USING VISUAL MANAGEMENT TO IMPROVE TRANSPARENCY IN PLANNING AND CONTROL IN CONSTRUCTION

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Publications

Brady, D., Tzortzopoulos, P. and Rooke, J. 2011, "An examination of the barriers to Last Planner implementation", *In the proceedings of the 19th Annual Conference of the International Group for Lean Construction (IGLC), Lima, Peru.*

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Abbreviations

BIM: Building Information Modelling

CAD: Computer Aided Design

CPM: Critical Path Method

DP: Detailed Planning

ICT: Information and Communication Technologies

IGLC: International Group of Lean Construction

JIT: Just In Time

KPI: Key Performance Indicator

LCM: Lean Construction Management

LPS: Last Planner System

MIT: Massachusetts Institute of Technology

OPA: Overall Process Analysis

OPM: Overall Process Map

OTP: On-Time-Performance

PM: Project Management

PPC: Percentage Plan Complete

PP: Process Planning

SOP: Standard Operating Procedure

TFV: Transformaton-Flow-Value

TOC : Theory of Constraints

TPS : Toyota Production System

TSSC: Toyota Production System Support Centre

VR: Virtual Reality

VSM: Value Stream Mapping

WIP: Work In Process

Abstract

The principle of transparency is rarely evident on construction sites. Current practice shows that instability in the execution phase is common, where activities, assumed to be feasible, have be rescheduled initiating a chain of further readjustments and uncertainties. In responding to these uncertainties, the lack of transparency in the construction process leads to communication issues and inefficient decision-making. There is little transparency of activities in the execution phase, making it difficult to foresee and communicate problems and plan to resolve them.

The LCM model is a Visual Management Model based on the Lean concepts, designed to improve transparency in production planning and control in construction. LCM is an acronym for Lean Construction Management. The aim of this research work is the development of this Visual Management Model, by clarifying its contribution to theory and practice. To address this aim, the Design Science method is adopted in this investigation. Design Science is applied to develop artefacts for solving problems with practical relevance and potential for theoretical contributions. Outputs of the work include i) the LCM model itself ii) instantiations of the LCM model to refurbishment and power plant construction (demonstrating that the solution works) iii) an evaluation of the utility and applicability of the model and iv) an explanation of its theoretical significance. The research focuses on three case studies which were important for devising, further improving and evaluating the model. This research provides a new model and associated method for applying Visual Management for production planning and control in construction. The model demonstrates how visual tools are systematically applied to manage information flow, support communication and to shed light on the deficiencies of traditional project management. In addition, it demonstrates how visual tools can be used to improve communication barriers and transparency when applying other systems of planning and control in construction such as the Last Planner System.

1 Introduction

1.1 Introduction

This chapter provides a background on the research presented in this thesis. The first section addresses the problem of a lack of transparency in the construction process and presents the concept of Visual Management as a key approach for creating it. An overview of the importance of the principle of transparency for the construction process is given. Since the focus of this research is the development of a systematic Visual Management Model for production planning and control in construction based on the Lean concepts, the importance of broader solutions for application are addressed (Liker, 1997; Spear & Bowen, 1999; Lewis, 2008; Atkinson 2010; Liker, 2004; Boyle et al., 2010; Saurin et al., 2011). The significance of holistic thinking for Visual Management application is also explained.

The remainder of the chapter presents the personal motivation for this research, the aim and objectives of the research, an overview of the research process, the research contribution and an overview of the thesis structure.

1.2 Background on research problem

The research problem addressed in this work is a lack of transparency in the construction process (dos Santos et al., 1998). The traditional conversion model of understanding production systems as a set of conversions of inputs to outputs (Koskela, 1992) contributes to a lack of transparency in construction (dos Santos et al., 1998). The traditional method of cost estimation is at the heart of this view. The building or structure is divided into its constituent elements and for each element, the costs of needed materials and labor (conversion of input to output) are estimated (Koskela, 1992). In the conversion model, it is assumed that the total production process consists of a set of sub processes which convert an input to an output and which can be realised and analysed in isolation from each other (Koskela, 1992). Since it is assumed, that sub processes can be realised independently of one another, there appears to be no need for transparency between these sub processes.

