs are installed by being clipped in place at the top and bottom. Around the doors however, wooden studs are used as this offers more stiffness than the steel studs. To finish the work, a worker installs two wooden studs onto the bathroom cabin as a strong toilet attachment point, as well as installs sills and studs for the remainder of the walls separating the apartments.

DURATIONS OF INITIAL OPERATION

In this study we operated with the term "sessions" as a time unit; One session from morning to lunch (7am-11am), one from lunch to afternoon (11.30am-3.00pm) and also an occasional evening session (3pm-7pm). The reason for this is that it was found that many tasks' durations fit well with this, as they took either one or two sessions. Also, "one session" is perceived as more systematic than "half a day" with regards to time.

While observing the work, the production rate was documented. The durations of the unaltered tasks (marking and installing sills and studs) remained the same during the study, showing that the general pace of the work was constant and the results obtained were not gained from working faster, but working smarter.

The marking took approximately three sessions per floor. Receiving and transporting materials inside took approximately one session, making the total time of the marking-task four sessions. Cutting the sills for one zone (half a floor) took about one session, and installing them took about one session per apartment. Cutting studs took one session for one zone as well. Installing the studs took two sessions.

RESULTS AND DISCUSSION

QUANTITATIVE RESULTS

Performance was measured for the initial and then the revised operation. By "revised operation" we refer to the alternative method of executing the inner wall production, which was tested in the last week of the study. From a representable starting point it was measured how much time and how many man hours would be spent in producing the inner walls for exactly one floor. That entailed marking, cutting sills, installing sills, cutting studs (not for revised method) and installing studs for seven apartments. As the floors were identical, both variations of the operation produced identical walls.

Initial operation	*Cycle Time*	*71.25 work hours (19 sessions)*
	Man hours	*150 MH*
Revised operation	*Cycle Time*	*37.5 work hours (10 sessions)*
	Man hours	*120 MH*
Improvement	*Cycle Time*	*47.4%*
	Man hours	*20.0%*
	Cost of changes	*0.-*

The revised operation is both significantly faster and more cost-efficient. There are several changes that contribute to this result, some more easily quantifiable than others, and in the following sections these improvements will be presented and discussed.

At the start of each session, each worker made an estimate on how much he would be able to produce. To see to what extent these commitments were met, PPC was measured. 81.4% of the promises made were completed as planned, showing that the crew close to execution had a fairly good idea of how productive the next session would be. However, one could argue that not being able to foretell the production for the next 3-4 hours in 18.6% of the cases is actually not too impressive. The causes for non-completion were tracked:

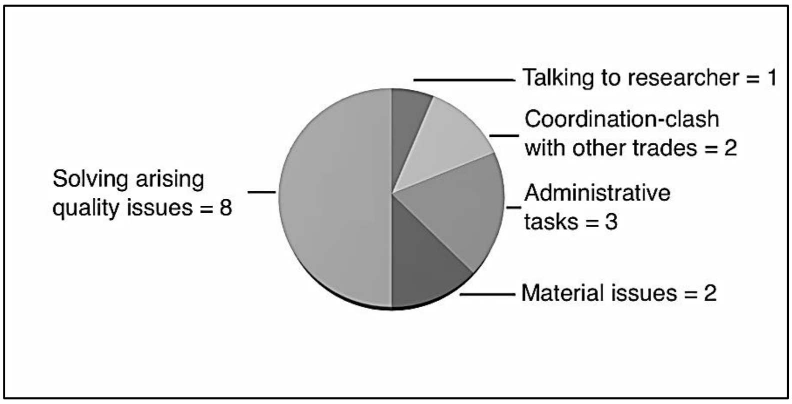

Figure 1: Causes for non-completion
(Four weeks, PPC=81,4%, 16 non-completions of 86 promises made)

