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Implementation of lean construction tools on an on-going project: A case study on a tower project.

By

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Abstract

Since the early 1990s, scholars analyse possibilities for the Lean production principles to be translated into the construction industry. The implementation of such production philosophy to a different industry as conservative and complex makes it a bigger challenge which was studied for decades by some scholars. In order to grasp a correct understanding of the philosophy, extensive study is carried out on the original philosophy as well as changes to the philosophy in order to translate it to the construction industry. Such changes were unavoidable in order to correspond to the very specificity of the construction industry while the soul of the philosophy was kept intact.

This study provides a set of tools from the Lean construction philosophy that can be implemented in order to reach performances achieved and repeated within the manufactory industry. These tools are defined with their main components, goals and their area of influence. The implementation of new processes is defined and the different stages to follow are assessed. The influence of the phase of implementation is discussed as well as the potential implementation barriers to expect.

Finally a case study on an on going tower project is used as a real life experiment of these tools and their implementation. An assesment of the processes used on the project is run as well as an identification of the potential improvements to work on. The results obtained from this implementation, at an early stage as well as at a later stage are discussed. The results are compared with the expected performances displayed by the theory and analyses on these results are carried out in order to understand them.

Conclusions are drawn as to the variability of results that can be obtain from Lean construction tools implementation depending on the project phase implementation but also on the cooperation of the different actors and the very parameters of the project in which these tools are implemented.

Preface

This Thesis is made in the fourth semester of the master's program: *Management in the Building Industry* at Aalborg University. The thesis is made on the basis of the overall theme of the project period: *Master's Thesis.*

The Thesis is produced in order to complete the study program and confirm the acquisition of significant knowledge, skills and competences within the civil engineering field. Along with the thesis, according to the curriculum, the following knowledge, skills and competences will be displayed:

- Knowledge of the management in the construction industry at the highest international level.
- Ability to assess knowledge and identify emerging issues within the specialization area.
- Ability to independently explain the choice of scientific theoretical and/or experimental methods.
- Ability to critic the chosen theories and methods as well as analyse the results and conclusions.
- Ability to use a broad spectrum of engineering methods for research and development in the specialisation area.
- Ability to provide solid time and work plans for the project, independently and critically assess progress.

[Aalborg University, 2015, page 21]

Based on the curriculum's requirements, relevant knowledge that is acquired through the overall master's program have been used in the report.

I would like to express my gratitude to my supervisor, Industrial PhD Henrik Sørensen for his inspiring guidance and constructive feedback. He has been of great help advising on this research. I also am grateful to Senior Consultant Darren Poultney for his cooperation and help to provide necessary insight and technical support throughout the entire thesis project and beyond. Finally I would like to thank the Manhattan Loft Gardens management team for their support and input in this research without which the outcome would have been much different.

Gwendal Christophe Le Gratiet

Reading Guide

The overall thesis is uploaded together with appendices and attachments.

Through the thesis there are references to literature, which are gathered in the list of references at the end of the report. The Harvard Method is used for the references. The references to sources are stated by "[Last name/Organisation, Year]", and if relevant the reference may contain a specific page number or a specific table/figure. Literature is listed in the list of references with author, title and date.

The report contains figures which are numbered with respect to chapter where they can be found. For instance, the first figure in chapter 5 has 5.1 as a reference number.

In addition to the report, any relevant file adding value and comprehension is attached during upload. The full list of attachment is in appendix A. When referring to this project material the reference may look as follows: Appendix A file 001. A list of attachments can be found in Appendix A.

With the intent of making the thesis clearer and easier to read, it has been decided to use the following abbreviations:

- Aalborg University - *AAU*
- Value Stream Mapping - *VSM*
- Manhattan Loft Gardens - *MLG*
- Bouygues UK - *BYUK*
- Health & Safety - H&S

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1 Introduction

In this section, the reasons leading to choosing a thesis on this subject are displayed as well as the research focus on such a broad topic, the aims and objectives to achieve throughout the study as well as the methods used to gather sufficient and relevant data. Finally the structure of the report will be introduced.

1.1 Background

In today's world, developpers are increasing their expectations on several aspects of their projects, requiring it to be cheaper, completed faster, with an increasing quality without lacking on the safety [Mastroianni and Abdelhamid, 2003]. This situation which has grown greater with the subprime crisis of 2008, comforted the industry to thrive for means to eliminate wastes and increase profit. Due to the compressed project schedules, the construction often begins without the final design being released for construction [Hanna et al., 1999]. Such situation have led scholars to study on other industry so to find other means of management, which proved producing better results, in order to translate it to the construction industry.

As early as during the 1990s, the research community analysed the possibility to translate the Lean production principles, introduced by the Toyota's engineer Taiichi Ohno, to the construction industry [L. Koskela, 1992; G. Howell and G. Ballard, 1994]. The manufacturing environment and processes being fairly different from the ones occuring in the construction industry naturally led to deep interests and analysis of the Lean production philosophy, hence the creation of the International Group for Lean Construction (IGLC) contributing to a significant part of the theoretical lean construction theories produced.

Although the Lean management studies are in profusion, the very nature of the construction industry with its prototype oriented projects could make its implementation difficult and limit it to a case-to-case process. Tower projects suffer from a reputation of "copy and paste" process due to their floors stuck one on tp of another one which could reveal to be real in some cases but not the norm. This study aims at providing literature within the Lean construction management implementation related to tower projects with high variability of design.

1.2 Research focus

Extensive studies have been conducted to the Lean production principles within the manufactory industry due to its origin and a growing number of studies related to the Lean construction management, with results and revisions, are published since the 1990s. However, there is a lack of literature regarding the implementation of such management philosophy to high rises with high design variability which this study aims at filling part of the gap. The main focus of the study will be at a project level however the findings might lead the way for an implementation at a company level.

Throughout the study, the lean construction philosophy is described as its main features. The implementation of the new management method is studied as well as potential implementation barriers and best practice on the different tools suggested. Critical thoughts are drawn over the primary results from the case study worked upon for a real life example at the end.

1.3 Aims and Objectives

The broad possibilities provided by the lean philosophy offers a wide range of interpretation to various industry with little to no relation. In order to obtain the maximum possibilities for future readers to gather ideas and principles to relate to their own case study or project, a focus to the construction industry is necessary. Its construction variant as well as the implementation of such management system requires a set of steps to be followed in order to achieve the best outcome possible. The different steps to follow are: a thorough definition of the Lean production management which provides the roots of the philosophy; its translation to the construction industry; and finally tools used within a Lean construction management. The implementation of a management tool and its barriers are discussed to finally sum up and gather concrete results with a case study.

The different objectives of the report can be summarised as follow:

- To provide Extensive knowledge on the lean production philosophy with its origins and main components.
- To compare this philosophy to other similar production philosophies in order to capture its specificities and position it amongst them.
- To understand the concrete possibilities and application of Lean management to the construction industry in general with the differences occuring from the original philosophy.
- To define diffrent tools used to reach a Lean construction project, with their specificities, field of application and how to use them.
- To fully grasp the parameters to consider, the processes to follow and the best practices to follow for an optimal implementation of the set of Lean construction tools.
- Assess specificities linked to a tower project.
- To compare results on a real project with the theory, analyse the results with the possible difficulties in its implementation and performance improvements discovered, based on a case study.
- To draw conclusions on the methods suggested and their efficiency with the parameters set as an on going high rise project with a high variability of design.

1.4 Methodology

In order to obtain the required data for this study, different methods were used depending on the phase of the study. The study is divided in two parts witha first part being totally focused on theory and the second one being the case study.

In order to set good foundations to this study and set a common ground, a literature study is firstly done. The necessary data for the first part of the study was naturally gathered through secondary review from previous scholar works. The validity of the information gathered was confirmed through different mean such as the recognition from peers, the cross references of the different papers and the redundance of information. The process for literature selection was strictly ruled as to obtain the information from reliable scientific journals but as well publications from organisations or authors recognised by their peers for similar works.

The second part of the study was focused on a case study. A case study is a research strategy followed in the attempt to examine a phenomenon in a real-life context [Yin, 1981]. In this particular case, the study was conducted in order to obtain quantitative data to obtain values to be linked with performances but also qualitative data to understand the meaning behind these values. The different data gathered was identified as relevant prior study so to restrict it to the minimum required and not overwhelm future readers with meaningless information. The rough data was provided without any bias such as to divert the research analysis and conclusions by the Lean consultant on site, whose role on the project is described in section 5.2. The type of data gathered and the approach to the project specific issues were discussed regarding other possibilities that might have ended in better outcomes but also in analyzing the data collected so to understand its meaning.

Although the works by the consultant were not strictly followed during this study, I was at all times present on the project during their data gathering and thus had an overview of the data gathered but also on the figure modifications through time. As an observator of the events that occured on the case study, I could be assured of the veracity of the data but also gather data that would not be seen as relevant by the consultant.

1.4.1 Limitations

Due to the restricted semester duration and the needs for such research, close to no primary data is used throughout the report as well as little I had little influence to change the course of the events regarding the implementation. The project phase to which the lean construction tools were implemented is a main parameter playing in the implementation results. A focus was given throughout this study on the production tools for Lean whereas the design possibilities were overseen for the most. On another case study, results may vary due to the different parameters but also due to the different phase in which Lean construction tools are implemented.

1.5 Structure of the Thesis

This study aims at providing thorough knowledge for implementation of Lean construction management. The specificity of the case study on a high rise construction will help professionals to appreciate the benefits that can provide a Lean construction approach to a complex project. The Lean production origins will be defined so to assess the foundation of the philosophy. The transition to the construction industry as well as the differences to the original philosophy are detailed so to shift the research closer to its original purpose. Finally the implementation of such tool is discussed and detailed with potential implementation barriers to expect. In order to provide a concrete case with tangible results, a case study follow on the case of a high rise with scarce storage and a high variability design. The thesis structure is graphically summarized on figure 5.3.

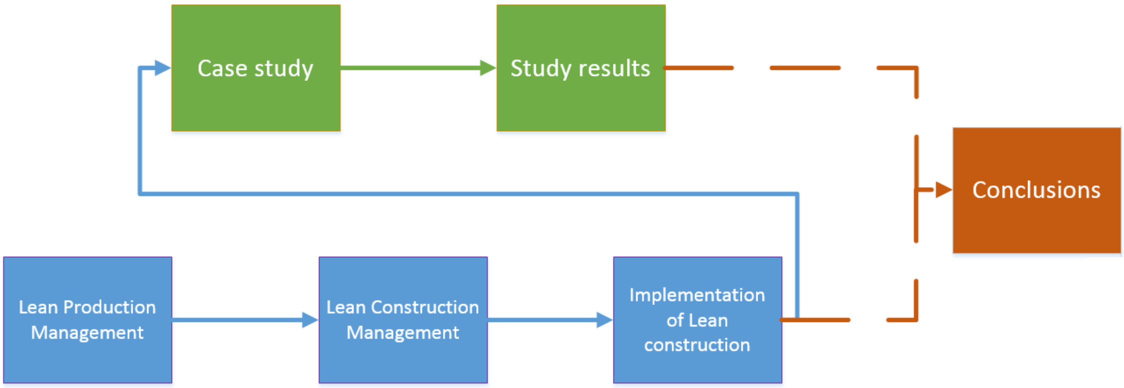


Figure 1.1. Thesis' structure

The underlying philosophy of Lean production 2

In this section the Lean production philosophy origins, ideas and features are studied to set a common ground of knowledge. A comparison to similar philosophies is carried out in order to gauge against what Lean production propose and why it is chosen. Finally the interest of the construction industry in this philosophy is examined.

2.1 Introduction

Soon after the second world war the world focused on rebuilding their society which translated to a focus on the economy. As early as in the 1950s, the engineer Taiichi Ohno, from the Japanese company Toyota Motor company, studied the americans industrials such as Ford in order to understand and capture where room for improvement could be obtained from their system of productions. The americans had their focus on a mass production with large batch sizes [Mastroianni and Abdelhamid, 2003; Singh et al., 2010], which were already all functioning due to the few losses endured in the USA during the war. The leap to take for Toyota was substential and another mean to reach a better productivity leading to profits and growth was needed. Ohno decided to look at the situation from a different angle from the americans and rather than increasing more and more the production, he focused on reducing the existing wastes in processes already in place by continuously striving for improvement. [Mastroianni and Abdelhamid, 2003]

The Toyota production system, as it was later described by Womack et al. [1990], spread around the world firstly among the manufacturing industries with their supply base system in the 1970s and then their distribution and sales operations in the 1980s [Ikovenko and Bradley, 2004]. The performance gap between the japanese and the western automobile industry was described as a result of key elements gathering under the "lean production" philosophy. *Lean* was used as a reference to the little ressources used among different departments of the company such as the manufacturing, product development or custom relations with regard to the capital invested, time, inventory or human resources. The Lean manufacturing strives to associate the best from mass production and craft production: achieving cost reductions and quality improvements to high extents while widening the range of available products. [Womack et al., 1990]

As identified previously, the main reason of this high performances are due to the "waste hunt" carried out continuously leading to reductions of expenditures of capital, time and human resources. Wastes are defined as any activity that does not create value to the final product. Value which is commonly defined as the pecuniary worth of an item is aquired through processes improving its condition such as raw minerals becoming jewelry. In the manufacturing industry it is estimated that only 5% of the activities are value-adding to the item produced at the end of the production line. The 95% non value-added remaining activities are divided between non avoidable activities and avoidable activities. The avoidable activities are considered waste or *Muda* [Ikovenko and Bradley, 2004]. Seven types of Muda have been identified and categorised as follow:

- **Overproduction**: Producing more than required is considered as a waste due to the resources unconsiderally spent, contrarly to a *Just-In-Time* sort of production. This waste naturally leads to the next waste
- **Inventory**: This item leads to expenditures in storage and items handling with a data base and thus resources that could be spent on other value adding processes.
- **Extra Processing Steps**: These steps could be defined as "administrative steps". These steps are fundamentally non-value adding or even counter-productive.
- **Motion**: The useless movement of goods through the process such as double handling.
- **Defects**: Defects significantly decrease the performances as the item must go back through the system to be corrected and thus pass the quality tests or worse be thrown away leading to a total waste.
- **Waiting**: Any time spent without producing is obviously a waste as a better organisation would lead to no interruption in the production line.
- **Transportation**: The resources and time spent on transportation of an item does not improve its value by any mean and thus these activities should be reduced to the maximum.

In order to tackle these different wastes defined by Ohno. A series of tools were created over the years which eventually helped to reach better performances described by Womack et al. [1990].

2.2 The lean manufacturing

Moving toward zero waste along the production chain required a different approach to production which traditionnally in Western industry was in a push system [Howell, 1999]. Such system of production requires a large inventory due to the unreliability of production. The pressure created so to keep the production line running leads to defects along the line creating uncertainity in the production. This uncertainity along with the single activity performance control leads to overproduction, inventory, defects and in some cases motion wastes that were all identified by Ohno and other Japanese engineer during their plant visits in the USA.

The objective of Lean production is to focus on improving the production line so to reduce continuously the possible wastes. The value of the product is key to the philosophy and thus the quality is at heart within the production line with a prevention of sub-optimisation that would lead to defects [Howell, 1999]. Sub-optimisation could be reduced through an increased transparency of the requirements, processes in the production line [Howell, 1999; Mao and Zhang, 2008]. The reliability of the system and its continuous pace was key to Ohno as a reduction of uncertainity would automatically lead to a reduction of overproduction and thus inventory. [Howell, 1999]

In contrast with Western manufacturers, Toyota strived for perfection among a wide range of products. Such goal to achieve, required a clear identification of the customer needs with regards to the product requirement and value. The value was key to fully capture so to eliminate the non-value added activities as well as any defects along the production line. Lean manufacuring is a philosophy aiming at increasing to the maximum the performances of the production system while meeting the unique customer requirements.

The main components of the Lean manufacturing philosophy could be summarised as manufacturing the right quantity of the right product through the least time possible while minimizing waste and meeting variable customer requirements [Ikovenko and Bradley, 2004]. Lean production philosophy directly settles within the different quality philosophy, similar in many aspects and yet differentiable.

2.3 Comparable philosophies

Among the different quality management philosophies, various topics and focus are discussed and studied. They all could be linked together one way or another due to the vast parameters interlinked and influencing the quality of a product or service created through a process.

As early as in the 1950s, scholars and businesses focused on ways to improve quality [Nicholas and Steyn, 2012]. Dr W. Edwards Deming suggested a philosophy including the use of sampling and statistical techniques (for monitoring purposes), the use of a single-source supplier rather than several (for a better control and collaboration toward quality), skills training and leadership at all levels (to raise awareness regarding quality and involve people at every stage of the hierarchy), with the aim to pursue a continuous improvement within a process or a company.

Since the 1980s, the most popular movement is the *Total Quality Management* or *TQM* which is an ambitious approach to improving total effectiveness of a company with a set of techniques and a mindset to be shared within an organisation. TQM focuses on identifying the missions and objectives of an organisation; acting correspondingly to these objectives; and putting the client satisfaction as a steering element. TQM as its denomination suggests requires the whole organisation to be involved in the quality production of the goods from the frontline workers to the top management. Quality issues are systematically identified, investigated and resolved for a continuous improvement of the process. Unlike Lean production philosophy, TQM is a global quality management that could be considered as a *starter philosophy* towards quality management with an overall involvement of the different actors in the process. The principal focus is on quality, for quality, whereas Lean production aims at improving quality on different aspect with the goal to reduce resources spent.

The Six sigma method is another comparable philosophy. In the late 1980s, Motorola developed a system with the aim to reach near-perfection regarding the quality of their products [Beary and Abdelhamid, 2005; Nicholas and Steyn, 2012]. As defined by Nicholas and Steyn [2012], quality is not only to meet the requirements of the client, but also to satisfy them with undisclosed expectations. The quality implies as well an absence of defects which is a term often going along with quality and that could be replaced by *"product non-conformity"*. The six sigma system aims at detecting and removing variability within the process regarding performance (the mean and standard deviation), but also, with a set of tools and statiscal method, help to reach a close to zero-defect product. With the help of a heuristic, organised and systematic method for process improvement, consequent reduction of customer perceived defects is observed. This methodology is known as DMAIC (Define, Measure, Analyse, Improve, Control). As a statistical model, data is extracted such as the standard deviation also known as *Sigma*. In a normal distribution diagram, a Standard deviation of six sigma would mean a level of product without defect at around 99,99966%. Such performance would directly translate to 3.4 defects in a million products. Six sigma is a wonderful method in order to improve quality by reducing to the maximum defects in the process and it is its main purpose, while Lean production philosophy aims at reducing to the minimum resources used in the process with a focus on quality as part of the parameters.

Having identified the different philosophies amongst which Lean management is located, it is clearly set that the *TQM* and *Six Sigma* have a complete focus on quality whereas Lean management aims at improving performances while keeping quality as a main component. Indeed, quality shared information, processes and delivery of products along the production line leads eventually to better performances.

2.4 Translation to the construction industry

The well recognized and admired results from the lean production philosophy on Toyota's performances led scholars to study the philosophy and look for different industries that could benefit from it. The main objectives of the Lean philosophy (a uniquely custom product, instant delivery with close to zero inventory, and production with zero waste) are perfectly suitable for the construction industry assuming that every project is a uniquely custom product.

Therefore from the middle of the 1990s, scholar started to look at possible translation to the construction industry of the newly studied Lean prodution philosophy [L. Koskela, 1992; Ballard and Howell, 1994], but also created the International Group for Lean Construction (IGLC) meeting annually around the world and gathering the new researches and advances towards achieving the same results within the construction industry as in the manufacturing industring and especially the original example: Toyota. Such philosophy that was first develop for a manufacturing environment which is routine driven, challenged scholars in a way that the construction industry is more directive driven [Howell and Ballard, 1998].

The differences between the manufacturing industry and the construction industry do not stick only to the routine/directive steering force, but also on the environment of works, the different actors and potential control over them. In order to fully comprehend and obtain the most out of such translation. A good understanding of the traditionnal management method within the construction industry is necessary.