The lack of transparency in construction, stemming from the nature of the traditional conversion model also leads to communication issues. Since work is assumed to flow from the authorisation of a task, it is also assumed that the task is fully understood, started and completed according to the plan once authorised (Koskela & Howell, 2002a). However, in reality this is not the case. Inputs to tasks are often unavailable leading to uncertainty and rescheduling of those tasks (Koskela & Howell, 2001). In addition, there is little feedback on the causes of problems in the process since control is focused on time and cost rather than on learning and improvement (Koskela & Howell, 2001).

Communication and transparency issues are also evident in the application of existing systems for planning and control in construction based on the Lean concepts, such as the Last Planner System (Alarcon & Conte, 2003; AlSehaimi et al., 2009; Kalsaas et al., 2009). These issues occurred mainly where participants were not present at the regular meetings taking place during implementation and missed important discussions and information relating to the process.

The following section expands further on the need for transparency in the construction process, which is addressed in this research work.

1.2.1 The need for transparency in construction

Two important findings from the literature review are 1) that the traditional conversion model contributes to a lack of transparency and difficulties in communication in construction and that 2) there is a need for increased transparency in construction to deal with the uncertainty that exists, to better understand the complicated relationship between activities and interfaces, thus anticipating and resolving problems earlier. The literature review on the critique of Project Management reveals critical issues in production planning and control, which hinder effective communication and the development of trust and team building between organisations involved in the procurement process (Koskela, 1992, 1999, 2001; Howell & Koskela, 2000; Koskela & Howell 2002 a, 2002 b, 2002 c).

The critical issues in production planning and control stem from several assumptions that are made about the construction process. The need for transparency in the construction process is disguised by these assumptions. The assumptions are:

- **that the execution process is unproblematic and linear**: which means that the execution phase commences on the basis that work can be carried out as planned which in reality is not the case. It is assumed that plans are feasible, requiring no transparency of how the execution process is carried out as no problems are anticipated. This leads to re-scheduling and uncertainty during daily operations.

- **that one way communication is adequate for the creation of sound commitments**: which means that there is little feedback on the feasibility of work in execution and daily issues in the construction process are discovered too late. There is no transparency of information between planning and execution, which makes it difficult to identify problems in execution earlier (Koskela & Howell, 2001).

- **that tasks can be carried out as planned with no need for root cause analysis on problems**: which means that there is no focus on understanding the sources of problems and encouraging a learning cycle for future projects. This assumption has been criticised in the literature (Johnston & Brennan, 1996) since it is not generally possible to maintain a complete and up-to-date representation of the current circumstances and the plan to change them. As a result of this assumption, there is no transparency of the execution process as the need to split the work down and question its feasibility against the current environment is not recognised. More meaningful, lower level plans do not exist and therefore informal systems of management arise which are geared towards handling uncertainty and interdependence (Koskela & Howell, 2001). Transparent, lower level plans are needed however, so that the execution process can be adapted according to the current status of the production system. Without transparency in the execution processes however, it is difficult to observe and react to the current status of the production system.

The need for transparency in the construction process can be classified into three main areas:

- **to facilitate a holistic view of the entire process and to implement flow:** in order to observe the construction process as a flow of activities and to achieve a holistic view of the overall process, a high capability of handling vast amounts of information is required. In order to overcome the difficulties associated with this additional information, production activities in construction must become more transparent. The application of the principle of transparency is a key concept for making the flow model viable (dos Santos et al., 1998).

- **to support continuous improvement:** in order to identify higher levels of improvements and understand what effect those improvements have on the overall process, it is necessary to make the process and information flow between the different interfaces transparent, and

- **to build trust and motivate process participants:** construction companies usually have few visual mechanisms to inspire, instruct or motivate workers to carry out their jobs more effectively, efficiently and safely (dos Santos et al., 1998).