QUALITATIVE RESULTS

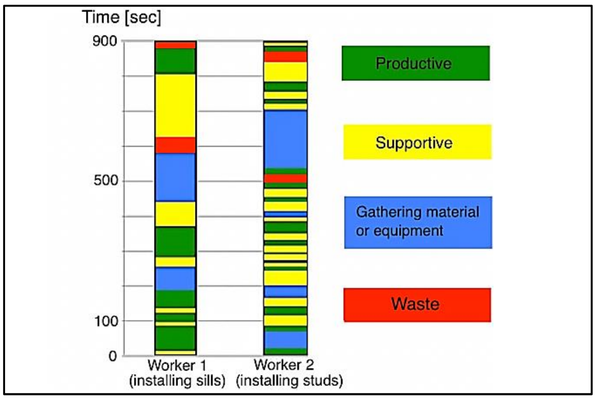

Figure 2: Crew Balance Chart for two workers, initial operation

The crew balance chart focuses mainly on work close to the actual transformation of input to output, and looks at how the workers physically perform their tasks for a short period of time. In this case, it shows that working with the prerequisites present, the work is fairly productive. The tasks of installing sills and studs were therefore left unchanged. As described later in the paper, the sill-cutting task was changed due to the changed material system and the stud cutting task eliminated. These were therefore irrelevant to consider in the crew balance chart analysis.

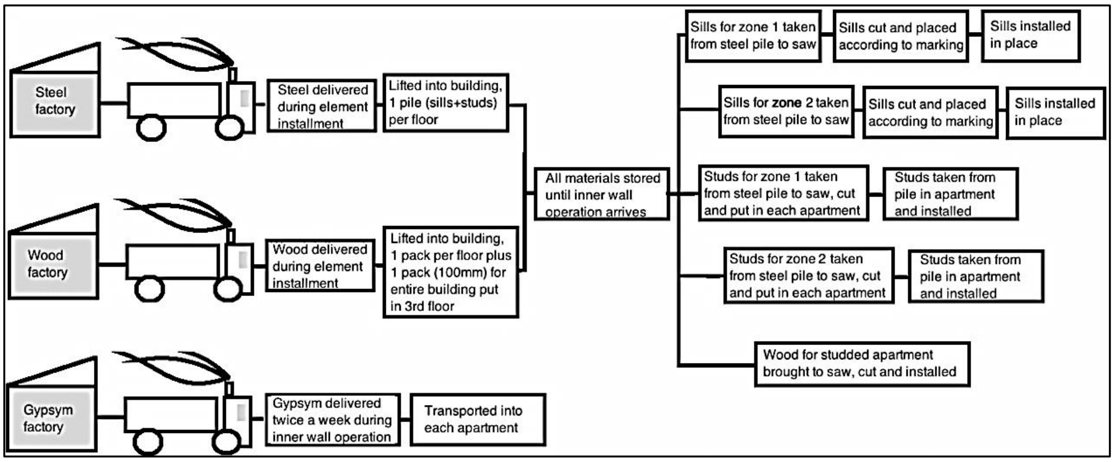

Figure 3: Process Map for all materials, initial operation

The Process Map focuses on the material flow and depicts a complicated system with several unnecessary steps. It was paramount in constructing the revised operation to reduce material handling and create a more sensible material flow. This is described later in this paper under the section about improvements made to the material system. Durations are often included in maps of this kind (Alves et al. 2005), but in this case the durations are hard to present in an informative way. For instance, the time span for storage of materials in the original operation is highly variable and uncertain.

Improvements Made To The Operation

Crew Members

The inner wall operation is typically performed by a crew of 2-4 workers plus one worker on battens, who is able to contribute when needed. In the months before and during the entire field study however, the number of crew members was constantly two plus the worker on battens. This introduced noticeable variability in the progress of the individual tasks of the operation.

Naturally, when both workers are needed for marking, all other tasks stop. Then both workers commence working on the sills, with one cutting and placing and the other installing. Only when the sills are installed for most of the floor does the work on studs start. To summarize, it is extremely hard to maintain a smooth, well-flowing production with only two workers.

It was therefore proposed as an improvement to standardize the amount of workers to three. When planning the work for a floor, it quickly became apparent that it was possible to maintain progress on every task at almost all times and get a much smoother production flow through the building. This effect is best illustrated through the cumulative progress presented on the next page.