2.4.1 Traditionnal management methods

A construction project is composed of multiple activities running one after another, or alongside, with different costs and duration as for the manufacturing industry, at the difference that in a manufactory every activity is run by actors from the same entity who are colleagues and to a certain extent performing together. In the construction industry, the different activities are traditionnally performed by different actors from different entities that have for only goal to achieve their specific tasks. Therefore the conventional approach for a construction project to be run is to increase the performance in terms of costs or duration on an activity basis. [Howell and Ballard, 1998]

No to little consideration is given to the needs or requirements to the next activity in the process and even less consideration is given, would that activity be at a later stage of the process resulting in no interaction between the different actors. Focus is given on a reduction of the cost of labour such as using different methods or cheaper workers, as well as on different materials that would show the same requirements at a lower price. Due to the overall approach suggested by the Lean production philosophy, a different approach of construction management should be created and followed so to match the specificities of the construction industry.

Construction project are often a set of crisis occuring one after another leading to engineers and manager working on a solution to fix it [Howell and Ballard, 1998]. However these types of improvements are often attributed to failure from an actor in the process rather than a failure in the process itself which often leads to people focusing on improving the person (or replacing it). In this situation people learn little as they try to cure a sickness by focusing on the symptoms rather than the causes. Howell and Ballard [1998] suggest that it would be easier to improve a system when this one is already working well as the team would not be biased as to focus on team member failures rather than the system.

Lean production philosophy should not be transposed as such to the construction industry, trying to standardize it and making it closer to a manufacturing industry; but rather embrace its differences and cherry-pick the different principle and technique striving to reach an ideal of perfection offered by the Lean production philosophy. [Howell and Ballard, 1998]

2.4.2 Modification to the original philosophy

According to Koskela and Howell [2002], the construction industry has three specific features that distinguish it from manufacturing: one-of-a-kind projects, in-situ production, and complexity (e.g., various actors working with different organisations on a temporary basis).

- One-of-a-kind production means that the product provided by the constructor gives limited room to standardization from other projects. Although the materials and methods used from one site to another are pretty similar. The change orders and specificities of a project lead to little room for optimization on that level.
- An in-situ production as opposed to a fixed-position manufacturing let the project be subject to the weather or the environmental conditions in which the project is located. Limited control is possible on these parameters which can cause delay to the main activities providing value to the product: the assembling and erecting of primary materials.
- Complexity is generated due to the amount of different actors involved from the suppliers to the "installators" on site. Little room is given to optimization between the suppliers and contractors on site as well as the selection of the supplier might be at a late stage of the design reducing the flexibility on site. Activities on site are then interellated and overlapping for the most, leading to dynamic systems in a complex and unique manner making it more difficult to follow a schedule.

These three characteristics lead to uncertainty which is one of the main cause of waste in a process [Koskela and Howell, 2002; Howell, 1999]. One of the main challenges that the construction industry is facing with regards to the lean construction management implementation is to find relevant tools and technics from the original philosophy as well as to convince the different actors of the benefits of cooperation within the project system.

The Lean construction management 3

The Lean management related to the construction industry is thoroughly studied along this chapter. A description of the overall knowledge within the area is carried out as well as a description of different processes existing and their use linked to Lean construction philosophy. Finally the influence of the philosophy on a construction project is discussed.

3.1 A new management system

As defined in section 2.4.1, traditionnal construction management methods are focused on improving activities. Improvements regarding the costs and duration of every step is the main focus so to keep pressure on the production in case of issue leading to a delay [Howell, 1999]. Such management method might be compared to the *La Fontaine's Fable "The Hare and the tortoise"* where the traditionnal method would be the hare, with a fast pace but drops or even production stops, and the tortoise would be the lean construction management philosophy, with a slower pace (if slower at all) but mainly a steady pace keeping moving forward without interruption or uncertainity as defined by Lean manufacturing philosophy.

Lean management construction differs from contemporary practices as it strives to achieve the following points:

- Set clear objectives for the delivery process: the delivery process can be broken down from the project delivery process to subcontractors delivering to other subcontractors or even within the activities when different tasks are carried out.
- Maximize, at a project level, performances for the Client: The whole process should be analysed; and low performances for an activity should be discussed, would this lower performance increase consequently another activity performances at a later stage. The overall performance is the value to keep track on.
- Design concurrently processes and the products: With coordinated designs and workshop meetings, the different potential clashes can be highlighted and improvements within the design can be worked upon from an early stage. This would lead to a proactive management process rather than a reactive process (react to issues occuring and thus overcome problems at the last minute which could lead to delays).
- Apply production control all along the life of the project: any variation from the design or unforseen event must be monitored so to have a better chance at improving the process and prevent possible delays or reoccurence of issues.

Lean construction management aims at performing on a project total cost and duration rather than activities [Howell and Ballard, 1998]. It focuses on the work flow and considers the combined effect of dependence from the activities and their possible variation [Howell, 1999]. A process that does not take into consideration the dependence and variation applied to the activities could be illustrated as vehicles on a motorway: every vehicle is different with different speed and sizes. If the drivers do not take in consideration these differences, a traffic jam will quickly occur leading to the overall motorway to be slowed down. High speed from a vehicle/activity does not assure a minimum travel distance/work schedule in conditions of variation and dependence. Lean construction works to isolate the activities from variation, from uncertainity by providing an adequate buffer for the team to keep working at a nominal pace without interruption from possible variations. [Howell, 1999]

Planning and control are two faces of the same coin as they are linked to each other. The planning defines the way to follow with milestones for the activities while control aims at keeping track on the plan and triggering learning from variances and replanning to keep accurate to a certain extent [Howell, 1999]. The structure of the works should be designed at an early stage with a good definition of the master project plan and lookahead process function. Common sense teaches to break down problems in pieces small enough to be solved, however the big picture with the implication of every single pieces must be kept in mind as the overall performance is more than sum of these pieces. [Howell, 1999]

As defined earlier, lean construction is focusing on two main aspects, the work flow and the effect of dependence and variation of the activities within a project. The workflow is defined as the execution of a process where tasks are passed from one participant to another for action, according to a set of procedural rules. Lean construction strives to reach a high performance workflow by reducing wastes within it which were defined in section 2.1. Such wastes can be applied to the construction industry as 8 forms rather than 7 as follow [Womack and Jones, 1996; Mastroianni and Abdelhamid, 2003]:

- **Over-production**: Producting more than needed on a specific activity leading to an excess of resources spent at the time which could eventually lead to a delay on another task. A crew can be working on different activities or area within a project.
- **Inventory**: the construction industry is traditionnally running on a paid-when-produced rather than paid-when-purchased. Therefore companies tend usually to have a low inventory as to reduce the resources spent ahead of works. However sometimes materials arrive earlier and could be in the way of other trades. This particular waste is difficult to master as reducing inventory could lead to possible lack of materials on site and thus become totally counter-productive.
- **Extra Processing Steps**: These steps could be grinding a wall or column in order to get a good finishing while it will be covered by plaster board resulting in a useless activity. It could also be administrative activities that are non value adding for the project.
- **Motion**: The useless movement of goods through the process such as double handling or use of facilities on site (for example: toilets, canteen, or smoking area).
- **Defects**: Defects usually occur when control are not performed during the process but also when the design was not discussed concurrently with the following activities so to assure the needs for future works to be performed. The punchlist might as well be deficient by having missing items to check or bad requirements. Defects can as well occur when a product or task is delivered too early in the process leading to the works being damaged by material movements (motion) or storages nearby (inventory).
- **Waiting**: Any time spent waiting for materials, a design, a defect to be fixed, or even a crew waiting for another one to finish what was promised to be finished.

- **Transportation**: The resources and time spent on transportation of an item does not improve its value by any mean and thus these activities should be reduced to the maximum. It could be materials stored far from the working area.
- **Human resources**: Any suggestions from the actors that is not appreciated. The operatives on site work daily within a process and might have ideas to improve the process or work task.

The workflow performances are traditionnally enhanced by increasing a crew size while working on these wastes could increase performances without adding manpower resources. In order to reduce these wastes and improve the planning and control of activities, a set of tools have been created.

3.2 Lean construction tools

Lean manufacturing has a set of tools that can be easily translated and used for the construction industry. These tools apply at different stages of the construction process with different goals and area of works. These tools provide a mean to:

- Assess the current process of the project and highlight possible sources of improvement
- Lead the way for the actors by setting clear goals to achieve and expectations to meet for other actors.
- Communicate between the different actors in the best manner so to reduce the timelag and look for possible clashes rather than undergo from it.
- Measure and control key performance indicator
- Improve the performances and learn from the mistakes

Lean manufacturing methods have been studied [Ballard and Howell, 1998; Koskela and Howell, 2002; G. Ballard, 1999; Ballard and Howell, 1994; Sacks et al., 2009; Freire and Alarcon, 2002; Lapinski et al., 2006], with more or less focus by scholars [G. Ballard and G. Howell, 2003], as well as their implementation within the construction industry with their adjustments [Alarcon and Calderon, 2003; Alarcon et al., 1994; Salem et al., 2005, 2006; S. A. Abbasian Hosseini and A. Nikakhtar and K. Y. Wong and A. Zavichi, 2011; Mastroianni and Abdelhamid, 2003]. In the following pages, a set of key tools is discussed with their functions and interests.

3.2.1 The Value Stream Mapping

Understanding the processes of a system is a key component of the lean principle and has been studied over the years revealing concluding results with regards to performance improvements [Lapinski et al., 2006; Singh et al., 2010]. The value stream mapping method (*VSM*) is a tool helping to establish a flow, eliminate waste and add value to a process [Rother and Shook, 2009]. Three flows can be created using this method: a flow of material, a flow of information and a flow of people/processes. Each flow is going from A to B as for the production flow from the raw material into the customers hands, or a design flow from the concept to the "ready-for-construction" documents [Rother and Shook, 2009]. This method helps at looking at the big picture and having a vision of the whole process rather than focusing on optimizing part of it. This tool can also serve as a mean to help involve the different actors of a process in participating on the improvements [Howell and Ballard, 1998]. Such a tool striving at including as many processes as possible, might be used with limits in order to keep a clear map or only keep processes that the creator of the map can influence on, but also as to keep new Lean practitioner within shallow water until confidence occurs and the map can be expended from a company-only perspective to a value-chain perspective, as per graph 3.1. [Rother and Shook, 2009]

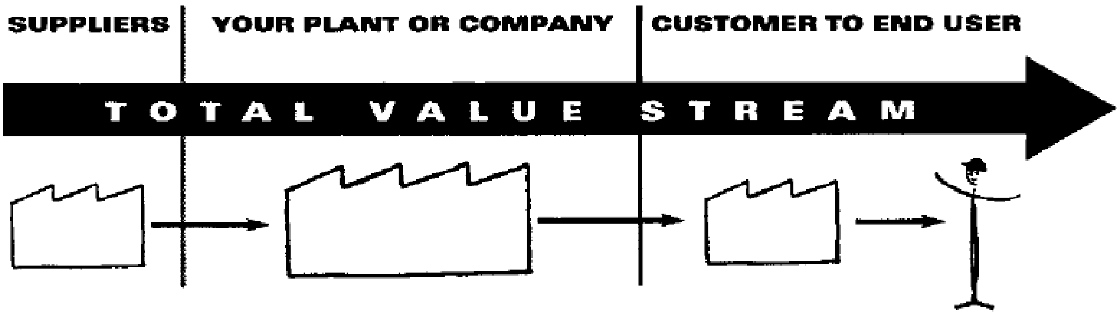


Figure 3.1. Value Stream from supplier to end user. [Rother and Shook, 2009]

In the construction industry, although this lean management tool can be used to obtain better result on a company scale, the lean construction management would change the "plant or company" section to "construction project". The *VSM* helps visualize not only the processes occuring in the system but also the connection between them, the flow. When processes are drawn on the paper and connected so to represent the flow of information or material, wasteful activities can be highlighted as well as their sources so to work on the real problem rather than its consequences [Rother and Shook, 2009]. On figure 3.2, an example of a whole process from the supplier to the customer is drawn.

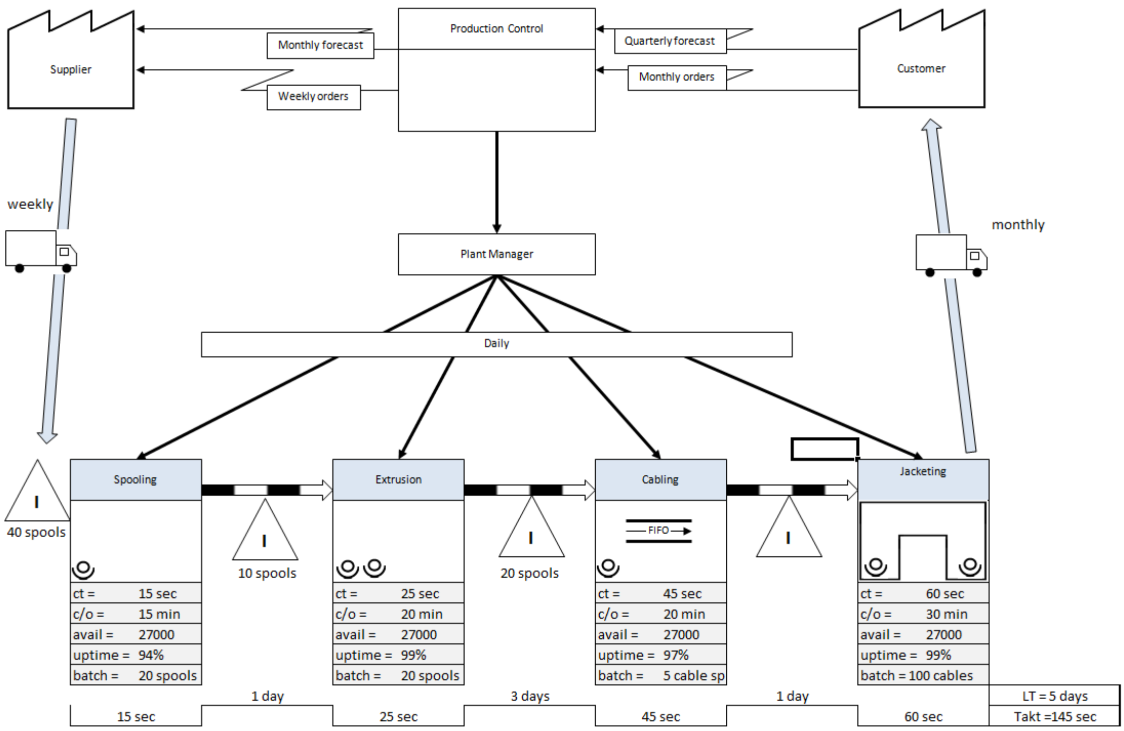


Figure 3.2. *VSM* including the suppliers and customers with various information about time, materials and connections. [Rother and Shook, 2009]

The creation of such flowchart set the foundation of an easy understanding for all of the processes and flow happening; it creates a common langage for everyone to participate and discuss possible improvement. This qualitative tool offers also tremendous help in order to comprehend and find steps needed to obtain information or material at a time needed. In order to produce a *VSM*, two topics must be detailled. These topics are key to obtain the best results and not to end up overwhelmed with the amount of information, nor missing any; and provide sufficient results:

- Information and material are often considered as two different notions whereas they actually are two faces of the same coin [Rother and Shook, 2009]. The information is needed for the material to be used when needed and where it is needed; and material is needed for the information to create value. In the construction industry the information would be the drawings for construction, the advancement of the previous contractor in the process, but also the changes from the client to name a few. The material would be the material delivered on site, but also the actual works done previously from another trade, to be ready.
- In a factory, the product created usually goes through several departments and functions which are operated individually by their respective managers. Rarely would you find someone that knows all the materials and processes needed for the product to be ready. On a construction site, put aside the smaller projects, processes are divided into packages leading to a division of the works similar to a factory. A Value Stream Manager could help tackle this lack of information by understanding the whole product value stream and improve it [Rother and Shook, 2009]. A product in the construction industry would not be the whole building *per se*, but a key activity focused on, for example the first fix, or closure of the ceilings. This person should report to top management on site in order to have the necessary power to help change happen, and should be present on a daily basis to keep implementation a priority on site.

The Value Stream Manager is the keystone in Lean construction management and particular attention should be drawn on having this particular manager rather than different area manager gathering their information from individual segment, it would simply not provide the results expected. [Rother and Shook, 2009]

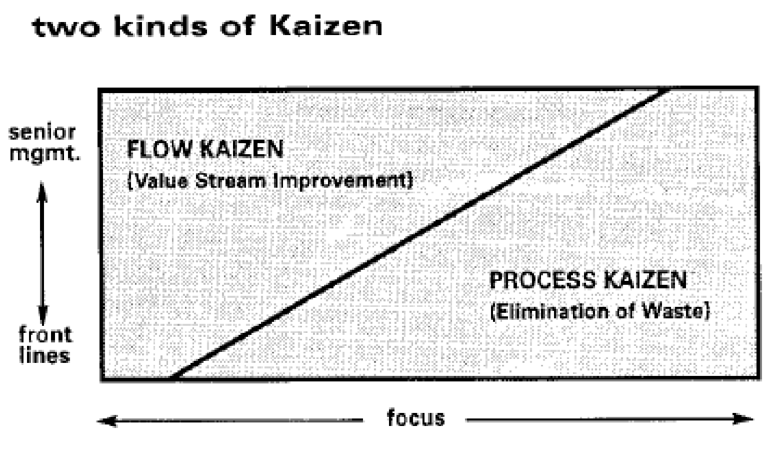


Figure 3.3. Relationship between management and improvement focus. [Rother and Shook, 2009]

The top management as well as the Value Stream Manager would focus essentially on the Value Stream improvement with focus on the information and material flow requiring an eye on the big picture. The front-line team due to its proximity and great understanding of the processes they work with, would focus on people and process flow for improvement (figure 3.3) [Rother and Shook, 2009]. A current-state map can then be created, and is recommended to be done by the Value Stream Manager as to have a clear understanding of the processes but also to prevent bias from other informant that might give false data so to make things better or worse than they really are. The Map should be drawn in four simple steps:

1. **Customer's value**: The goal of a *VSM* is to draw the process in the system towards the final product whith what the customer wants, which is what provides value to the customer. As the main focus of the Lean philosophy, it is naturally the first step to take in drawing the *VSM*: assess the customer requirements. Without a correct assessment of these requirements, it is possible to improve a value stream leading to something other than what the customer really wanted (or needed would that customer be another subcontractor). [Rother and Shook, 2009]
2. **The processes**: Add the different processes within the system. In the event that several processes run along, they can be drawn one on top of another; however only key processes should be drawn at first in order to keep focus on the product process studied and prevent the drawing from becoming messy. Information on the different processes can be added such as the quantity of material delivered in a time frame, or the time required for the process to run. [Rother and Shook, 2009]
3. **The material**: The input material at the beginning of the chain, as well as its output when finishing, can be drawn at this stage. Only key materials should be drawn and it is considered a key material when it has a specific lead time or particularly high impact on the final product.
4. **The information**: The connections with regards to information can be drawn with their specific function. Would the arrows lead to an enormous amount of lines on the drawings, that could mean information is part of an improvement scheme.
5. **The lead time**: The lead time of every activity can finally be added to the drawing. It is recommended to have it as a timeline at the bottom so to ease the understanding on which activities are "consuming" the most and potentially need improvement.

Using the *VSM* in a process such as a construction project can help to identify fundamental wastes defined by Womack and Jones [1996], such as overproduction. Producing too much when it is not needed can eventually lead to second-handling, storage of materials or even defects (other workers breaking the completed job). The value-added time could be sensibly short but the total time needed for the product to be finished, extensively big due to the idle time between processes, although no time was "purely" wasted. The overproduction which is often the problem of mass production can be seen as a way to reveal the root causes. When these root causes are identified, a first step towards finding solutions and improving the process is taken [Rother and Shook, 2009]. Works should be carried out only when needed and at a pace that is steady and continuous. Attention should be drawn on producing in a "Pull" manner so the right thing, the correct amount, at the required time is produced. The *VSM* helps to understand the needs and the right things to be produced. The required time for it to be produced needs another tool for everyone to follow. A schedule should be done which relates to the reality of the production and can serve as a mean of information, as well as of control.