The following section addresses the concept of Visual Management as a key approach for creating transparency and discusses important findings on Visual Management from the literature review.

1.2.2 Visual management

Visual Management is a core foundational element of the Toyota Production System and plays a key role in the creation of transparency (Liker, 1997; Formoso et al., 2002). Various definitions of Visual Management can be found in the literature but it can be described as a management strategy for organisational control, measurement and improvement which uses visual aids to externalise information and improve communication in the workplace by creating transparency (Greif, 1991; Ho & Cicmil, 1996; Liker, 1997; Imai 1997; Tomkins & Smith, 1998; Chua et al., 1999; Pries 2003).

An important characteristic of transparent processes is that they radiate relevant information in a physical way, facilitating communication, decision-making and promoting self-management (Bowen & Lawler, 1992; Galsworth, 1997; Bauch, 2004; Nijhof et al., 2009). Transparent processes build trust among parties and generate value (Sirota et al., 2005; Berggren & Bernshteyn, 2007; Crumpton, 2011). An important goal of Visual Management application is to make information easily accessible so that process participants can act in a purposeful way (Liker, 1995; Imai, 1997; Tomkins & Smith, 1997; Chua et al., 1999; Koskela, 2001). Various authors (Galsworth, 1997; dos Santos & Powell, 1998; Formoso et al., 2002) call for the use of visual tools and methodologies to increase transparency on construction sites, reduce information processing time and human errors, add different layers of information on workplace elements and promote self-management.

An important finding from the literature review on Visual Management application in construction is that most examples of Visual Management applications in construction are not systematic in nature, but mainly based on individual tools taken from manufacturing and applied in an isolated way to parts of the construction process (Arbulu et al., 2003; Picchi & Granja, 2004; Kemmer et al., 2006; Jang & Kim, 2007; Tommelein, 2008; Saurin et al., 2008). Tezel (2011) also observed the application of different individual visual tools existing on construction sites in Brazil and called for broader applications of Visual Management to construction. Broader applications of Visual Management help to identify crucial interactions and to recognise what the consequences of optimising one part of a process has on the whole. There is a need for broader solutions that can be applied to achieve a process view of the critical interfaces of the construction process and to support two-way communication, so that sound commitments can be created.

The following section presents the concept of holistic thinking, which is an important element when applying Visual Management to the construction process

1.2.3 Holistic thinking

When applying a Visual Management Model based on the Lean concepts to the construction process, a significant element to consider it the idea of holistic thinking. Holistic thinking focuses attention on both structure and process, viewing a situation or organisation from a higher standpoint, which takes interactions between the individual parts into account. A holistic view of the process is facilitated by the application of systematic solutions. Jackson (2006) argues that holistic thinking is needed today in order to deal with the increased complexity, change and diversity in organisations, where problems rarely present themselves individually but come related to other problems in richly interconnected situations. This is especially true for construction where a project is characterised as a complex, dynamic phenomenon in a complex and non-linear setting (Williams, 1997; Bertelsen, 2002).

The literature review reveals that the application of Lean is often confused with the implementation of a tool or a set of tools in practice. A failure exists in recognising that Lean application requires focusing on the entire system (Liker,1997; Spear & Bowen, 1999; Lewis, 2008; Atkinson 2010; Liker, 2004; Boyle et al., 2010; Saurin et al., 2011). It is hugely important to focus on the entire process when applying a Visual Management solution based on the Lean concepts, so that a true understanding of waste is achieved and higher levels of improvements are identified. Holistic thinking is essential for the application of Visual Management to the construction process, considering the interrelationship of all practices in order to improve overall levels of quality, productivity, integration and waste reduction, over all functional areas and along the supply chain (Boyle et al., 2010).