Work Sequence

It was a common conception among the crew that the best approach was to first do *all* the marking, then *all* the sills, then finally *all* the studs for a floor. Then the entire crew would move down one floor and repeat the operation. However, focusing manpower on one task at a time, while all other tasks stop, is not pursuing smooth production. The stairwell diagram below shows that with the revised operation, all the tasks gradually evolve.

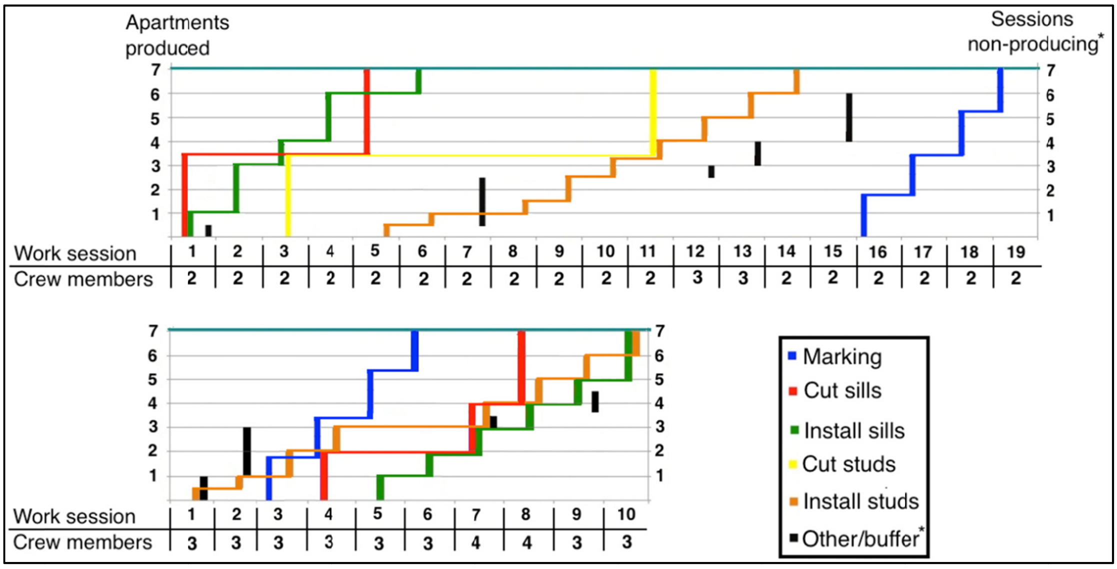

Figure 4: Cumulative progress, original (above) and revised (below) operation. Note that the right hand side scale is for the other/buffer category only.

Material System

The reasoning behind the initial material system is understandable in one way: Getting all the steel delivered during concrete element installation enables the crane to lift the material straight into the floors in between the installation, instead of the workers getting it on the delivery ramp and having to transport it in during production.

Unfortunately this means that all the steel is ordered and delivered for the building at once, and wrong quantities is not easily correctable during the following production. Considering that orders are based on experience rather than quantity take-offs from BIM or actual measurements, this introduces substantial uncertainty.

Also, steel was delivered in one package for each of the 6 floors as it would not make sense having the crane lift in 48 packs of steel (12 packs of sills and 36 packs of studs). This material system might seem superior at the point in time of the concrete element installation, but problems arise once the crew starts using the steel for inner wall production. A lot of material handling is required during the operation due to the batching and kitting of the steel packs. A more efficient system would be as follows:

- Just in time (JIT) ordering per floor so that materials arrive during the marking. This reduces both double-handling of materials and allows for corrections in material quantities from floor to floor.
- ALL the materials arrive at the same time (gypsum, steel, wood).
- The sills arrive in two piles that are transported straight to the two positions where the saw will be located on the floor.
- Studs are pre-cut to exact length (see next section) and delivered in one pack per apartment from the supplier.
- Studs are put on top of the gypsum packs and transported to their respective apartments. Added time from putting them on the packs is negligible.
- Wood is transported in and placed on a central location on the floor.

Increased Visualization

It was early noticed that other trades took up space needed by the inner wall operation, especially for storage of equipment and materials. Inner walls require few square meters, but are spread out all over the floor. There *is* in other words enough room for other trades, given that they use the *correct* space.