3.2.2 The Last planner

The Last Planner system is a tool developped by *Glenn Ballard* since 1992 over a decade [Herman G. Ballard, 2010; G. Ballard and G. Howell, 2003]. The studies and works carried out by the author on this system started by focusing on improving assignments in the weekly work plans, then adding a lookahead planning to help for a better work flow control, and eventually extend the different processes from the construction phase to the design phase [Herman G. Ballard, 2010]. Although firstly created as a tool for productivity improvement due to the dominant construction industry focus of the 1980s, the author rapidly shifted the purpose of this system towards work flow reliability in order to be more related to *lean production* as the author acquired inspiration from the Toyota Production System and contacts with *Lauri Koskela* another scholar working with production and Lean theories applied to the construction industry. Rather than looking at a project as several work scopes, the Last Planner system looks at them as a process flow [G. Ballard and G. Howell, 2003]. The system helped to achieve Completed work percentages above 76% and up to 90% while most projects rarely reach 70%. [Herman G. Ballard, 2010]

As a tool primarily conceived for productivity purposes, one of the main aspects focused on during its creation was the production control [Herman G. Ballard, 2010]. Although production as been asociated almost entirely to manufacturing, with a product being moved through different stations and crew; it can be associated to construction with a "fixed position manufacturing", as the product is too large to be moved through different crews, the crews must be moved within it until completion [Herman G. Ballard, 2010]. According to Ballard and Howell [1998], construction production control is traditionnally done in order to track and identify which party is at fault in the process rather than act on the production processes as in the manufacturing industry. As specified in 2.4.2, uncertainty is a source of waste and thus production control could be easily shifted towards Lean construction theories.

Traditionnally construction project are run and controlled following project control models that ultimately influence the production control methods [Herman G. Ballard, 2010]. The project control are generally focusing on time and resources (materials, labour hours). The project is divided into smaller parts using the *Work Breakdown Structure* (WBS). These *WBS* include a schedule and cost planning estimated which can be used for monitoring purposes by the management throughout the works process. These *WBS* are usually work packages which are often a contract package and are defined as the smallest unit of work [Herman G. Ballard, 2010]. This method helps to control against estimated cost and schedule without taking in consideration the quality behind. Looking at the figures, a package/project can be doing well with regards to the production over budget percentage, while the product quality or the correct works are not done accordingly [Herman G. Ballard, 2010]. This method of control with no consideration to the other works running around, the next works or *"direct customer"* requierements, nor the previous works carried out is typical from a push system and appropriate for a push system [Herman G. Ballard, 2010]. Works are carried out as fast as possible in order to be completed as soon as possible, and thus be ready in case of unexpected delays for another *Work package*, rather than have the works done when needed. The Last planner aims towards a Pull system which lead to works being done when required and ready to be done, as well as include quality aspects which eventually impact the productivity.

The last planner system is named after "the person or group that produces assignments" [Herman G. Ballard, 2010]. An assignment is a task, a specific work that is planned to be done the next day. These "assignments" are the last and most tangible steps within a should-can-will-did frame (figure 3.4):

- **Should**: This is what was planned to be done at a time *t* in the master schedule.
- **Can**: This is the set of tasks that can be carried out with regards to previous work required completed at a time *t*.
- **Will**: These are the "assignments" planned to be done for the next days *t+n*.
- **Did**: This is the works done the previous day *t-1* which are subject to control.

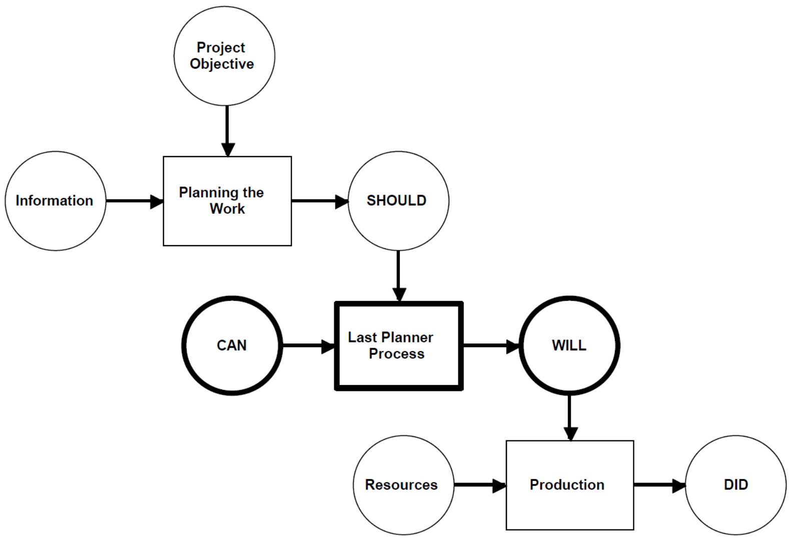


Figure 3.4. The Last Planner System by Herman G. Ballard [2010]

Whereas a Master schedule aims at planning a project in its overall, provides key milestones and is useful for the developper or project manager at an early stage but also for the rather little need for details during their meetings, the Last planner system with its *"reverse scheduling"* deals with the production on site on a daily basis. The Last Planner helps to transform what *should* be done and *can* be done, hence what was planned within a Lookahead schedule, into a *Weekly Work Plan* which is what *will* be done and is composed of "assignments" which are considered the smallest work scope and thus the most detailed [Alarcon and Calderon, 2003]. The lean philosophy as a whole helps toward a better use of resources and a reduction of wastes. The Last Planner translates this philosophy into *Percent Plan Complete* (*PPC*) which is a percentage of assignment completed; the higher the *PPC*, the "Leaner" the construction processes and eventually the construction flow. In other words, a project with 95% PPC is Leaner than a 5% PPC as the process is more reliable; what was agreed to be completed is indeed completed, resulting in less uncertainty and therefore reductions of buffers, leading to a leaner process. In order to obtain the highest *PPC*, criteria for the assignments to be written down were defined. [Herman G. Ballard, 2010; Ballard and Howell, 1998]

- **Definition**: The assignment should be specific enough to be quantifiable with regards to the materials needed (quantity and type), the potential coordination with other trades noticeable and its completion can be easily checked.
- **Soundness**: Are any prerequisite to the task ready? This includes any design to be completed, all the materials to be on hand and previous works completed. Ideally these prerequisites should be ready the week before the assignment is to be done.
- **Sequence**: Are the assignments selected from the construction processes required in a priority manner with regards to the customer process (the customer being here the next trade/crew)? Would this assignment fail to be done due to a previous failure up the stream, are any lower priority assignment available?
- **Size**: Is the assignment corresponding to the time frame and Crew size assigned, thus assuring no "void" in the process (too many workers for the task) nor lack of time (assignment too big for the time frame given). Does it produce sufficient work for the following production and its requierements?
- **Learning**: Are reasons for non-completion identified for improvement purposes ?

By following these criteria to write down the assignments in the Weekly Work Plan, Ballard and Howell [1998] found the *PPC* to be higher and the crew productivity increased as well. If any of these criteria is not met, whether the design is inadequate or missing, the materials is insufficient in quantity or inadequate, or previous works required are not completed, the assignments would take more time or be done incorrectly, leading to cost increase. The last item directly meets with the Lean philosophy regarding the *Kaizen*, or continuous improvement process. The reasons for non-completion can be chosen among a set of reasons that the supervisors have control on, and can be discussed and modified over time: materials, workers, design, previous work, changes, equipment, "bad luck" or act of God. Such reasons help to classify and create a reason chart which at the end of the week helps identify the main causes for non-completion. This chart usually narrows down the reasons to only a few due to the *Pareto* distribution or 80/20 principle, where 80% of the non-completed assignments come from only 20% of the reasons.

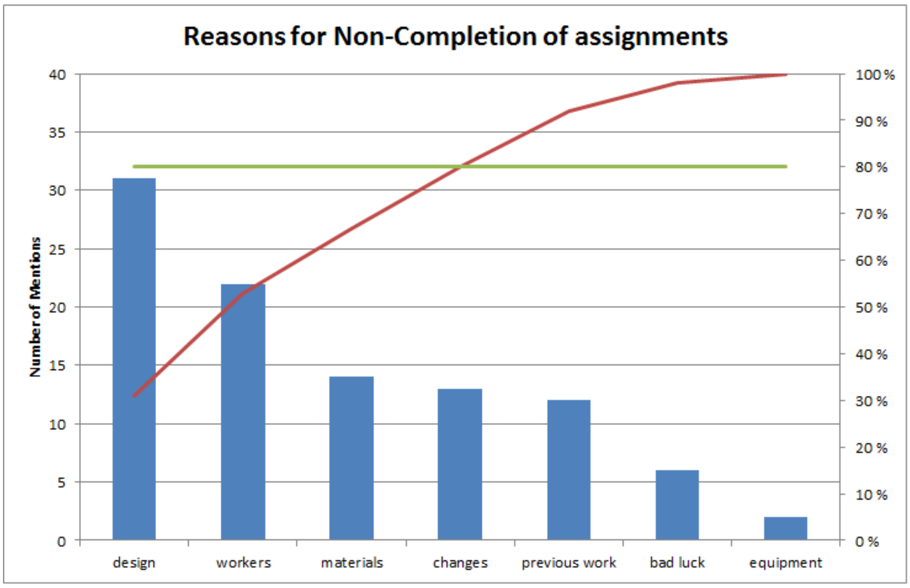


Figure 3.5. The Pareto principle

On figure 3.5, the red line is the cumulative percentage of the different reasons for non completion. This line crosses the 80% threshold at the "Changes" reason which means that any reason on the right can be left over as they are considered insignificant. By focusing on the few items on the left, work can be done on improving these reasons only and tangible results can be obtained faster. Alongside the Reason for non-completion chart, the PPC chart can be created over the weeks in order to track changes whether they are good or bad and discuss about it during huddle meetings which are detailed in the next section.

Keeping track on these assignments with the reasons for non completion and the smart use of the criteria for best results are also known as *"Shielding the production"* [Ballard and Howell, 1998]. Rather than relying on flexibility inherent to a push system where all available work is done in order to handle the high work flow uncertainty, sacrificing productivity to meet schedule deadlines, this assignment method helps to improve the productivity. As shown on figure 3.6, everything passing the thick line has passed the shielding process and therefore protect the production team from uncertainty, trading quantity for quality work. "Going slow to go fast" is a concept that proved working as data showed that 30% less labour was needed with a planning reliability higher than 50% [Ballard and Howell, 1998; G. Ballard, 1999]. A higher reliability results in a reduction of the buffers and thus the project duration, together with a cost reduction due to less labour needed.

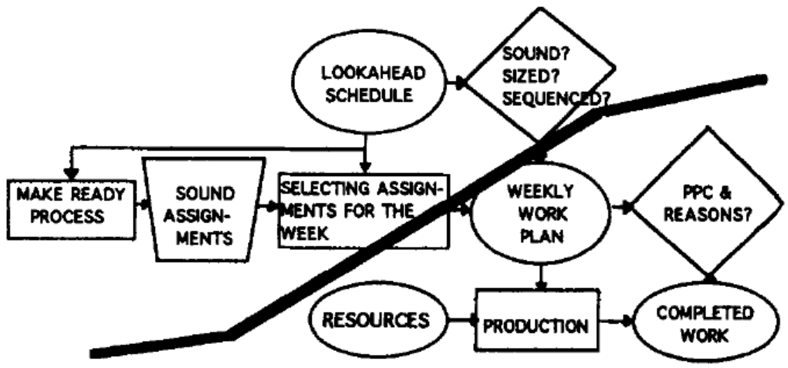


Figure 3.6. Shielding production. [Ballard and Howell, 1998]

The assignments for a daily control of the activities are all summarized within the Weekly work plan that is the key activity within the *shielding production*, nothing can pass this step would it not meet the criteria detailed previously. While the *PPC* defines what "did" get done and the Weekly Work Plan defines what "will" be done, the Lookahead schedule is a link between what "should" be done (provided by the master schedule) and what "can" be done (provided by previous works completed). While the Weekly Work Plan only display assignments that can be done when all previous requierements are completed, the Lookahead schedule displays the activities that are most likely to be ready for execution at the time scheduled. In addition the schedule should shape the sequence of works into work packages from the Master schedule with the crew capacity needed [Herman G. Ballard, 2010]. A backlog of ready work should be maintained to assure the most accurate results. The Lookahead schedule can be summarized as the master schedule looked at with a magnifier. The accuracy of such schedule was found to be linked to the extent to which it is detailed and failure to obtain an accurate schedule due to missing assignments can be reduced by the use of First-run Studies.

3.2.3 First-run study

Works carred out on a construction site are the physical processes of a long sequence of tasks leading to a final product. As any kind of process, planning is important and the bigger the works to be carried out, the more important is the planning accuracy. One way to strive for accuracy when planning is to use *First-run studies*. These studies can help to redesign the processes along the line thanks to the involvement of different representatives of the different functions involved [Alarcon, 1997]. The administration and resource management should be the first two main processes to be focused on. Traditionally the planning and process creation is examined but the time requirements for *Request For Information* (RFI), or change orders; as well as the leading time for materials, small tool supply, handling of materials on site, or hiring of tools, might be overseen, leading to consequent delays.

When a task can start, a first-run should be considered with the help of the different parties to gather ideas and suggestions, and experiment the previously planned work process. This think-tank and experiment procedure will be set as a standard goal not only to be achieved but to be overcome. According to Alarcon [1997], the time or cost of operations can often be reduced as well as the quality and safety be improved up to 50%. A common way that proved successful is the use of the *PDCA* cycle [Salem et al., 2006]. As displayed on figure 3.7, Such cycle is divided in four phases: Plan, Do, Check, Act.

- **Plan**:
    1. Select the work process to study: could be an interesting task with regards to its cost or variability.
    2. Review the drawings and specifications with special attention to missing information or clashes.
    3. Review the procedure of works with the foreman for possible improvement (eliminate, reduce or overlap process steps).
    4. Check process with regards to safety, anticipate potential hazards and specific preventions that might be required. If required processes can be changed for a safer option.
    5. Assign optimum labour and estimate equipment requirements.
    6. Set a date for the study to start.
- **Do**: Start the *"sample"* works for experiment. The procedure can be repeated two or three times to reduce possible bias.
- **Check**: Describe and measure the process on four main categories: the process, the errors, the safety, the resources. The process steps, the sequence actually followed and duration should be monitored; the errors, rework and differences to what was planned should be recorded; any near miss, hazard of accident should be reported; and the resources consumption compared to the outputs with regards to the materials used but also the equipment and labour hours.
- **Act**: Gather the different parties involved and review data. Share ideas for improvement, modify the sequence in consequence and set the improved method as standard to reach or beat.

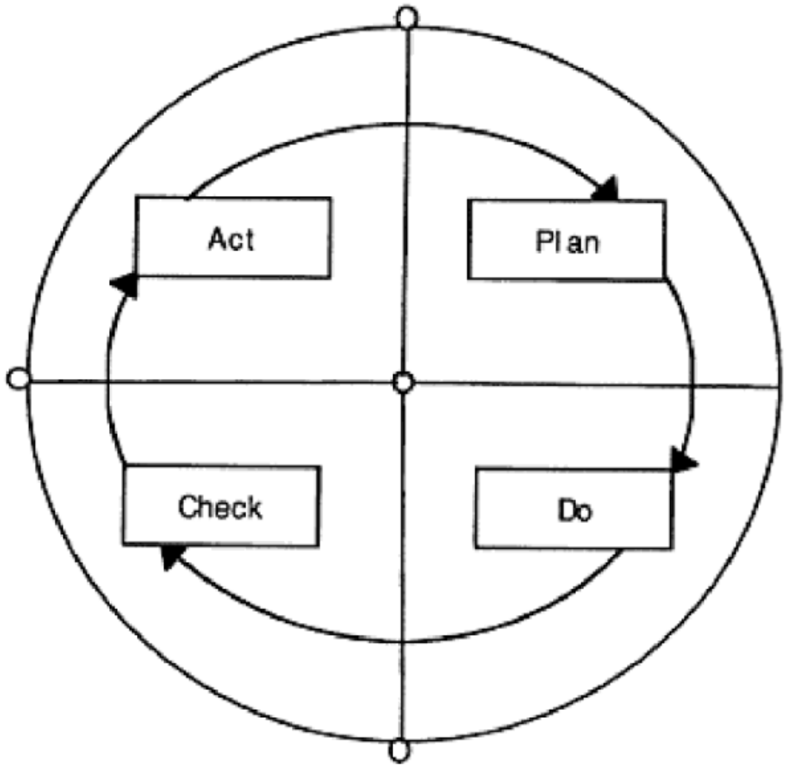


Figure 3.7. PDCA cycle. [Alarcon, 1997]

This experiment-based approach not only produces more reliable data for planning and production than assumption, but also helps to reduce costs, errors and accidents by teaching the crews on the methods to follow. This tool can become a routine in a company and be applied whenever a new process is designed, a new technology or tool is used, or new crews are formed.

3.2.4 Huddle meetings

On a construction project, many complex and specific activities are running concurrently in order to produce a final product to the developper. Due to the complexity and scale of the works, numerous parties with high specialization are involved. The subcontractors, although knowledgable in their field, are more often than not unaware of the sequence of works of other trades and their specific requirements. In order to counter any disruptency in the overall process, information must be shared as for the needs of everyone. It is common to have a formal weekly meeting between the different subcontractors regarding their main activities to be carried out in the following weeks, their specific needs and possible issues to come, however two simple and yet efficient informal meetings can be set to provide results.

Weekly meetings are a great opportunity to discuss coordination and main topics to come between the different contractors, however they do not help to solve issues raising during the week and needing a fast and efficient response. *All-Foremen-Meetings* have two main purposes: provide a quick answer to an issue on site and to share information from the different contractors. A daily meeting gathering the different foremen is key to assure a good communication and monitor the activities on site. These meetings are the room for discussion about various topics:

- Raise issue encountered on site with regards to certain needs that can only be fulfilled by another contractor, hence a requirement.
- Discuss safety-for-all with possible issues from another contractor or main contractor, but also the housekeeping.
- Review the works carried out and completed the previous day and compare with the planning.
- Communicate daily activities of the crews to highlight overlapping activities and adjust planning.
- Raise feedback from workers on problems, needs or ideas for improvements.

Start-Of-The-Day meetings are informal talks from the foremen to their teams summarizing the works to be done during the day for everyone in their teams to know. Important topics can be discussed during this meeting with regards to the safety or housekeeping. According to Salem et al. [2006], workers are more likely to talk to their foremen during that time of the day as well as raise issues or provide feedback. This meeting is a way to create a double way communication in order to share information from the workers perspective on issues unseen by managers or improvement that could be made, and summary of meetings from upper management and foremen meetings.

3.2.5 The five S's

The five S's defines "a system for workplace organisation and standardisation" [Evans and Lindsay, 2010]. In other terms, the *5S's* is a method for housekeeping in order to obtain a safer, more efficient and friendlier working environment. It comes from the Japanese terms: *Seiri, Seiton, Seiso, Seiketsu,* and *Shitsuke*; which are translated to respectively to: *Sort, Set in order, shine, standardize,* and *sustain.* As shown on figure 3.8, each term has a specific scope of influence with a very clear goal to achieve:

- **Sort (Seiri):** Ensure that, in a workplace, every and each item is in its proper place and that any item that is unnecessary is identified and removed. By sorting things up, the working area becomes free of obstacles or disturbance from unnecessary items. This step includes the waste removal as well in order to keep the area at all times clear. A good example is to have key items such as the rubbish wheelie bin in a defined area.
- **Set in order (Seiton):** Arrange equipment and materials so that they are easy to find and use. Prevent loss and waste of time by arranging the working area so that all equipment and tools is in close proximity, with a particular focus on having the most frequently used items the nearest to the working area. A typical example of this method is the toolboard that have the shape of the tools drawn on it so each tool has its own place on the board, making it easy to find it or identify tools missing.
- **Shine (Seiso):** Clean the working area, not only for safety reasons but also to quickly identify any issue or defect in the working area; for example: A hole in the slab that was not properly covered leading to a fall hasard. The working area must at all times stay clean and safe in order to be pleasing and easy to work at. The goal is to have a working place where anyone unfamiliar to the area can detect any problem.