1.3 Summary of research problem

This research work focuses on the problem of a lack of transparency in the construction process (dos Santos et al., 1998). It is argued that the traditional approach to project management has led to a functional view of the construction process with little transparency of information on interdependencies between the different interfaces. This lack of transparency contributes to the fact that production systems in construction often operate well below their full potential (Formoso et al., 2002). Workers are often forced to use their time searching, wandering, and waiting for tools, material and information instead of performing value-adding operations. This work argues that there is a need for transparency in the construction process to deal with the uncertainty that exists, to better understand the complicated relationship between activities and interfaces, thus anticipating and resolving problems earlier.

The lack of transparency in the construction process also leads to communication issues. Since it is assumed that work flows from the point of authorisation in execution (Koskela & Howell, 2002 a), there is little information on the feasibility of that work in practice. This work argues that feedback on feasibility is necessary for the creation of sound commitments (Winograd & Flores, 1983) and there is a need for structures to facilitate this feedback process by making relevant information transparent. Similarly, communication and transparency issues are also evident in the application of existing systems for planning and control in construction based on the Lean concepts, such as the Last Planner System (Alarcon & Conte, 2003; AlSehaimi et al., 2009; Kalsaas et al., 2009). This work proposes that by using visual tools to manage the information process and making the most important information available at all times in a central area, communication and transparency issues in production planning and control can be improved.

A further problem that is addressed by this research is the lack of systematic Visual Management solutions existing to improve transparency in the production planning and control of construction projects. Most examples of Visual Management application in construction are not systematic in nature, but mainly based on individual tools taken from manufacturing and applied in an isolated way to parts of the construction process (Arbulu et al., 2003; Picchi & Granja, 2004; Kemmer et al., 2006; Jang & Kim, 2007; Tommelein, 2008; Saurin et al., 2008). While these isolated applications provide valuable contributions, it is argued that a more comprehensive approach could lead to a deeper understanding of Visual Management in construction and better applications of Lean concepts. A holistic view of the process, facilitated by broader solutions, focuses attention on both structure and process taking interactions between key interfaces into account. A holistic view of processes is needed in construction today in order to deal with the increased complexity, change and diversity associated with this industry, where problems rarely present themselves individually but come related to other problems in richly interconnected situations (Williams, 1997; Bertelsen, 2002; Jackson, 2006).

1.4 Research motivation

This section explains the researcher's personal motivation for this research. This research work is an important part of the researcher's Lean journey which began in 2002. Between 2002 and 2007, the researcher was involved in the implementation of approximately 100 Lean projects of various types in manufacturing throughout Europe and in Malaysia. The projects were conducted based on the Lean concepts of the Toyota Production System. During these years, one important observation made by the researcher was the significant role Visual Management played in creating transparency and facilitating continuous improvement.

In 2007, the researcher joined a company based in Germany, focusing on the Project Management and optimisation of real estate projects. The following years were spent understanding the nature of construction projects and developing ways of how the Lean concepts could be adapted and applied to the specifics of construction projects. The first case study project in practice in 2007, led to the initial development of the LCM[1] model by the researcher, in her role as a consultant with the company. LCM is a Visual Management Model for improving production planning and control in construction by creating transparency in the overall construction process. In 2009, the researcher began this PhD research, which focuses on the formalisation of the development of the LCM model; clarifying the models practical and theoretical significance. The unique situation to be able to research and implement the LCM model parallel in projects, led to a deeper understanding of the underpinnings of both the models practical and theoretical significance.

[1] At the time of writing "the LCM method" as is known in practice, has been renamed to LSP "Lean Site Planning".

1.5 Aims and objectives

1.5.1 Research aim

The aim of this research is the development of a Visual Management Model for production planning and control in construction.

1.5.2 Research objectives

In order to achieve the aim of the research, three objectives were defined:

- To understand the problem of a lack of transparency in production planning and control and Visual Management application in construction.

- To formalise the initial development of the model and associated method.

- To test the applicability of the model and formally evaluate its instantiations.