In week one, the inner wall operation entered an apartment that a plumber had used for storage of equipment and materials, which was obstructing the inner wall operation. The amount stored was not *too* extensive, but was placed in a way that setting up the saw and sills for cutting was impossible.

A suggestion for dealing with the situation was using spray paint to mark the ground well ahead of time where the saw, steel, wood and gypsum packs would be located. This took only a few minutes for an entire floor, and ensured that the other trades had physical cues where they couldn't take up space. The spraying was done during the marking, but could also have been done before this. Already after the concrete elements were installed, the interior wall crew knew how they wanted to solve their logistics and could mark this on the concrete floors. After the spray was introduced, no conflicts of space between trades were observed.

Eliminating Cutting Of Studs

The steel studs used was already pre-cut by the supplier, but to a length of 5cm longer than required, and therefore needed to be cut again on site to the correct length. By doing measurements of the actual height on each floor, studs could be ordered cut to the correct length, thus eliminating the entire cutting operation and enabling the material batching described earlier. Also, deeper sills could be ordered to allow more inaccuracy on the length. Studs pre-cut to correct length and deeper sills is done at another project in the region by the same contractor, where they have had excellent experiences with the system.

More Efficient Logistics for Cutting Sills

Both considering time and ergonomics it is advisable to avoid the sills being placed on the floor at any time before the actual placement. In the initial operation, the sills were put in the steel pile, picked up and carried to the saw, put on the ground, and then one by one picked up and cut and placed on the marking on the floor.

It was therefore perceived as a great improvement that the sills were delivered straight to the saw location and placed on A-frames at the same height as the saw. This allowed sliding the sills straight onto the saw from the pile, cutting them and placing them on the floor, thus reducing both the amount of material handling and the number of times bending down from three to one.

General Lean Thinking

A constructive study is based on collaboration between the researcher and the observed organization. It was a natural effect from the study that the observed team got interested in Lean Construction and requested additional information on the topic. The two workers observed the first week actually asked to read the preparing report for this very paper and gradually acquired a Lean Construction language. The last week of the study, talks with the team with terms like push and pull, variability, waste, standardization and even kaizen were occurring.

During the study, the team undoubtedly acquired a way of thinking that involved continuously looking for improvement in their practices, eliminating waste and viewing production analytically. Thoughts on how tasks, crew, equipment and materials should flow smoothly were clearly awoken in them.

It seems ambitious to expect a similar response on any project where a similar study is conducted, and the researcher got confirmation from administration that this project was well developed in Lean thinking. Much of the progress was clearly dependent on the attitudes of the people involved, both researcher and the workers. In this case it was clear that a respectful understanding, that this could be a positive experience with learning potential for both parties, was present.

CONCLUSIONS AND RECOMMENDATIONS

This paper has investigated the effect of analysing a work operation and implementing Lean Construction principles to improve its performance and reliability. The study was conducted as a constructive study, with the researcher first analysing the operations in its initial state, then improving it in collaboration with the workers. The suggested improvements were then tested in the final week of the field study. The performance of this revised operation was superior to the initial operation. The cycle time for producing one floor was improved from 71.25 to 37.5 hours and the amount of man hours were reduced from 150 to 120. In other words improvements of 47.4% in time and 20% in cost were achieved.

The most notable improvements to the operation were increasing the number of crew members from two to three, changing the work sequence to ensure smoother progress for the different tasks, changing the material system, introducing spray paint to mark the floor to visualize material and equipment flow, eliminating a cutting operation and bettering the logistics for the cutting of sills.

The empirical improvement work benefited from the application of generic lean principles such as striving to achieve smoother production, good sequencing and batching, Just In Time, simplifying by minimizing steps, parts and linkages, increase the transparency, reducing non-value adding activity and to establish a Lean Construction culture for further improvement and to build continuous improvement into the process.

When it comes to the last principle, which is also related to the validity and reliability of the results, the study seems to have created an improvement atmosphere indicated by proactive attitudes by those involved on the construction site.

A challenge in analyzing the study was that some of the effects from the implementation of the lean oriented changes were hard to quantify. Further work should therefore be done to understand in which ways the different alterations improved performance.

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