- **Standardize (Seiketsu):** Formalize the procedures and practices developped for the previous points. This will create consistency and ensure that things are done in a correct manner. Any process the organisation puts in place to reach the best results from the first *3S's* should be formalized and become standard through the organisation.
- **Sustain (Shitsuke):** The whole process created up to this final item should be kept going through trainings, communication and regular audits. The goal is to reach a "do without being told" attitude. This can be obtained through regular feedback and reward on good behaviour from workers.

Every item has its own frequency of use that differs depending on their complexity. The three first ones are to be done and checked to be correctly followed on a daily basis, while the two last ones are more of a mindset to be taught and sustained among the working force but also the management through training and discipline. This housekeeping tool, although simple in its principles and advices might be one of the hardest to be followed due to the correlation often made between a construction site and a mess, leading to little cooperation from workers to clean up and sort things. Focus should be done on easing things for the workers to cooperate. This can be achieved by the use of teaching methods rather than repressive ones, among which site communication, through posters in the working areas, can help.

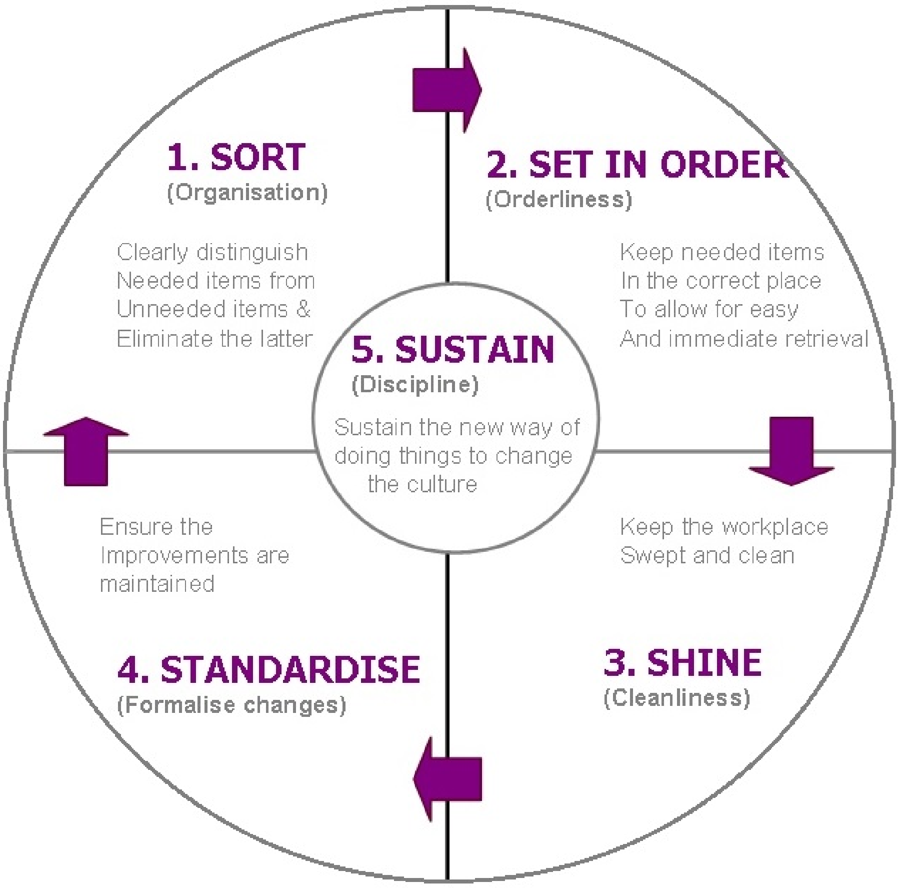


Figure 3.8. The 5S's principles

3.2.6 Increased vizualisation

The past few tools described as Lean processes help to provide data on current practices as well as to assess performances for improvement while keeping at heart safety. In order to assure that key messages, data, and goals are shared to everyone, a good communication tool is key. A. Tezel and L. Koskela and P. Tzortzopoulos [2000] defines visual management as a mean to serve different "functions within an organisation, namely transparency, discipline, continuous improvement, job facilitation". Visual management can be linked to various management systems such as: Quality management, Safety management, Production management, or Performance management [A. Tezel and L. Koskela and P. Tzortzopoulos, 2000]. The *5S's* tool is among tools that share this visualization improvement leading to better performances, however other simple tool can be implemented with an impact on different values linked to Lean philosophy:

- **Visual signs:** Highly visual posters which contains good practices on site, regarding health and safety (e.g. Character with all the PPE) or desired practices (e.g. "your colleagues are working with you not for you, be nice", picture with a confuse worker looking at a messy place to promote order on site). These signs can have an impact on various topics due to their easiness of use, such as the Health and Safety or housekeeping.
- **Poka Yoke:** the Japanese term for mistake-proofing defines any mechanism that prevents a mistake or defect (e.g. electrical plugs). Poka-yoke and root causes or problems are identified to reduce variability in production systems and thus be part of a Lean construction philosophy. [L. Koskela, 1992]
- **Performance charts:** The different performances indicators (KPI) provided by the Last Planner system (PPC, reasons for failure), supplier or subcontractors performance can be displayed on site for everyone to see. These charts displayed create an extra motivation for performance improvement [A. Tezel and L. Koskela and P. Tzortzopoulos, 2000], but also helps at a quick glance to obtain information on the particular points to give extra attention for improvement.
- **Quality control:** Quality defects identified on site during inspections should be displayed with their resolution in the working areas where similar tasks are performed as well as within the huddle meeting room, for discussion but also for information. Quality defects might reoccur as all the workers might not get the information about the defect or forget to pay attention on this particular point.
- **Work advancement:** Pull production is a way to move the process forward when it is needed and required rather than when it is possible to be done as traditional construction management. Such pull production can be applied on site with the help of visual signs displayed at the entrance of a working area. Ultimately this would lead to a stronger involvement and more freedom to the workers that would not be relying on their managers call.
- **Material management (Kanban):** Kanban is a visual mean that helps to identify, generally in a binary way, the stage at which a resource is. The use of a two colour system (e.g. red and green) helps the manager in charge of ordering to quickly see what materials need to be reordered without asking workers on site, but also helps to identify a need, prior the resource to run out. The specific material with relevant information for orders can be included on the signs or cards to ease the ordering process.

The involvement of the workers as well as the use of "funny" signs creates a better response and results with regards to health and safety and good practices [Salem et al., 2006]. Moreover, the instructive light-hearted signs will not be perceived as repressive which can help to keep happiness for the workers, which is linked to a better productivity. [Oswald et al., 2015]

3.3 An overall influence

The different tools described in the previous chapter, although not exhaustive, provide a wide range of topics subject to possible improvements. Due to the complexity of the construction industry, the Lean philosophy had to be developped for various stages of the construction as well as for various parameters. Consequently tools were developped with an influence at early stages of a construction project, also known as the design phase, such as the *VSM* or Last planner, while others were specifically designed for the construction phase with a focus at a micro scale such as the *5S's* or increased vizualisation. However, it can be argued that some of these tools, such as the first-run study or the huddle meetings, are at the junction between the design and construction phase due to their specific position in the process. Indeed they can highlight forecoming problems or unefficient design at an early stage of the construction for the design to be modified.

The pull-system preached by the Lean philosophy helps to reduce the amount of information, materials and work created and shared to the strict minimum so to reduce wastes and thus obtain better performances. Although, it must be clear that Lean philosophy does not mean "cuts in budget" as the main four topics within the construction industry are monitored and kept at high standard:

- **Safety**: In an industry as dangerous as the construction industry, safety is a game changer for companies to thrive but also to survive. It is in this optic that the huddle meetings with their safety talks and the *5S's* were created and are used.
- **Quality**: Value is brought to the customer by meeting his requirements but also achieving or overcoming quality expectations. The vizualisation tools discussed and the Last planner way of organising the works aim both at reaching the best of quality with a better efficiency.
- **Schedule**: One of the most monitored aspect of a construction site is the schedule and as such the Last planner and VSM helps towards keeping track on the works activities, preventing unnecessary delays and foresee better critical paths.
- **Budget**: As a low profit industry, savings on wasteful activities and prevention of reworks from the VSM and last planner can help to reduce costs with barely no effect on the three previous items.

The Lean construction philosophy through the help of scholars and the cooperation of professionals can help construction project to be run in a different way. The construction processes rather than being seen as a conversion of inputs into outputs (conversion view) can be seen as a flow of resources and information providing value to the customer (Flow view and Value generation) [Herman G. Ballard, 2010]. The different tools set within a Lean perspective can help towards a value generating project led through a "flow model". However these tools are not a warranty of success and their implementation must be studied.

Implementation of Lean principles 4

The implementation of new processes is discused in this chapter as a general feature, with the meaning of an implementation and the processes to follow for a successful one. Then the discussion narrows down to the implementation of Lean construction management and the influence of the stage of implementation. The potential implementation barriers are highlighted for better results during the implementation process.

4.1 Implementation of new processes

According to The Oxford Dictionary [2017], an implementation is "the process of putting a decision or a plan into effect" or the start of a new plan or system in an organism [Cambridge Dictionary, 2017]. An implementation is therefore a mandatory step for any organisation willing to change in anyway their current ways of practices. This change can be the result of actors within the organism willing to use a new technology which can be defined as a system of component or information which act or change a product from one state to another [Goodman and Griffith, 1991]; as well as an innovation or improvement in a system that is actually used elsewhere but novel to the company [Slaughter, 2000]. Six stages for implementation where identified by Slaughter [2000], which can be linked to previous stages identified in previous works [Goodman and Griffith, 1991], totalling at eight stages for implementation: the identification; the evaluation; the commitment; the preparation; the use; the feedback and redesign; the final evaluation; and the diffusion. These stages are linked together in a circle as to continuously make the process relevant and efficient, although after a first round the term of "implementation" might be discussed and changed for "continuous improvement". The eight stages for implementation, displayed on figure 4.1, are defined as follow:

- **Identification**: The objectives to achieve associated with the project should be compared with the potential innovation to implement. A critical factor at this stage is to have among the team identifying these objectives a person aware of potential issues that led to this research for new technology or innovation but also that could provide relevant information when assessing these goals. [Slaughter, 2000]
- **Evaluation**: With respect to the objectives identified previously, the innovation should be evaluated. This evaluation is commonly carried out with regards to the costs reduction that might occur but also on the improvements on performances of the design or construction process. The evaluation criteria might differ whether it is implemented on a project scale or on a company scale. Projects would focus mainly on the costs, duration, feasibility, complexity, risks of failure and performances of the innovation; whereas a company would probably have more concern on the reputation gains, initial commitment or compatibility with existing methods or materials. [Slaughter, 2000]
- **Commitment**: This is the company demonstration through resources allocated, public announcement and acknowledgement to follow the innovation. Among the different actions to set, the election of a "champion" willing to be proactive towards

the implementation of this innovation is a good practice. The commitment can be translated by the resources spent on the innovation whether they are financial, material, personnel or equipment.

- **Preparation**: The personnel involved in the innovation process implemented must be trained to the new methods of working and team leaders must coordinate everything for there teams but also together with the others for a better start. [Slaughter, 2000]
- **Use**: When the new process is implemented, performances must be monitored as adjustments and changes will arise especially at an early stage. More efficient methods of use or unforseen details might arise, hence a need for observation and action for improvement. The more complex a system to which a process is implemented, the more possibilities for adjustment might arise. [Slaughter, 2000]
- **Feedback and Redesign**: Collection of data during implementation should be done in order to discover unintended oppotunities but also unexpected negative consequences. This feeback during implementation follows the Lean principle of constant improvement and thus is relevant to be added amongst the stages.
- **Final evaluation**: Data and relevant information should be collected prior implementation during the preparation step, but also during the implementation to monitor the performances. The first comparison should be done between the expected results and the actual ones. Among the different information relevant after implementation can be cited: the actual implementations carried out; the modifications made; the performances measured; the problems encountered; or the commitment from the management, project teams.
- **Diffusion**: This stage refers to the spread of the new system to another part of the organization, whether it is another construction site when at a company scale, or another phase of the construction process on a project scale. The diffusion stage facilitates the development of a standard process with the new system implemented but also helps to legitimate it within the organisation.

During the implementation process, rewarding should be discussed with regards to the personnel involved and achievements occuring. An incentive can be given although some rewards might be considered "free of costs", such as pride of achievement, challenges overcome, or less fatiguing work [Goodman and Griffith, 1991]. What is rewarding for one might not be for another actor, as well as a reward might not be perceived as such in a later time of the implementation but rather as a standard to be provided. [Goodman and Griffith, 1991]

The implementation of Lean construction philosophy within a complex system such as a construction project makes it a bigger challenge. Such implementation can be described as a system innovation due to many interfaces resulting from the tremendous amount of actors involved with different organisations. Such system innovation is most successful when implemented by a source that has control and expertise on the overall system, which would be the general contractor. The complementarity of the different innovations implemented in such an innovation can be a critical factor to meet the objectives set within the evaluation phase [Slaughter, 2000]. Although Slaughter [2000] argues that the different innovation implemented in a system innovation might neglect the overall performances when evaluated individualy, in the case of Lean construction, each tool developped in

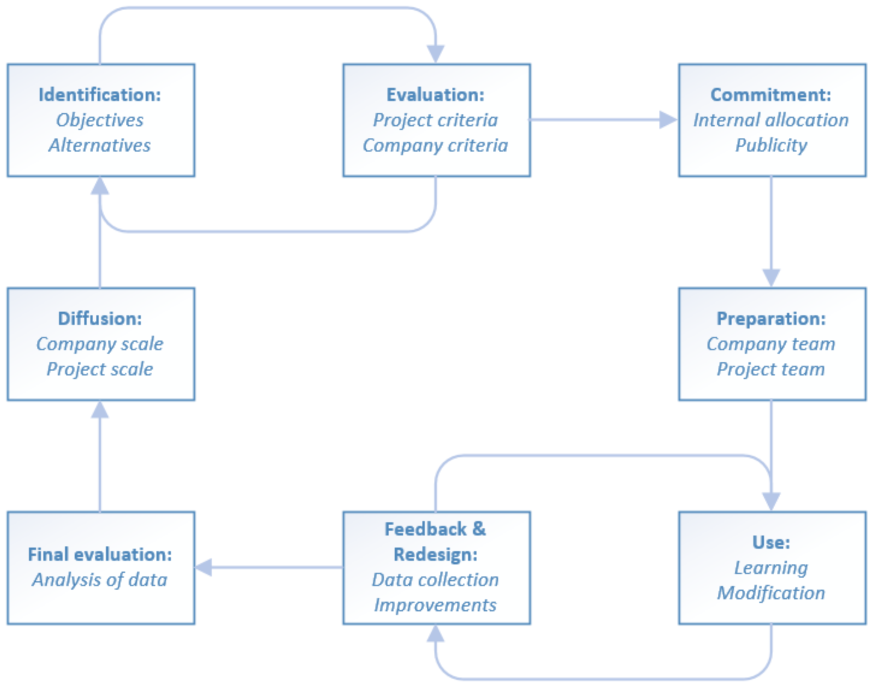


Figure 4.1. The eight stages of implementation. [Slaughter, 2000]

section 3.2 should be evaluated both individualy to assess their relevance and impact but also among the general evaluation of the implementation. The complexity of the whole processes implemented makes it difficult to evaluate the obtained performances to other configurations whether it is simply without implementation of Lean construction or another similar construction management philosophy.

The implementation of such a system will have different requierements with regards to the commitment needed and the role of the "champion" [Slaughter, 2000]. The functionality and modifiability of the processes to implement, as well as a gradual implementation of the changes have been positively associated to a successful implementation [Goodman and Griffith, 1991]. All project members will be asked to embrace and integrate the innovations for best results, while the champion will be asked to promote the innovations amongst the different project team as they enter the system. An active collaboration of the different actors is highly correlated to success and benefits from the implementation [Slaughter, 2000]. During the early *use* stage of the implementation, the decision-makers will have to control the direction of the new implemented process and maintain focus on the objectives previously set. Along the implementation phases, results from evaluation and challenges encountered should be documented to provide the basis for an effective implementation on future projects and company-wide if proven successful. [Slaughter, 2000]

4.2 Lean Construction Implementation

The implementation of Lean construction has been linked to a system innovation, however this implementation will be done within an already complex system where the implementation performance results and potential for improvement is highly related to the phase of a construction project. For simplification purposes and because the Lean construction principles would influence mainly these phases, a construction project can be divided in two main phases that overlap throughout the project duration: the design, and the construction. Lean construction tools have different outcomes and different processes on which it has an influence (cf 3.2).

The design phase

This phase could be described as every process occuring before any works occurs on site, including procurement of materials. At this stage, the maximum outcome can be expected as everything is to be created for the works to be carried out. Although the construction industry is very traditionnal and tends to evoluate slowly, the design phase has the potential to provide the biggest changes when new processes or innovations are implemented. The different Lean construction tools can be presented at this stage, as they can help the designers to consider future needs and foresee in a proactive manner potential clashes or issues. Moreover, as an early stage of a construction project, more strings can be pulled which on the long run lead to more reductions of wastes and therefore an earlier completion with positive finances.

The construction phase

In this phase the construction project physically starts with the works being started. At this stage, most of the design for the package should be done and less room for improvement is available. Any changes might lead to considerable delays and costs. However, a construction project has the design and construction phase which are "working" concurrently on different plans as the design does not need to be completed for the whole project prior works commencement. Therefore an implementation at an early construction stage can still provide significant results. Moreover, the lean construction tool presented in section 3.2 are for the most only usable during the construction phase for a safer and smoother process on site.

Whether the Lean construction philosophy get introduced during the design phase or the construction phase, it will provide different outcomes and challenges with potential resistance from the users or environment. The Lean construction tools should provide specific processes or way of working with impact to the design. These changes have been summarized on graph 4.2 which is the Mcleamy curve. This curve represents the relationship between the changes impact and costs depending on the project phase at which it occurs. The last phase where design changes can be considered as viable is during the construction documentation phase which can be considered as an early stage of construction when the project construction time for a package is large enough to have room for modification without impacting the productivity on site such as by waiting for the design.

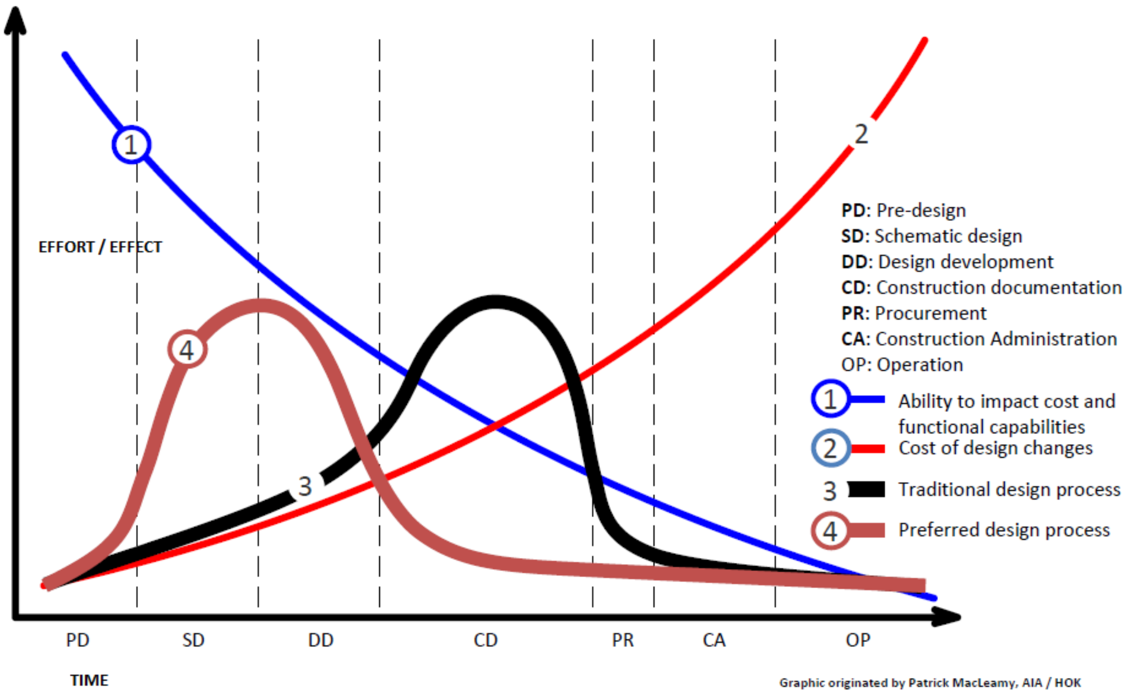


Figure 4.2. The Macleamy curve with the relationship between the impact of changes and costs depending on the project phase.