1.6 Research process

Figure 1.1 presents an outline of the research process and a summary of the main activities undertaken. The research is carried out in three parts which follow the steps of the process model for Design Science application proposed by Peffers et al. (2007): 1) problem identification, 2) define objectives for a solution, 3) design & develop, 4) demonstrate, 5) evaluate, 6) communicate and includes feedback cycles between the steps as shown by the arrows in Figure 1.1.

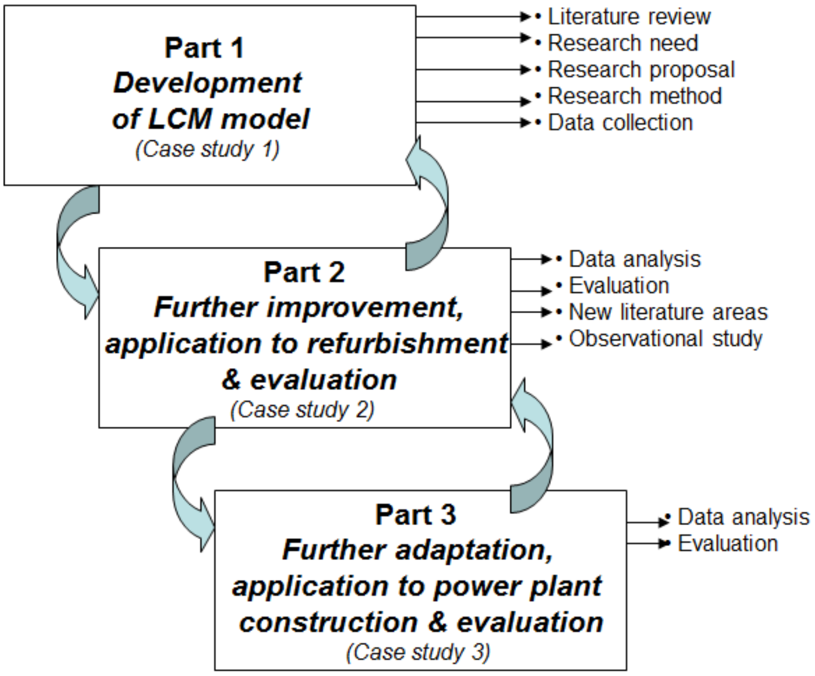


Figure 1.1: Outline of research process

Part 1 represents the first stage of the research, beginning where a solution had been developed in practice by the researcher and the research process begins by the researcher "working backwards" to apply rigor to this process (Peffers et al., 2007). The goal of part 1 is to formally explain and clarify the development of the LCM model in practice by applying the six steps of Peffers et al. (2007) process model for Design Science retroactively. The initial development of the model is analysed and reflected upon by building an explanation of the process using the case study method. An important focus of part 1 was clearly defining the problem identified in practice and deepening the knowledge of this problem through a synthesis of the literature. Part 1 also included an initial reflection on and evaluation of the first application of version 1 to the construction project to access if an improvement in transparency was achieved and to make recommendations for the future application and improvement of the model. An evaluation framework was developed as basis for the evaluation in parts 1, 2 and 3 of the research.

The aim of parts 2 and 3 of the research is the further development, application and evaluation of the model. In part 2, the applicability of the LCM model to refurbishment construction is demonstrated and evaluated based on important criteria from the Design Science literature and the objectives of the model. Part 2 follows Peffers et al. (2007) steps 3-6; design and development, demonstrate, evaluate and communicate. The objective of step 3, design and development is to show how the LCM model was further developed and to explain what new elements are part of this further development. The objective of the demonstration (step 4) is to form an explanation of how the further improved LCM model was applied to refurbishment construction. A key focus of this stage of the research is an evaluation of the model (step 5) and its application and adaptation by both third parties and the researcher to two refurbishment projects. During part 2, the researcher also conducted a research trip to Brazil to carry out an observational study of the Visual Management practices evident on sites in there, to establish how these relate to the LCM model.