4.3 Implementation barriers

The implementation of new systems of work can be faced with difficulties not only at first but on a certain period of time. These barriers may be due to human factors which can be either intentional or not, but can also be due to other processes within the system. Most often than not, changes are resisted as it shifts a system and processes that the actors are used to, to something new that lead them to a learning process and discomfort. When faced with the possibility to implement a new tool for Lean construction, defensive reactions arise [Ballard and Howell, 1998]:

- **It is unnecessary**: Participants from any hierachical rank in the system may argue that the tools are not needed and things are running well as they are or improvements can be obtained without its help. Depending on the tool to implement, data and explanations on how and what particular points can gain from this tool are needed to remove this reaction.
- **It is impossible**: The participants may argue that: the tools suggested are impossible to be used; the results displayed cannot be achieved; or it is counter-intuitive. A tool such as *the last planner system* may seem counter-intuitive and especially with its shielding preaching to wait for an activity's prerequisites to be fully ready prior start of the works.
- **It is already done**: Participants may argue that Lean methods are already set in place. Whether that is true or not, it is suggested to evaluate the situation visiting on site and monitoring with PPC for a while in order to gather sufficient data to assess the situation.

These reactions are the first barrier to expect from project participants when the Lean construction question arises. However, other barriers can arise and last throughout an implementation. A non exhaustive list of reccurring implementation barriers is required for a better preparation:

- Freire and Alarcon [2002] noted that people may feel controlled when the evaluation process of an implementation is carried out. People do not like to be controlled or evaluated on practices that could be theirs for many years, and moreover when it is by an external consultant. Good communication on the reasons for evaluation, helps to reduce the tensions as the workers are aware of the possible outcome.
- Time is one of the main factors influencing an implementation. It is also an identified implementation barrier as actors of the changes may feel as they lack time to focus on an implementation [Alarcon et al., 1994]. A Lean champion focusing on the tools to implement and helping out the other participants, is key to tackle this barrier.
- The organization in which a system or company is integrated may slow down an implementation process [Alarcon et al., 1994]. The heavy administration can impact the responsiveness in the face of unexpected event, or challenges, leading ultimately to a worse handling of the situation.
- Sef-criticism is the very first step towards improving a situation. With regards to Lean construction, the participants may oversee aspects of the processes as not deficient, reducing the potential for improvements.
- A poor use of the information obtained is a main barrier to an efficient implementation as the results or outcome gathered with the different tools are not used for improvement and learning purposes [Alarcon and Calderon, 2003]. The data generated by the different tools should be studied and used for improvement, otherwise these very tools implemented for waste removal will become themselves wasteful activities.

Some implementation barriers could be defined as "deficiencies". These "deficiencies" are linked to an implementation process and may be not easily fixable but certainly easy to catch and work on for improvements such as: training properly on the tools to be set in place; increase the communication amongst the different participants; integrate in a better way the different actors in the chain (client; subcontractors; suppliers). [Alarcon et al., 1994]

The cooperation of the participants in the implementation is one of the most if not the key to a successful implementation. Creating an environment of cooperation between the participants but also between the participants and the lean instigator is the very first step towards removing barriers and moving forward the implementation. An atmosphere of learning and suggestions should be created rather than reppressive so to obtain the participants' support and therefore a pro-active team spirit lifting the project towards better results.

A case study: Manhattan Loft Gardens 5

In order to have a better understanding of the potential benefits of Lean management practices implementation on a construction project, the following chapter displays the case of the Manhattan Loft Gardens project. A description of the specificities from the project is carried out so to set the particular parameters linked to the implementation. Then an assessment of the current situation which is the first stage of the Lean process and implementation is done. From the assessment, room for improvement is identified and analysed. Improvements and possible results are provided as well as ways to follow-up and control the on going process leading to the next step after implementation.

5.1 Background of the project

This section is for the most referenced to a previous work of mine during the previous semester which was my internship period [Gwendal C. Le Gratiet, 2016]. Some specifities in relation to Lean construction and the project are added towards the end.

Manhattan Loft Gardens (*MLG*) is a project located in East London in the Startford Neighborhood. The project is located right next to the international station linking London to Paris through the *Eurostar lines* as displayed on figure 5.1. Given the proximity of the station and railways, a residential tower such as MLG makes it an interesting project on many aspects. The Stratford district is a former industrial area which has developped to reach the second economical place in East London with a major event having occured in 2012: the summer olympics.

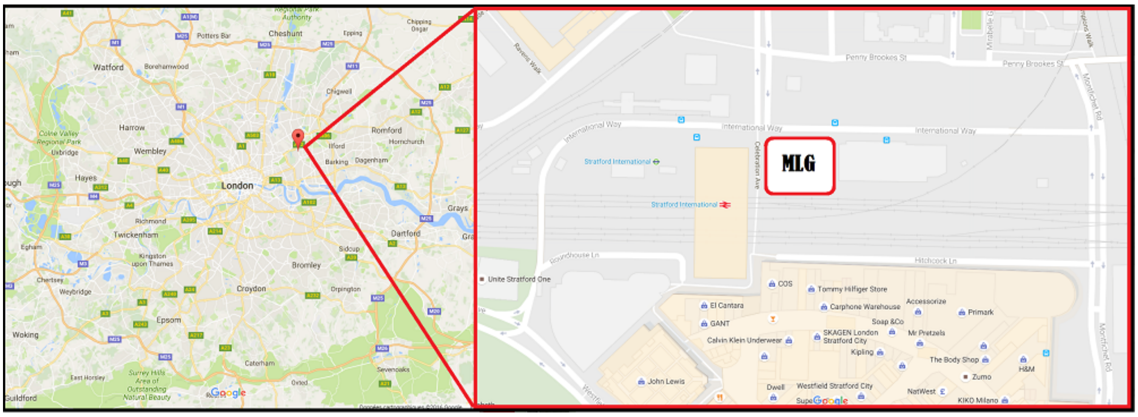


Figure 5.1. Location on the Manhattan Loft Gardens project.

The 42 storeys building is divided in two with the 7 first storeys being a world-class hotel topped with a sky garden, and the 34 storeys remaining being a residential tower composed of 13 different types of flats and lofts totalizing at 248 dwellings and a penthouse on top. The 143m high building is one of the highest construction in the area as these lines are written and reaches a project area close to 40,000m^2 with a ground area of 2,500m^2. The hotel has a triple height lobby to welcome visitors in one of its 150 hotel rooms, spa and rooftop restaurant. The tower has a base of around 30m x 30m and has the specificity to have two cantilevers level 10 and 28 which allow outdoor spaces with trees or "sky gardens", hence the project name. The last 6 storeys are in a triangular shape reminding of the cantilever levels. [Skidmore, Owings &Merrill LLP, 2016]

Figure 5.2. Architectural representation of the project.

The works on site started the 20th of November 2014 and are to finish in April 2018. The structural works and the facade works on the tower are completed as these lines are written. The project has been won in tender by *Bouygues UK* as main contractor at £110 million. The Structural part of the project on its own, reaches £12 million and has been carried out by the main contractor.

Bouygues UK (*BYUK*) is a branch company founded in 1997 for the British market as part of the international group *Bouygues construction* which is operating in 80 countries worldwide. *BYUK* has currently 1500 employees and a turnover of around £800 million [Bouygues UK, 2016]. Although the Bouygues construction group has extensive knowledge of great projects such as the *stade de France* in Paris, the new *philarmonic de Paris* or the *MahaNakhon* tower of Bangkok; the *MLG* project was the first of its kind for the British branch.

The Lean construction consultant arrived on site beginning of November when the structural works where at 90% completion (figure 5.3) and the phase 0/1 of the fit-outs started (figure 5.4). The phase 0/1 on a construction site is defined as the partitioning of the different appartments including the mechanical and electrical trades networks. The operatives on site were around **150** with half of them being part of the structural team. The main subcontractors on site were the facade contractor, the mechanical contractor and the dry-lining contractor.

Figure 5.3. *MLG* structure beginning of November 2016.

Figure 5.4. Phase 0/1 beginning of Novenber 2016.

5.2 Assessment of current processes

In chapter 4.1, 8 stages for implementation are introduced as best practice to follow for a successful implementation. Lean construction philosophy was brought to the *MLG* project from the project director which was introduced formally to the concept by "Bouygues Bâtiment International", the international branch of the group [Attachment-File,3.Frederic Perez]. *BYUK* top management identified the potential benefits of Lean construction philosophy and decided to evaluate and implement Lean construction through the implementation in 6 pilot projects, chosen through volunteering. These pilot projects would be the case studies for the company to understand the philosophy and judge for an implementation at a company scale.

During a presentation to different projects, the *MLG* project director seized the potential of the philosophy with regards to the specificities linked to the *MLG* project. The project director evaluated the project needs for Lean to be irrelevant during the structural phase due to good performances linked to *Bouygues construction* traditional business in the structural phase with their own production team, and due to a culture of processes. Prior to any formal assessment of the situation on the project, the early objectives for the Lean implementation were:

- **Assess the performances of the project**: Although the performances in term of costs and time proper to *BYUK* were strictly monitored and analysed, the "project" performances linked to other actors and especially in relation with the coordination were loose.
- **Identify room for improvement**: The relationship between the design team and the main contractor was not optimal but no concrete reason for low performances had been identified.
- **Provide a formal "toolbox" for the management team**: as identified by the project director: "the managers in my team use great tools but not everyone uses the same ones, nor they use these tools to their full potential". [Attachment-File,3. Frederic Perez]

A Lean consultant was chosen to work on the project during the last months of the structural phase (early September 2016). They were hired full time on the project for a 6 months period with the 2 first months focused on observation for the assessment of the project prior implementation (early November). The project team was introduced to the Lean consultant as well as the Lean philosophy through a formal meeting concluding by a presentation of their work plan.

As defined by the project director [Attachment-File,3.Frederic Perez], a tower project can be compared to a Formula 1: "looking very simple on the outside but very complex in the details". A tower project may seem as a succesion of floors with the same partitions and technical subjects to follow, however most of the floors are different due to the different apartments layout and even more on the *MLG* project. Indeed different lay-outs were submitted reaching a total of more than 70 different types of flats. This high variability in the design led to the Lean philosophy to be interesting to be tested. The reduction of waste and process to make a smoother flow of activities would highly sollicited as the Lean philosophy, spirit state, would be used throughout most of the project.

5.3 Problem identification

In order to implement Lean tools to an on-going project with existing processes and production having already started, an assessment of the project processes and key performances is necessary. Following this statement, the lean consultant on the project investigated, through studying the different consultant and main contractor, the interaction between them with regards to the design process of the hotel mock-up rooms of the project. The study was concluded with a meeting gathering a representative of the main consultants and main contractor design team to create a flowchart using stickers (figure 5.5). For a better understanding, different colours were used to identify different aspects of the chart.

The green stickers were the processes, the yellow stickers the resources and time values, whereas the orange and pink stickers were questions and issues encountered.

Figure 5.5. Consultants and main contractor design team creating the flowchart.

The results of this meeting are compiled in the flowchart enclosed to the report and in Appendix B. As per suggestions in section 3.2, a Value Stream Map can be of good help to understand the processes, their value to the system and resource consumption. A value stream mapping was not created precisely as per the rules for a different set of reasons among which the regularity of the processes cannot be assessed. Indeed the design process which can be argued to be to a certain extent redundant, cannot be compared to a manufactory processes where the products can go in circle as it is a standard enquiry. Designs in a construction project cannot be considered as a production line from a manufactory perspective. A second difference is that although the client might be considered the client in the stream, it becomes difficult to assess a release rate in the process. Finally the customer link in the stream can be of different sources with demands varying significantly. Therefore a VSM should be created for all the different parameters existing to recreate the complexity of a construction project. The flowchart created during this meeting session, although different from the *VSM* method, shows similarities on different aspects that can link them together. The value created by this process is the "stage 3 report" which is the sum of the requirements and drawings for the hotel mock-up rooms.

During the creation of this flowchart, different colours were used for an easier reading of the informations displayed. Along the session, questions arised and issues could be shared and discussed with the different parties. Having all the different parties gathered to create this chart, helped everyone to be aware of processes occuring and difficulties which were faced.

This exercise helped to identify key information regarding the design process on a specific topic which was the hotel mock-up rooms (*HMUR*) which, through discussion with he different actors around the table, could be extrapolated to a general design process occuring on site. As displayed on figure 5.6, the first notifiable information is that the validation phase of the process although requiring 16% of the total amount of resources spent in the process, requires 1/3 of the time spent throughout the process. A certain amount of questions and issues were identified during this session as the non-presece of the consultants on site, the overproduction of drawings or the overprocessing of drawings due to different CAD softwares used by the consultants.

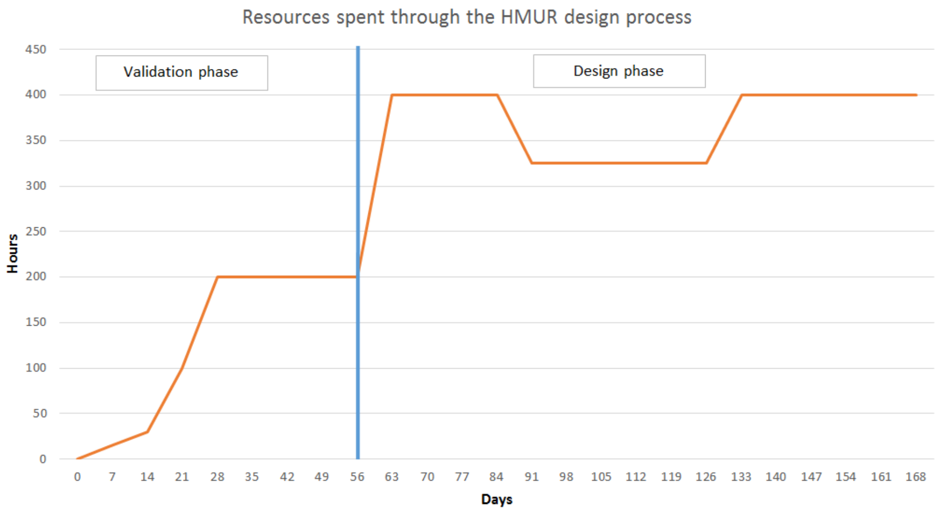


Figure 5.6. Resources spent through the HMUR design process over time.

As the production started on site, observation could be run in order to understand the processes ocurring on site, the difficulties that may be encountered on a daily basis. During this observation period, a few key points were monitored such as the advancements of the works, the waiting time from the different trades regarding their needs from other trades or the reworks to name a few. The different observations made were as follow:

- The design for construction was often delaying the works due to the complexity of the project. A tower design, and especially on the *MLG* project, is not a copy and paste of every floor one on top of another. Little regularity was observed in the design leading to a need for the designs to be produced for every floor.
- A lack of communication between the trades regarding their needs prior works leading to workers going back and forth on small tasks forgotten as the needs were not shared prior completion.
- A lack of communication on the completed works for the following trade to start.
- A bad housekeeping regarding the tidiness on site but also the storage of materials in the floors.

It was also observed that some Lean construction tools were already in place to a certain extent as follow. The project was already using first-run studies as part of their company processes. New contractors were asked to create "samples" of their works to assess the different different important points such as the quality of the works, the methods used, the potential clashes occuring on site in real conditions or their requirements that were unforseen. The housekeeping system (*5's*) was not implemented as such on site although a few ideas were already set in place. Storage of the materials within the different flats were requested to be stored in an orderly way and away from emergency routes. The "5@11" rules was followed on site, which is a company policy to have every worker taking 10 minutes at the end of the day to clear up the working area from rubbish, materials and tools.

5.4 Improvements assessment and implementation

After assessment of the processes on the project whether ahead of production or directly on site, a set of tools was presented to the project and the main contractor team for use. In relation with the issues observed during the design process meeting and the observations on site, a few activities were implemented from the beginning of November, following the observation period.

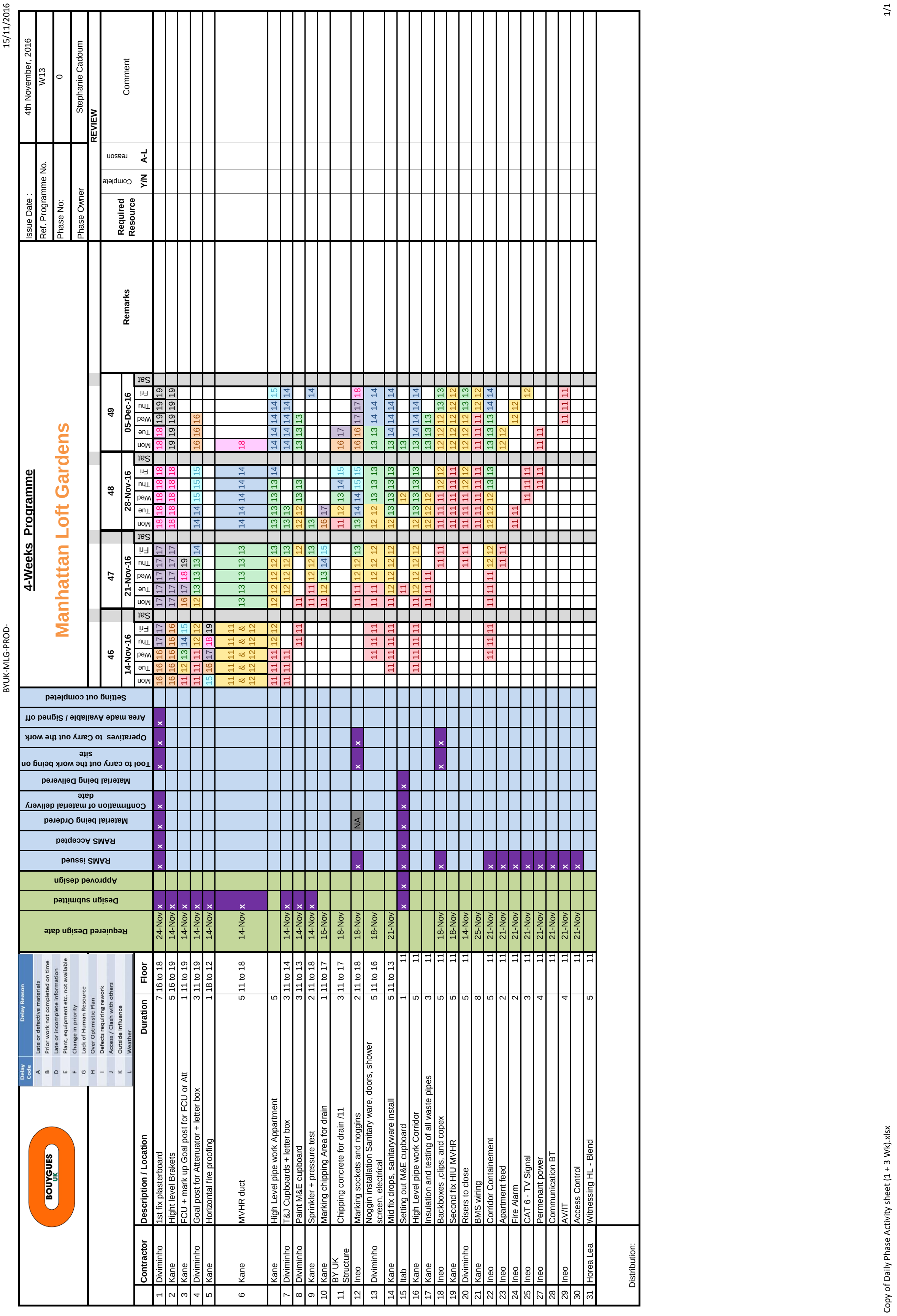
The last planner

The last planner system was introduced with the use of a 4-weeks look ahead programme and weekly work plans. Following the suggestions from chapter 3.2, these two programmes would help to increase the accuracy of plannings with the reality seen from the last planner in the chain. The 4-weeks look ahead programme was reviewed weekly as well as a weekly work plan was asked from the different subcontractors during a Project management meeting.

The 4-weeks look ahead programme was firstly design as seen on figure 5.8. The contractor with the task associated, duration and location where displayed on the left of the table followed by the necessary prerequisites needed for it to be completed as planned. The 4-weeks lookahead representing what "Should" be done, missing prerequisites helps to assess whether the activity can proceed to the weekly work plan. The middle part of the programme was a more traditionnal schedule of works with the dates and floors worked on for the activities. Finally the right handside was the "quality" side with the different review and comments to make with regards to the non completion of an activity. The 8 reasons for non completion of an activity are displayed on figure 5.7. The production was "shielded" by introducting activities to be done only when the prerequisites for it were all completed. The programme was displayed for everyone to see in the black hat meeting room.

Delay Code	Delay Reason
A	Late or defective materials
B	Prior work not completed on time
D	Late or incomplete information
E	Plant, equipment etc. not available
F	Change in priority
G	Lack of Human Resource
H	Over Optimistic Plan
I	Defects requiring rework
J	Access / Clash with others
K	Outside Influence
L	Weather

Figure 5.7. Reasons for non-completion of an activity.



	Contractor	Description / Location	Duration	Floor	Requiered Design date	Design submitted	Approved design
1	Diviminho	1st fix plasterboard	7	16 to 18	24-Nov	x	
2	Kane	Hight level Brakets	5	16 to 19	14-Nov	x	
3	Kane	FCU + mark up Goal post for FCU or Att	1	11 to 19	14-Nov	x	
4	Diviminho	Goal post for Attenuator + letter box	3	11 to 19	14-Nov	x	
5	Kane	Horizontal fire proofing	1	18 to 12	14-Nov	x	
6	Kane	MVHR duct	5	11 to 18	14-Nov	x	
	Kane	High Level pipe work Appartment	5				
7	Diviminho	T&J Cupboards + letter box	3	11 to 14	14-Nov	x	
8	Diviminho	Paint M&E cupboard	3	11 to 13	14-Nov	x	
9	Kane	Sprinkler + pressure test	2	11 to 18	14-Nov	x	
10	Kane	Marking chipping Area for drain	1	11 to 17	16-Nov		
11	BY UK Structure	Chipping concrete for drain /11	3	11 to 17	18-Nov		
12	Ineo	Marking sockets and noggins	2	11 to 18	18-Nov		
13	Diviminho	Noggin installation Sanitary ware, doors, shower screen, electrical	5	11 to 16	18-Nov		
14	Kane	Mid fix drops, sanitaryware install	5	11 to 13	21-Nov		
15	Itab	Setting out M&E cupboard	1	11		x	x
16	Kane	High Level pipe work Corridor	5	11			
17	Kane	Insulation and testing of all waste pipes	3	11			
18	Ineo	Backboxes ,clips, and copex	5	11	18-Nov		
19	Kane	Second fix HIU MVHR	5	11	18-Nov		
20	Diviminho	Risers to close	5	11	14-Nov		
21	Kane	BMS wiring	8		25-Nov		
22	Ineo	Corridor Containement	5	11	21-Nov		
23	Ineo	Apartment feed	2	11	21-Nov		
24	Ineo	Fire Alarm	2	11	21-Nov		
25	Ineo	CAT 6 - TV Signal	3	11	21-Nov		
27	Ineo	Permenant power	4	11	21-Nov		
28		Communication BT		11	21-Nov		
29	Ineo	AV/IT	4	11	21-Nov		
30		Access Control		11	21-Nov		
31	Horea Lea	Witnessing HL - Blend	5	11			

Figure 5.8. Design table used on the project.

Design productivity monitoring

In order to reduce the processing time of the drawings along the design processes, the different designers and the phase 0/1 managers were given production goals to achieve. They were asked by the Lean team to ensure the smooth process of the different drawings through the system as these drawings were usually left for days without any changes while comments were required from either consultant or manager. The goal was to make sure that the drawings were spending the least time along the process prior release for construction. In order to obtain the best results, its implementation was done through a presentation of task to the main actors with the expected results. The design needs from the site were also shared directly to the design team through a Pull system. A table shared in the office next to the design team was displaying the different topics to be clarified with the person in charge written next to it 5.9.

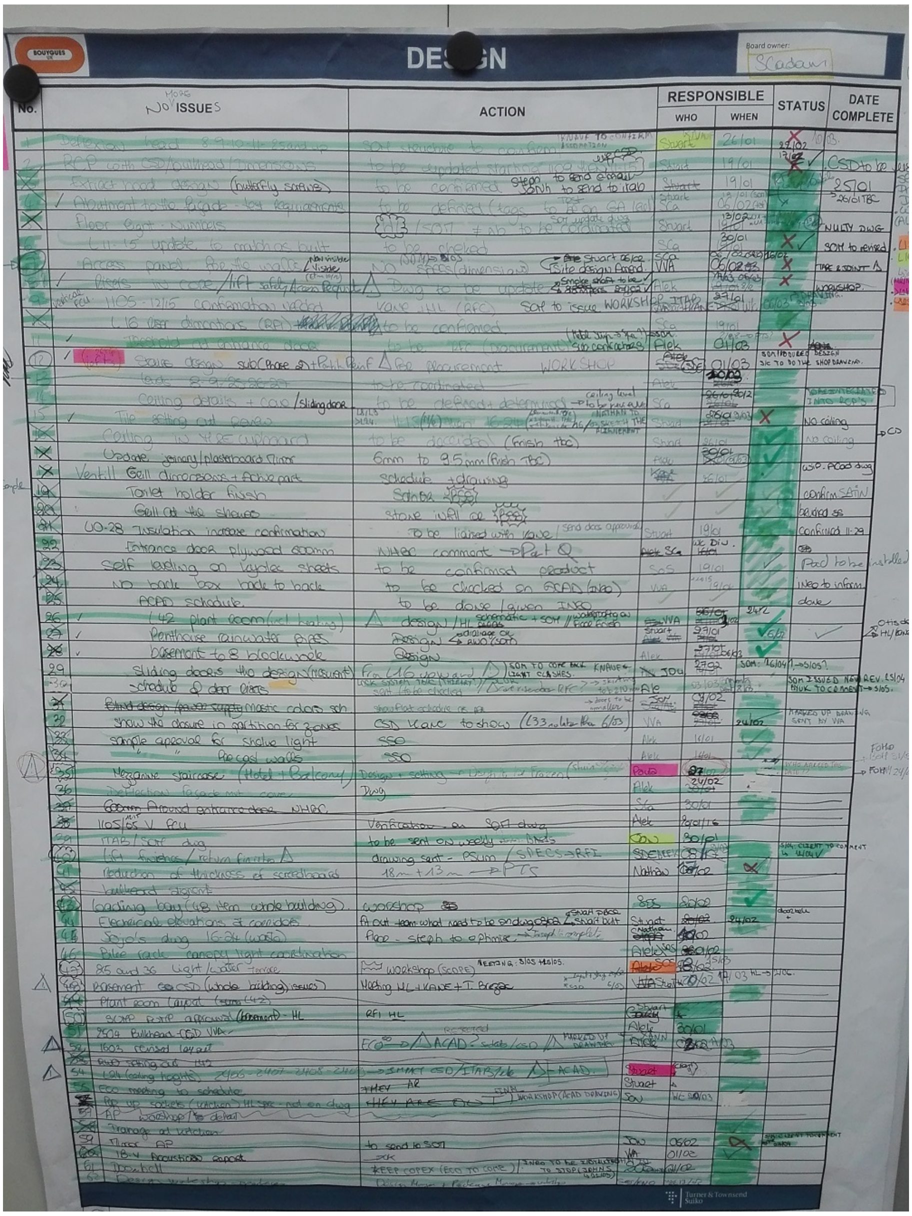


Figure 5.9. Design table used on the project.

Black hat meetings

The black hats were the project supervisors on the *MLG* project. It was decided to implement a daily meeting with the different subcontractors supervisors to review the last planner tools such as the weekly work plan and 4-weeks look ahead schedule but also to keep track on advancement on site for everyone to know. This meetings were set so any needs from the subcontractors, any issue encountered on site could be discussed with the different parties gathered for a solution to be found and action to be taken. The works completed during the previous day as well as the manpower from the different trades were displayed to everyone as a monitoring tool. The three topics of Quality, Health and Safety, and Housekeeping were also discussed as an important part not to be overlooked upon. A table was created with all this information and can be seen on figure 5.10 and in Appendix C.

Figure 5.10. Black hat daily review board first version.

Increazed visualisation

The visualisation on site was mainly focused on safety prior implementation of Lean construction tools. In this optic, simple and funny posters were displayed on site regarding health and safety as for the importance of the Protective Personal Equipment (PPE) or communication from accident that occured on other sites with the roots of the problem and the solutions to counter it. The housekeeping was discussed and non-storage areas were defined as well as specific areas for the wheelie bins to be stored in the floors.

Other visual items were implemented as the performance charts from the site and the subcontractors for everyone to see as a tool for commitment and motivation. The advancement regarding key activities in the flats were displayed using a punch list on the front door in order to catch the information without spending time in the flat. Quality issues that occured and were discussed during the black hat meetings were then compiled in posters displaying the quality to achieve and particular point to focus on so to prevent it from happening again.

The black hat meeting board as well as the Last planner processes were created and designed with the involvement of the project team for a better preparation for their future use but also to obtain insight from the future users and a better involvement in the processes.

5.5 Follow-up of suggested processes

At an early stage of the implementation, particular attention was taken on improvements to the different tools in order to become more personal to the project, fit better the different actors of the Lean construction processes but also simply improve from suggestions given by the people that were not involved in the design and implementation of these tools from day one. This led rapidly to changes in the visual designs of the 4 weeks lookahead table and the Daily meeting board template which for the latter, became a real board for more convinience of use (Appendix C).

The different tools set in place, with the use of the Black-hat meetings, were all discussed and used on a daily basis resulting in an easy way to gather data on the performances to monitor but also on quality information that could help to provide meaning to the figures obtained. As suggested by Ballard and Howell [1998], the completed work percentages should be monitored to assess lean success. These works were identified in the weekly work plan shared by the end of a week and actual works were put against the planned ones during the meetings. The manpower on site was also monitored as a complementary information for explanation purposes to have a more complete understanding of the performances.

The black hat meeting became a key process in the monitoring of the Lean tools implementation as well as part of them. Indeed the different Lean construction tools implemented could be monitored daily: the prerequisites needed for a shielding of the production; the health and safety, quality and housekeeping issues on site; or the reasons for non completion of works.

Results and analysis 6

In this chapter the results obtained from the Lean tools implemented are displayed, analysed and commented. Feedback from different actors on the project are discussed as well as suggestions for improvement on the experiment.

6.1 Preliminary results

The different tools implemented on the *MLG* project received various welcome from the different actors and showed different results with regards to the performances obtained but also the acceptance of new processes. Following the implementation process described in section 4.1, my evaluation of the implementation was done after a 20 weeks period of use.

Barriers encountered

As discussed in section 4.3, implementation barriers were encountered at different levels. The first one came from from the production director who did not see the Lean construction management as a necessary tool as the company running processes of works and management of subcontractors were perceived as sufficient. However this barrier did not last long as the first results from the Lean processes implemented proved the needs for improvements as well as their impact on the performances.

The time required to work with the tools implemented was a main barrier encountered. Firstly the Lean "Precursors" amongst the main contractor team were concerned about the amount of time to input in these activities and processes to prepare, implement and follow as their weeks were already loaded with over 60 hours a week. The Contractors opposed resistance as for the Black hat meetings implementation due to the one hour a day spent on this. Although the attendance to these daily meetings was not consistent at first, the results obtained proved of their importance remove this barrier. However, a Lean champion was not appointed as such which led to overloading the phase 0/1 manager, reducing the speed of implementation of the processes as well as the support needed from the different actors during their introduction to the processes.

Design productivity

In order to improve the design productivity and reduces the time required during to go along the design processes as described in section 5.3, a set of goals to reach for the designers were fixed. These goals were set in order to make sure the information required through the Pull system in place with the Last planner, could go smoothly without impacting the information chain. This implementation turned out to become counter-productive as the designers focused more on reaching these targets rather than ensuring the drawings they were validating in the process were actually ready to be so. Eventually the drawings which proceed along the chain had to go back to the designers as information was missing or mistakes were left without any comments from the designers.

The tool which was supposed to ensure a "shielded" production through the creations of targets composed of activities with dates before completion, proved unuseful as the targets were simply unreachable with the resources in place for the design team. This could be explained by the lack of commitment from the designers in place but also by a lack of time or designers to carry out the different tasks asked while ensuring the quality process was followed.

6.1.1 Production performances

The Black hats meetings were the main Lean construction tool implemented on this project and the one providing the most data and potential of improvement. These meetings provided elements such as the prerequisites needed for an activity to proceed on site and was therefore to some extent the responsible of the activities and productivity required by the design team discussed in the previous paragraph. As described in section 3.2.2, the Percent Plan Complete (PPC) is a great value for comparison in the Lean philosophy. This value was monitored amongst others and the results can be found on the graph 6.1.

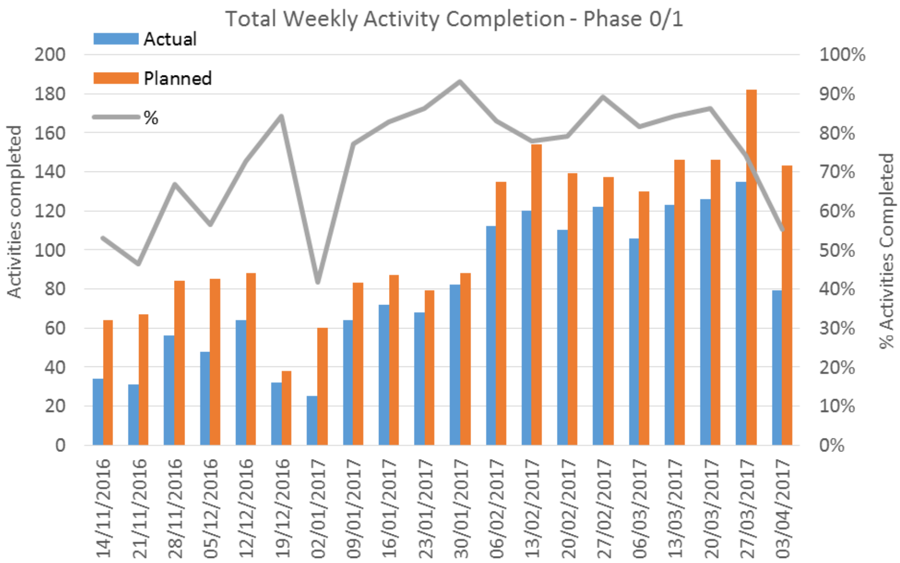


Figure 6.1. Weekly activity completion over a six months period.

After 5 weeks of implementation the PPC reached over 70% which was a value most project do not achieve according to Herman G. Ballard [2010]. Although the amount of activities completed kept increasing, the PPC stayed in a range between 78% and 93% which are great results meaning that the different actors commited to what they planned to do and overall that the activities encountered just a few reasons for non completion which could not have a big effect on the results. The little amount of completed activities during the week commencing (w/c) the 19th of December as well as the bad results obtained during the w/c the 2nd of January can be explained by the end of the year holidays creating disruptencies in the normal processes. The reasons for non completion were as well monitored as well as their frequencies as per figure 6.2.

The reasons for non completion of an activity were monitored and categorized as per figure 5.7. At an early stage little reasons were marked down and this can be explained by a little involvement of the participants in finding reasons but also in little understanding of what were the processes to follow to find a root cause of a problem or to actually identify where a problem was. During this 5 months period, 6 weeks can be left aside from the study as they could bias the amount of reasons per week on an average. These weeks are from the 19/12/16 to the 02/01/17 where due to the holidays, people were less involved in the Lean measures on site, whereas the 30/01/17, the 06/03/17 and the 13/03/17 were weeks unfollowed rigorously as the "Lean champion" was on holiday and noone replaced them. The monitoring of the reasons leed to the identification of main reasons to be focused on for improvements. These reasons were gathered in the pie chart 6.3 which displays the reasons for non completion during the first 6weeks on implementation.

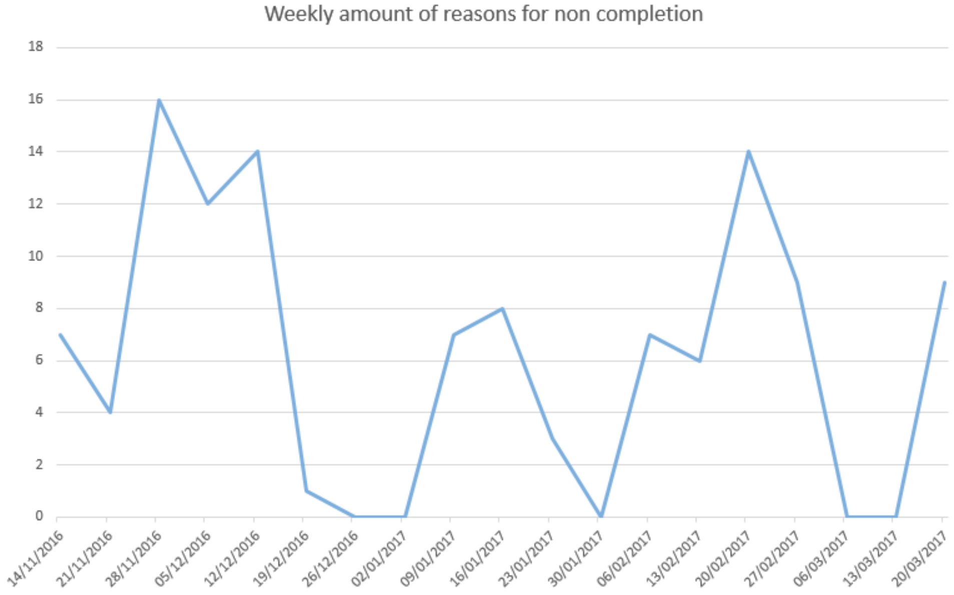


Figure 6.2. Weekly amount of reasons for non completion of a planned activity.

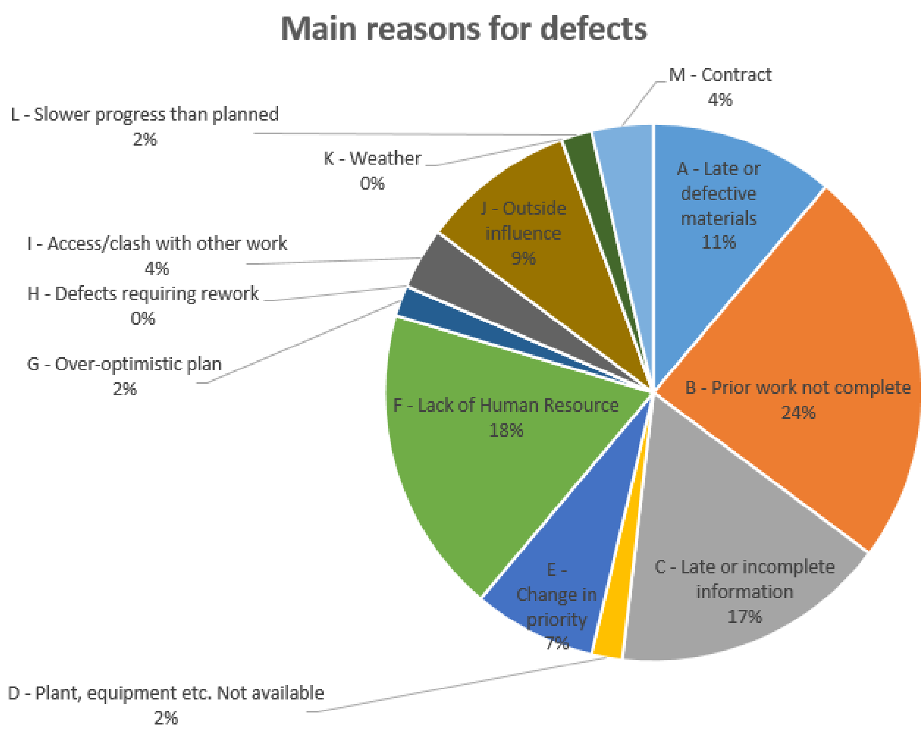


Figure 6.3. Early main reasons for defects (first 6 weeks).

As expected a Pareto effect is present with 79% of the reasons for non completion comming from 5 main reasons:

1. **B** - Prior work not complete **24%**
2. **F** - Lack of Human Resources **18%**
3. **C** - Late or incomplete information **17%**
4. **A** - Late or defective materials **11%**
5. **J** - Outside Influence **9%**

In order to tackle these reasons and improve the performances, actions were taken. The reasons B, F and C were part of reasons that the Last planner tool could handle. The reason B could be handle through a better knowledge of the activities during the following week and therefore a better planning of the activities for the other trades while the reason C could be countered using a Pull system with the information needed before works written down in the prerequisites. The reason F would be monitored throughout the week to understand how much of an impact it had on the productivity as well as to ensure it would not increase. The chart pie 6.4 describes the reasons for non completion encountered during the last 8weeks of monitoring.

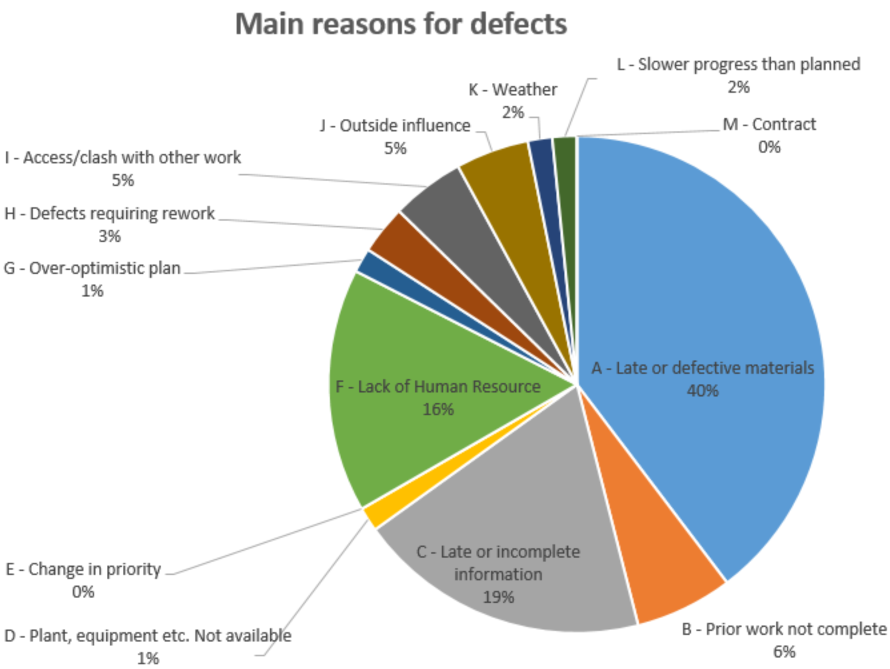


Figure 6.4. Later main reasons for defects (last 8 weeks).

The reasons for non completion shifted significantly for the reason A and B. 81% of the reasons for non completion were due to the following 4 reasons:

1. **A** - Late or defective materials **40%**
2. **C** - Late or incomplete information **19%**
3. **F** - Lack of Human Resources **16%**
4. **B** - Prior work not complete **6%**

The enormous share of *the Late or defective materials* reason can be explained in two parts. Firstly the amount of works created was increasing and therefore the possibility for it to be damaged by other workers. Secondly the very specificity linked to this project with scarce storage areas and little area of works on each floors led to logistics issues resulting in difficulties of supply on site but also within the floors. The late or incomplete information kept an equivalent share of the reasons due to the design processes having not improved as expected during the implementation. However the non completion of prior works as well as the change in priority were dramatically reduced which can be linked to a good understanding and used of the Last planner and prerequisites needed expecially linked to the other works needed rather than the designs. The human resources on site, although monitored and increasing over the weeks (see figure 6.5), kept a reason for non completion at a similar proportion to the early stage.

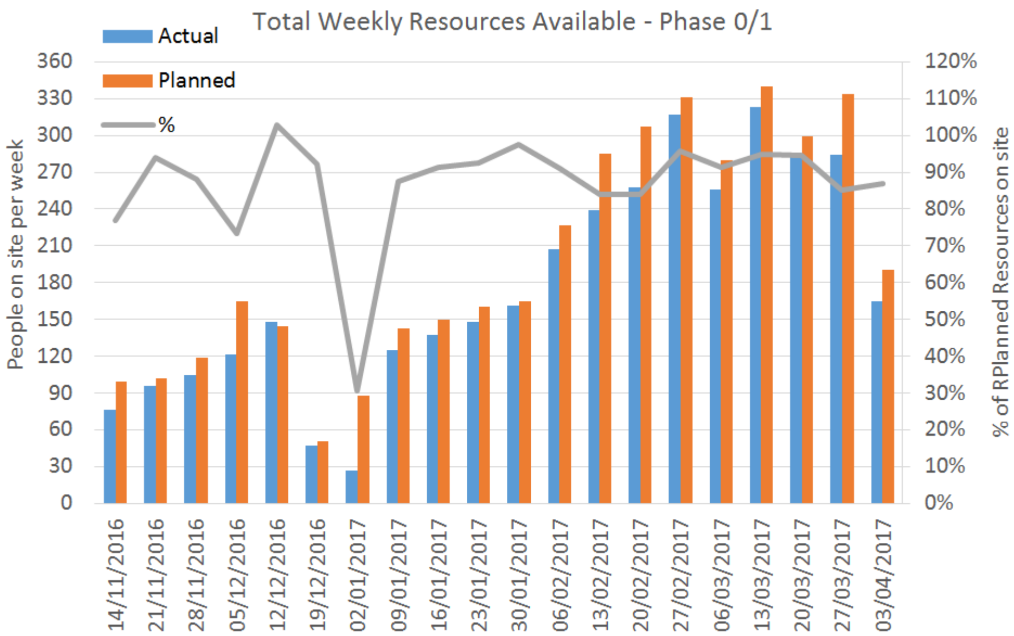


Figure 6.5. Manpower available over a six months period.

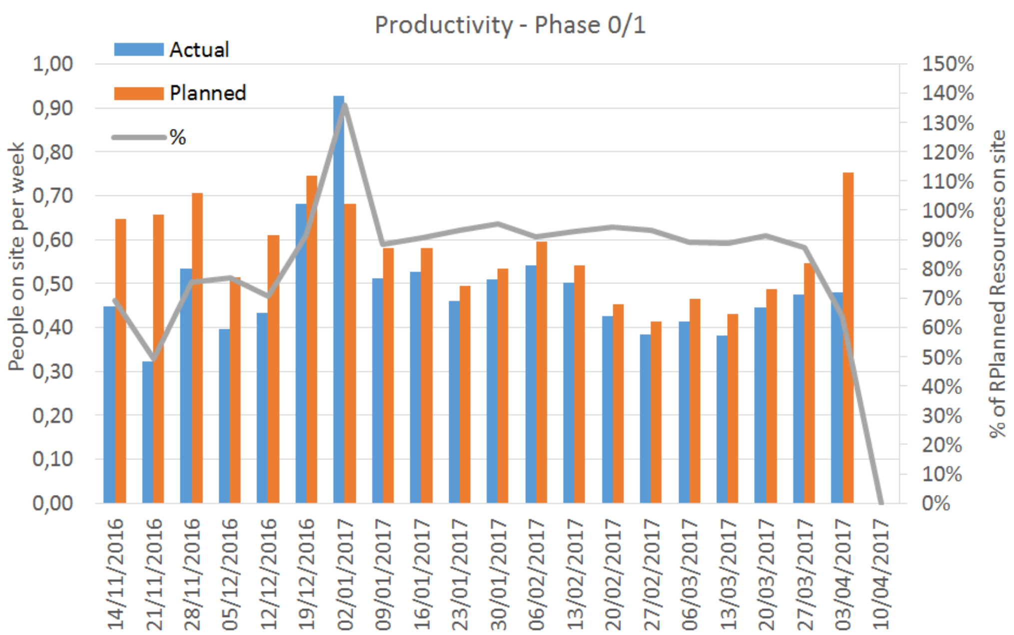


Figure 6.6. Productivity of the labour force.

The manpower was monitored in order to ensure that the activities that needed to be carried out could be actually completed. This monitoring helped to two main information, firstly that the amount of operatives was constantly growing until reaching the pick of activities estimated to be carried out by each subcontractor. Secondly that the productivity stayed at a ratio above 90%. Indeed the productivity on figure 6.6 defines the amount of activity per people over a week with the percentage between the actual and planned ratio with the objective to be as close as possible to 100% which would mean that the manpower was well handled.

Although the resources and productivity ratio encountered throughout the monitoring were of 90% of average, their monitoring was not a guaranty of good overall performances. As displayed on figure 6.7, the project was completely delayed compared to the master schedule with 3 months of general delay and 4 months of delay for the Plasterboard subcontractor. The green boxes are the completed activities whereas the red boxes are the planned activities to be completed at the time.

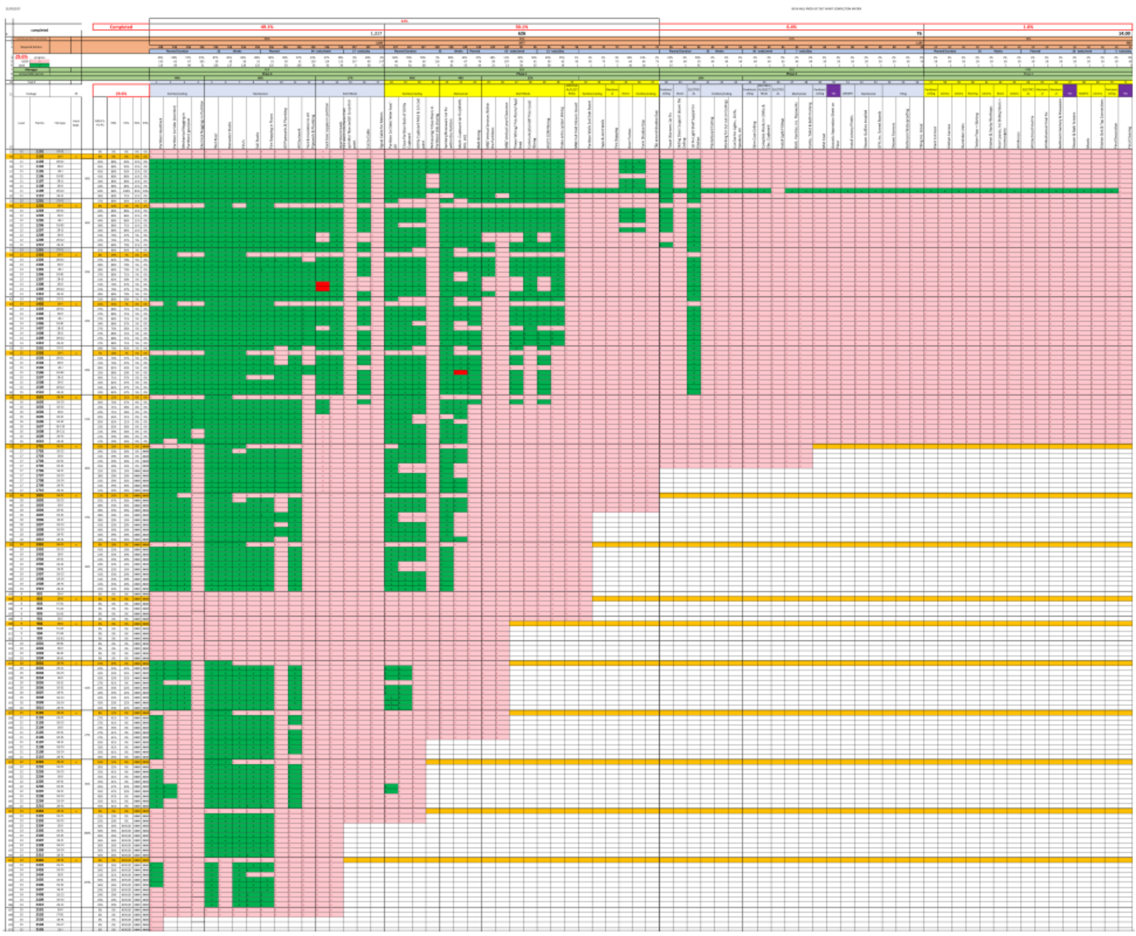


Figure 6.7. Completion matrix for the flats only.

The general production performances with regards to the Lean tools implemented as the Huddle meeting and the Last planner during this case study must be considered in their environment. Indeed the performance results obtained throughout this study, whether at the very beginning or at a later stage confirm the theory as for the improvements yield to the tools implemented. Better figures occured after a while compared to early results, proving of their efficiency. However attention must be drawn on the project master schedule as this important tool of measurement of a project performances with regards to the time allowed, was definitely not performing. For instance, the good results from the PPC can be linked to fewer activities that the subcontractors commit to, in order to obtain better results although the schedule is not followed.

The design complexity of the project led the partition walls to be closed and opened back again 5 times on the 5 first floors worked in the tower due in particular to modifications in the design. This particular topic could be subject of an analysis regarding the benefits of Lean with regards to waiting for the design, which is a prerequisite, to be finalised and confirmed as sch, prior any completion: "going slow to go fast". [Ballard and Howell, 1998]

6.1.2 Other key performace indicators

Lean construction advises as well to monitor different key performance indicators (kpi) in order to grasp potential for improvement as these values could be linked to wastes in a production process. The Health and safety, the quality and the housekeeping were monitored throughout the study as for their occurences during the week.

Health & Safety

Health and safety (H&S) issues little occurence at first is explained by low standard of H&S shown by the subcontractors. After discussion around the H&S expectations on site and commitment from all, the occurences naturally raised which was linked not only to a poor H&S awareness of the different actors and workers but also to an increased standard to reach for a safer working place. A safer working place would eventually be linked to less wastes due to accidents or near misses with a little involvement from everyone.

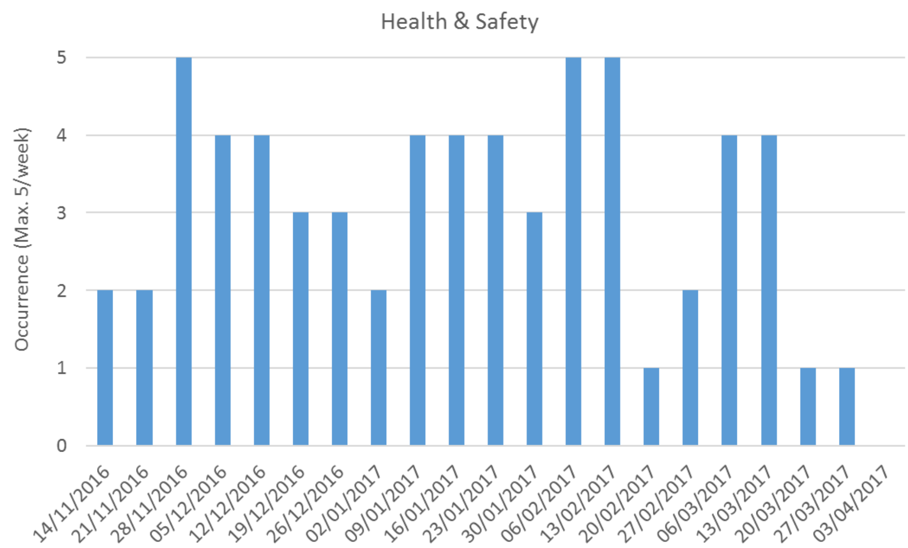


Figure 6.8. Health & Safety issues occurence.

When the occurence where reaching a low as for the first week of January, the standard were raised again in order to keep aware of any dangerous situation. The H&S posters around the site as well as the regular toolbox talk in case of H&S issue helped to maintain a safe working place.

Quality

The quality kept a high occurencing topic throughout the weeks for several reasons amongst which interfaces with other trades increased. Defects created by workers from another trades occured with issues such as nails through pipes behind a partition wall or screws from a nogging (Wooden reinforcement within a partition wall) popping out of the partition wall. Although quality alerts were set in place (see Attachment-File,2.h), new quality issues occured as well as other kept reoccuring.

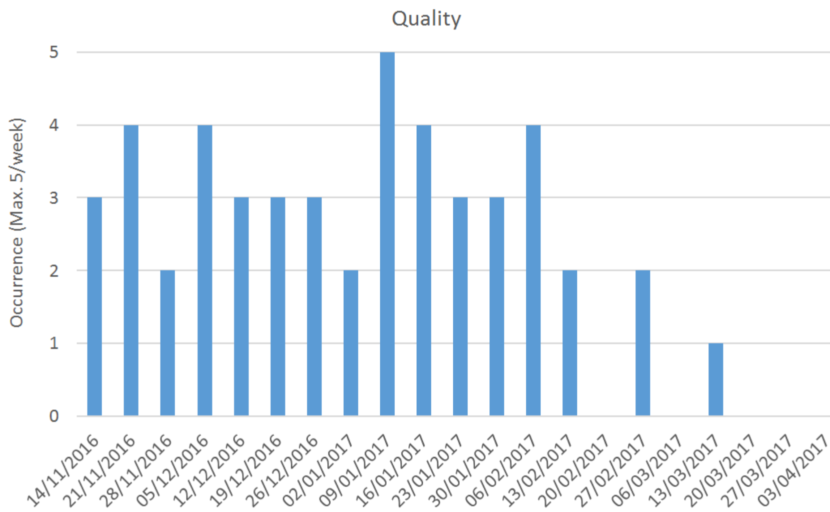


Figure 6.9. Quality issues occurence.

Housekeeping

The housekeeping on site was maintained to a certain extent with the use of rubbish bins at every floor and the *5@11* philosophy from the main contractor Bouygues UK. However once every week, the housekeeping topic arised and cleaning notices were issued. The two first weeks after the end of the holidays shown the most occurence of housekeeping issues which can be linked to workers having stopped focusing on the housekeeping after the break. This issue was corrected and the housekeeping occurence diminished.

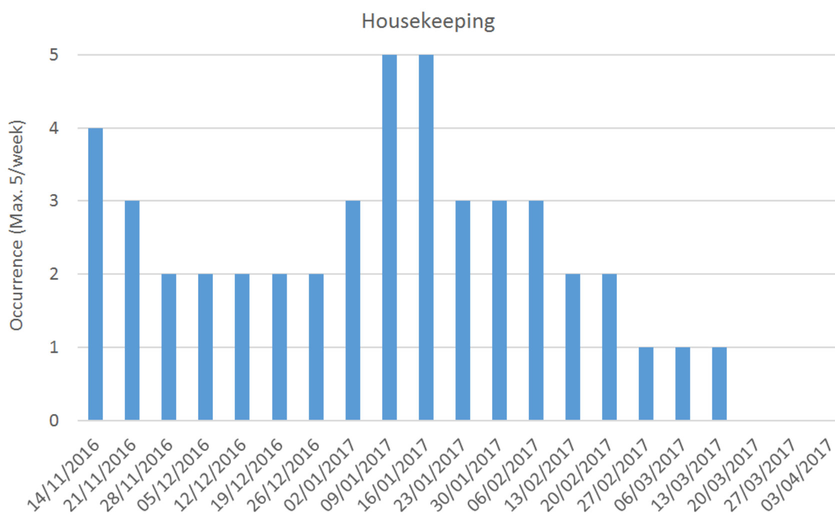


Figure 6.10. Housekeeping issues occurence.

6.2 Modifications to the theory

Along this Lean construction Implementation, the different tools suggested in Chapter 3 were either followed as per the book, modified or ignored for various reason.

The VSM

The *VSM* was not strictly followed for several reasons. The first reason being that the construction industry and more specifically the *MLG* project relies on several processes with different suppliers and customers for the same product. The creation of such Stream would have to become either very simplified and a lot of information would be missing, or very complex to grasps all the relevant element to consider for this product reducing the lisibility of the stream. It is in this optic that the *HRMU* flowchart was created with a simplication of the processes on one hand to keep the maximum lisibility but also to prevent the exercise from becoming counter-productive in the amount of resources spent compared to the potential benefits. Secondly, as a static production system, rather than having the product going along the line within different production teams, it is the production teams that move around the product. This would lead to a completely different scheme in order to represent the real process and the complexity would once again render it illisible.

On the other hand, the process Kaizen was followed in order to stay in an improvement mindset on an everyday basis through the other tools set in place and the general reactive mindset that occurs on a daily management routine. The tool proved to be useful at an early stage in order to assess the design general process and pin point potential improvements, however production processes could have benefitted from such tool.

The Last Planner & Huddle meetings

The last planner tool was by far the most used, followed and implemented as per the recommendations, tool on the project in coordination with the huddle meeting or Black Hats meetings. The "*Should, can, will, did* rule was strictly followed with:

- A display of the master schedule in the Project management meetings but also the daily black hats meetings. (should)
- An awareness of all the prerequisites completed as per requirements from the actors but also main contractor. (can)
- The weekly Work Plan to assess the upcoming activities chosen through the shielding production discussed in 3.2. (will)
- The monitoring of the daily activities and principal actions to be completed previously during the site supervision meetings (Black Hat meetings). (did)

This tool was implemented and used with barely any concrete modifications. The modifications having occured were mainly due to fit the site specificities (addition of the floor plans on the board) or to be more convenient to use (layout of the 4weeks lookahead schedule and Review board). This tool was appreciated and proved to be the main reason of performances on site.

The remaining tools developped in the chapter 3 were lightly implemented or developped on the project. The first-run studies were an already used process amongst *BYUK* and therefore the potential for improvement was considered insignificant to be considered and work on; although some digging and study on the concrete improvements could be done. The five S's housekeeping method was complicated to implement strictly as per recommendation due to the moving working station. Straigthning and having things in order at the same place could be rarely translated on site apart from rare situations such as in the storages from the different subcontractors which was part of the suggestions implemented on site. The housekeeping was nonetheless kept at heart with the topic being discussed daily during the Black hats meetings. Finally the increased visualization was improved on site with the use of posters related to health and safety, housekeeping and welfare on site. The wheelie bins area were also marked on each floor in order to make it easier for everyone to encounter it when changing to another floor (they were always right next to the external elevator).

Implementation of a new process

The implementation of a new process as defined in section 4.1 was followed as close to the theory as possible. The identification of the objectives to reach with this Lean construction philosophy, was carried out by top management in Bouygues International as well as the company criteria for it to be implemented. The evaluation of the *MLG* project criteria were done by the Project director during the volunteering to participate to the experiment. The commitment to the new process was achieved by selecting a Lean consultant and presenting the consultant, objectives and road to follow towards a Lean construction project, to the whole project team. The preparation for implementation was done in coordination with the different consultant and main managers from the Main contractor using as best practices an early involvement of the actors for better results. The use step was strictly followed with several modifications to the Last planned and huddle meeting tool during the very first weeks of implementation. The feedback with data collection was also carried out during the whole study and is still on going as these lines are written.

The three final steps for a complete implementation in this project were carried out on a small scale as the evaluation of the benefits from the philosophy were assessed and the other subcontractors were kindly asked to follow the philosophy. On a company scale, these three last steps would need more results and data prior final evaluation and diffusion through the company.

6.3 Feedback on the experiment

In order to gather feedback from the different actors that have participated in this experiment, I decided to use interviews. Interviews were chosen as the preferred qualitative study method, by which analysable data would appear. With this study methodology, it was possible to gather information from the interviewee's perspective. The interviews were done with relevant actors at the MLG project with regards to the Lean implementation. The interviews provided knowledge on the implementation barriers encountered, the perceived influence of the Lean construction implementation on the project but also the interviewee.

The interviews were designed as *semi structured* interviews. The purpose of this form of interview was to gather the informatn's perspective on the Lean implementation and clarification if required. The selected interview guide is designed with main questions plus clarifying questions, if doubts arise concerning the informant's answer. With this interview structure, it is possible to follow up on neglected issues that appears during the interview.

The interviews were carried out with various actors on the project such as: the project director, the Lean "champion" and the site supervisors. From the different interviews, information could be gathered as follow:

- Little was known about Lean philosophy amongst the site supervisors who are the direct link between the management teams and the production crews. It was the first time they heard about it although some ideas were known to them.
- Better performances were expected in general although these expectations were considered met for some but not all. The supervisors on site considered that the site benefited a lot from lean implementation whereas the management team was more perplex.
- Everyone shared to have learnt from the experiment regarding the importance of cooperation or better monitoring tools.
- The improvements to the tools gathered during these interviews were for the most related to the involvement of the different actors but also on the stage of implementation of such management philosophy.
- The better communication on site between the different actors regarding issues occuring, their needs and programm for the upcoming weeks was the most appreciated and spoken improvement.

The implementation of the Lean construction tools were globally well accepted although resistance occured at first. The opinions of the different actors interviewed is globally positive regarding the tools and their influence on the project, although most of the actors shared a common opinion on improvements still to come to reach the full potential of Lean. The formal tools implemented were appreciated as some processes were in place by the different actors but nothing in common or set in a formal way

Conclusions 7

Along this study, extensive theory was developped with regards to the Lean production philosophy. The origins of the philosophy from the Japanese car company Toyota and their innovative engineer Ohno, father to the philosophy with the wastes identification. The main objective of Lean was defined as a constent effort towards reducing wastes within a process in order to reduce with it the costs of production. The philosophy position amongst other production philosophy was defined in order to comprehend in which environment it had been created and the main goal people strive to achieve with its use. The philosophy translation to the construction industry was defined starting by an assessment of traditional management practices.

The construction variant of the philosophy was defined and Lean construction tools were identified. These tools were described with a definition of their use, phases in which they are used and improvements to expect from them. The influence of these tools was proven to exist over topics traditionally monitored: the safety, the quality, the schedule and the budget. The implementation of a new process within an organisation was studied as well as the eight stages to follow in order to achieve an implementation. Each step was defined and the collaboration of the different party involved was identified as key. The phase of implementation was found to have a great influence on the results to expect from the implementation with an early implementation yielding the most improvements. The implementation was argued to be considered as late as soon as the construction phase started due to design commitment complexifying any process changes. Finally implementation barriers to expect were discussed in order to help future readers to prepare against them or prevent them.

The case study followed, although very specific as for its phase of implementation but also its particularly variable design, showed interesting results with regards to the implementation of Lean construction tools but also their efficiency in use. The assessment of improvements through the use of a *VSM* variant helped to identify room for improvement within the design phase. The assessment was late compared to the advancement of the project but could theoretically still help to obtain better results for trades getting involved at a later stage of the project as well as for following required designs due to the high variability of design on the project. The reality proved to obtain little results from the design side of the project. The lean tools set in place were seen as targets to reach without fully understanding the meaning behind. The designers tended to focus on reaching these goals for better personnal results while the quality of the drawings released was not achieved, resulting in a counter productive performance and ultimately leading to no improvement.

The production tools implemented for the construction phase such as the Black hat meetings and the Last planner system were globally well received and accepted by the actors. The early implementation barriers faded away with diligence as the first results appeared and the different actors fully embraced the tools. Good results and performances were gathered throughout the weeks with a constant improvement during the first 6 weeks and a stagnation between 80% and 90% of *PPC* later on. However a quick comparison on the master schedule from the planned progress to the current progress proved that the good performances from the Last planner if not linked to the overall Main schedule, cannot be a guaranty of good performances. The subcontractors tended to focus more on having good results than on following the master schedule or seemed to have less remorse showing a delay due to their good performances from the Lean construction tools. Moreover reworks from quality issues or changes in design were difficult to show in the monitoring from the last planner leading to the wrong assumption, from an external observer having only the Lean figures to assess of a situation, that the project was running well.

The results obtained during this study helped to understand the importance of key factors in a successful implementation of Lean construction tools:

- The phase of implementation is important as an early implementation, at the beginning of the design phase, promises of better results as changes would have more impact at a smaller cost.
- The cooperation of the different actors is of great importance to ensure a good assessment of prerequisites, issues identification and problem solving.
- Keep your mind on the bigger picture and do not focus simply on the Lean key performance figures. These figures although positive might hide the schedule disaster happening.

Perspectives 8

In this chapter further works to be carried out in order to gather complementary data to confirm or to oppose the results encountered in this study are discussed.

8.1 Results in a few months time

Having assessed after a five months period the results of Lean construction tools implementation with their issues and room for improvements, changes and refocus on the objectives to follow should be done. Improvements with regards to the design team involvement as well as refocus on the master schedule together with the Lean performance figures could provide different results or even prove to be difficult to achieve. The different values monitored throughout this previous study could be kept and monitored for another 6 months. Moreover, other subcontractors are going to get involved next to the three main subcontractors from this study which could lead to significantly different results.

The increase of participant in the Lean construction Last planner tool and Black Hat meetings might provide interesting data with regards to the importance of the cooperation between the different actors but also the various KPI and their relation to the Master schedule. Other values with a qualitative meaning such as the H&S, quality and housekeeping could be interesting to monitor in order to assess whether they become key aspects with a good or bad impact on the performances of the project.

8.2 Appointment of a Lean Champion

During this study a Lean champion was unofficially appointed and their role was not completely focused on that purpose. Studying the impact of a totally dedicated manager to the Lean construction implementation could help to ensure a correct implementation of the processes, support to the different actors within the project processes but also to have a bigger picture of the whole and ensure that the subcontractors do not fall in a "high score" performances focus. They could also identify potential improvements to focus on.

Studying their role which was identified in the chapter 3.2, could help to identify their usefulness in the implementation process but also in the general running of the processes.

8.3 Implementation on a different project

A similar study should be run on a different project: either with similar parameters (high variability of design, tower project, scarce storage...) but at an earlier stage; or at a similar phase of the project (during the early stage of construction) with one different parameter (different design variability; or a "flatter" project; or profusion of storage area...). Implementing Lean construction tools at an earlier stage might help to assess the influence on the implementation acceptance from the different actors but also on the results from the Lean construction tools.

Implementing these processes and tools at an early stage could help to create a proactive mindset from everyone at an early stage in order to think beforehand future issues that might occur. It could also on the contrary highlight weaknesses in a process to identify key points due to a lack of information from future subcontractors as their requirements are unknown at this stage of the project.

Another project could help identify the influence of different parameters on the implementation of these tools. The "volume" of the building with its verticality and area, as well as its storage areas or specific designs could be all parameters having a specific influence on the implementation of the process. The different actors working together on a project could be another parameter to take in consideration as well, due to the relationships between companies that could influence the results.

8.4 Make it a company process

After completion of this project and monitoring of Lean construction tools implementation over a longer period of time. The lessons learnt with regards to the mistakes not to recreate, the changes to the tools made during the implementation and the best practices encountered could be gathered and shared to the Top management of the company for an implementation at a company level would these results be satisfactory.

These processes could be extended to the company itself processes in order to become leaner and thus would most likely go back to a Lean management philosophy, focusing on the flow of information and resources amongst the company. An extension of the Lean construction philosophy could be done with the prefered suppliers of the company so to obtain even better results with regards to the supply chain flows.

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List of attachments to the report A

Below is a list of files, which are attached to the report during upload. It is also described what the file is about:

1. **VSM**: Flowchart of the Hotel Mock-up Rooms design process.
   a) Value Stream Mapping (Microsoft Visio)
   b) Value Stream Mapping (PDF)
   c) Stage 3 Hotel - Panoramic map
2. **Black Hat meetings**: Different support used during these daily meetings.
   a) **Daily Review Board** - Portrait Draft V2 + pictures of use: This board was the first version used during the black hats meetings. It was an A0 paper displayed under a glass board.
   b) **Daily Phase Review Board** - Last version of the board used on site + picture of use: This board was the upgraded version used during the black hats meetings. Its main difference to the previous one is that a small plan of each floor is added to pin point where the main activities from the subcontractor where carried out as well as this board was a real board and could be reused.
   c) **Reasons for non completion** - Pictures over a 4 months period + Excel summary.
   d) **4 weeks look ahead schedule - V1**: shows the prerequisites necessary prior carrying out the task, the floor and date at which the activities are planned to be done as well as some space for comments that can be added during the daily reviews.
   e) **4 weeks look ahead schedule - V2**: Main changes are the addition of a Design and procurement schedule (D&P - on the right side) with comments regarding the latters, the addition of the master schedule at the bottom to compare current progress with master plan.
   f) **Phase 0/1 KPI measurements summary**
   g) **Daily activity sheet** - Template + picture of use
   h) **Quality Alert**: Used when a Defects was encountered.
   i) **Single Point Lesson**: Used when a standard of Health and safety, housekeeping or even quality was not reached.
   j) **Completion Checklist**: Displayed at the entrance of the flats to assess quickly the progress.
3. **Interviews**: Copy of the notes taken during the interviews of the following people:
   - Frederic Perez : Project Director (BYUK)
   - Stephanie Cadoum : Project Fit-out Manager (BYUK)
   - Nuno Sampaio : Project Manager (Drylining Subcontractor)
   - Jose Guimaraes : Project Supervisor (Drylining Subcontractor)
   - Darren King : Project Supervisor (Mechanical Subcontractor)
   - Gary Potten : Project Supervisor (Electrical Subcontractor)
4. **Completion Matrix**: Completion progress of the fit outs phase 0 at the 5$^{\text{th}}$ of April 2017.

B HMUR design process flowchart

On the following pages the flowchart created through discussion with the different consultants and design team from the main contractor is displayed. A PDF and the visio version are enclosed with this report for an easier reading of it.


Phase 1 Design process
Validation
Stage 3 (Design)
Developer's team
BYUK (Main contractor)
SOM (Architects)
Hoare Lea (MEP/Services consultant)
Space (Interiors consultant)
Tricon (Catering consultant)
Blend (AV/IT consultant)
Timeline (Days)
Resources (Hours)
Questions
Issues
Instruction received
Stage 3 launch
Confirm receipt of instruction (Brief)
Review scope & resources with existing consultants
Mobilise teams
Prepare draft programmes
Prepare draft programmes (consolidated)
Agree deliverables (from brief)
Present programme & projects
Test Fit exercise (start)
Interim presentation
Feedback on validation
Whole building systems
Validation report / Brief
Commence stage 3
Revise programme
Review design
Waste strategy
Coordinate stage 3 design
Hotel Mock-Up rooms design
Level 01 plantroom reconfiguration
Room type development iterations
Enhanced brief issued
Signed appointments
Tender issued for Mock-Up rooms
Detailed drawing for Hotel Mock-Up room
Prepared planning drawings
Cost advice for Hotel Mock-Up room
Move offices
Review of Mock-Up package
Update Detail drawings to reflect Space comments
Value Engineering review of the Hotel Mock-Up rooms
Communicate Value Engineering options to specialist supply chain
Update design to reflect Value Engineering
Lighting strategy (Hotel Mock-Up rooms scheme amended)
Amend cost advice to reflect Value Engineering
Review Stage 3 deliverables
Advise on Hotel grease trap
First draft Stage 3 report
Submission of Stage 3 report
Stage 3 report
Explanation
Milestone
Data
Process
Document
Timeline
Resources
Questions/Issues

Black hat meetings C

On the following pages the following items are displayed in order of appearance:

1. The first version of the Black hat meeting board template.
2. Pictures on site from the use of this tool.
3. Last version of the Black hat meeting board template.
4. Pictures on site from use of this tool.

Figure C.1. First design of the Black hat daily review board.

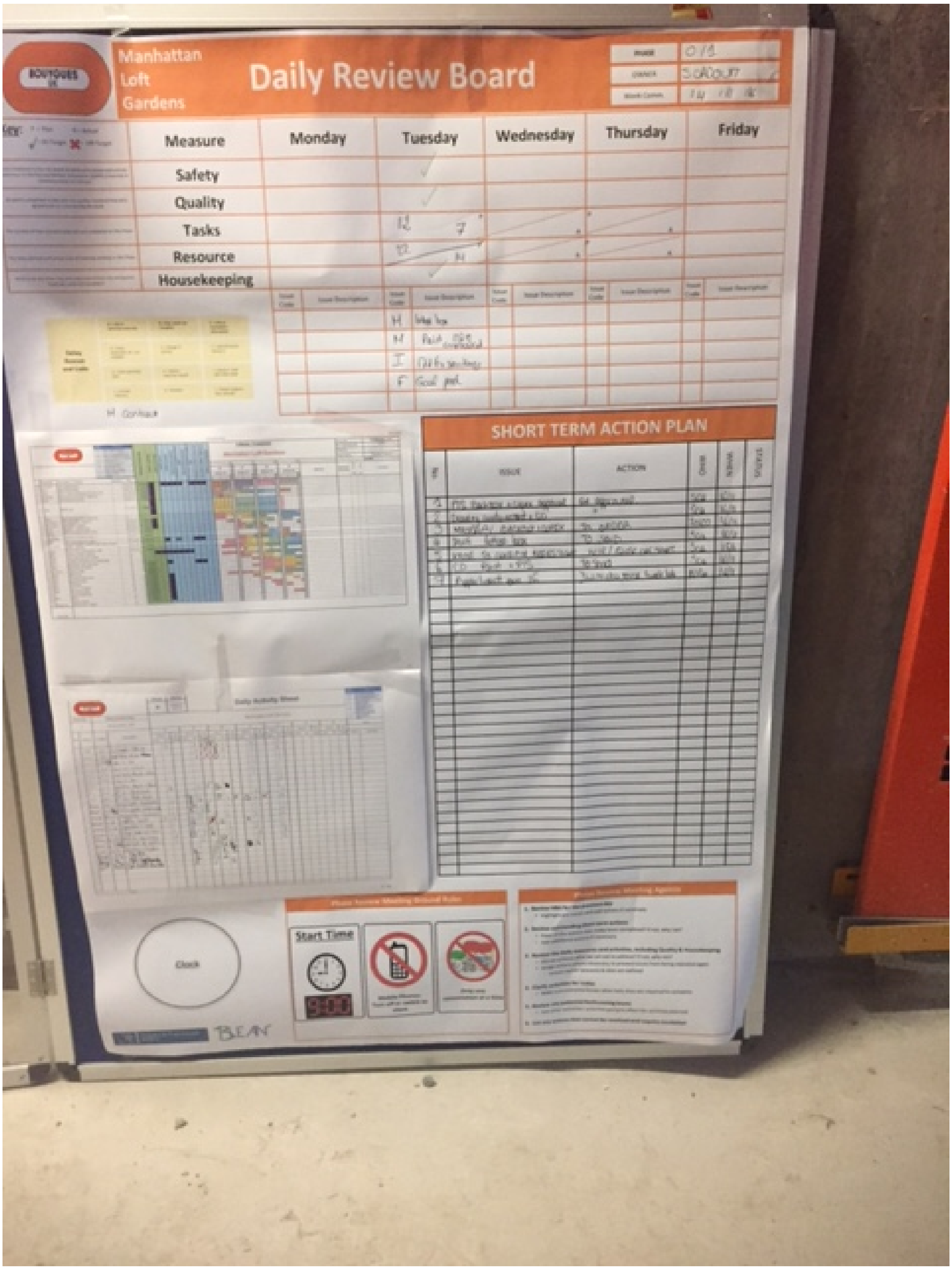

Figure C.2. Use of the firstly designed board.

Figure C.3. Last design of the daily review board.

Figure C.4. Use of the last black hat daily review board.