Likewise in part 3, the applicability of the LCM model to power plant construction is demonstrated and evaluated. Part 3 represents the final stage of the research where the LCM model is further developed and applied to five power plant construction projects. Part 3, like part 2 is structured around Peffers et al. (2007) steps 3-6; design and development, demonstrate, evaluate and communicate. The further development and demonstration of the applicability of the model to a different type of construction and the evaluation of its effectiveness and utility are an important focus of this part of the research.

In chapter 3, a detailed explanation of the research process is presented providing a comprehensive description and justification for the application of Design Science.

1.7 Content of thesis

The thesis is structured around 8 chapters which are summarised as follows:

- **Chapter 1** presents a general introduction, outlining the research background, problem and need for the research. The research aim and objectives and an outline of the research process are explained.

- **Chapter 2** presents the literature review and synthesis. Gaps in the Visual Management and production planning and control literature are identified. The significance of the principle of transparency and holistic thinking for the improvement of planning and control and Lean application to construction are clarified.
- **Chapter 3** describes the research method adopted for this research. A justification for the application of the Design Science method is presented. The research process is explained, including a detailed description of the methods used and an overview of the case studies focused on during the research.
- **Chapter 4** focuses on case study 1. In case study 1, the original development of the LCM model (version 1) in practice during the construction of a new residential building based in south Germany is presented. This case study explains how the model was developed and applied for the first time in practice. This chapter includes a reflection on and an initial evaluation of the first application to establish whether the model contributed to an improvement in transparency of daily operations onsite. In addition, an important part of this initial evaluation is to identify improvements to the model and make recommendations for future applications in practice.
- **Chapter 5** focuses on case study 2. Case study 2 involves the further development, application and evaluation of the LCM model (version 2) based on two refurbishment projects (two instantiations of the model, 2A & 2B). One instantiation is carried out by the researcher and one by a third party.
- **Chapter 6** focuses on an observational study carried out in Brazil. The observational study, provides an opportunity to compare Visual Management practices observed on sites in Brazil to the LCM model to establish if similar models are evident and if the LCM model can contribute to existing practices observed there. Focus groups and presentations of the research work which were carried out for practitioners and academics, contributed to the overall development of the work at this stage of the research.
- **Chapter 7** focuses on case study 3 which involves the further development and

application of the LCM model to power plant construction by third parties (5 instantiations of the model (3A-3E) at five individual power plants. An evaluation of the LCM model is carried out to establish whether the model is applicable and adaptable to power plant construction scenarios and whether there is evidence to show that it is a useful model in improving transparency on these types of construction projects.

- **Chapter 8** presents a summary of the research findings, the contribution of the work and its theoretical significance. The achievement of the aim and objectives of the research work is examined, presenting conclusions on the contributions and recommendations for future research.

1.8 Chapter summary

This chapter presented an introduction to the research presented in this thesis. The research background was discussed, explaining the problem of a lack of transparency in the construction process and why it is needed. Transparency in the construction process is needed to 1) facilitate a holistic view of the process 2) to support continuous improvement and 3) to build trust and motivate participants. The key role Visual Management plays in creating transparency was discussed and it was established that there is a lack of examples to be found in the literature showing how Visual Management can be applied in a systematic way to construction projects. The chapter concluded with an outline of the research process and an overview of the thesis structure.

The next chapter presents a review and synthesis of the relevant literature, providing the theoretical background of this research.

2 Literature review

2.1 Introduction

This chapter presents a literature review of the relevant areas under investigation in this research work. The LCM model, developed and formalised as part of this work, is a Visual Management Model for planning and control in construction based on the Lean concepts. A previous publication on the implementation of this model to refurbishment (Bryde & Schulmeister, 2012) focused on investigating the effects of applying the Lean concepts to this type of project. While the study indicated difficulties in applying certain aspects of Lean to refurbishment such as pull scheduling and JIT (Section 2.2), it was found that the use of the visual elements of the model had a beneficial impact on communication. This work focuses on the development and further adaptation of the model, clarifying its contribution to the areas of Visual Management and project management in construction.

The chapter begins with an overview of the Lean concepts, from where this work originates. The principle of transparency is presented as an important element of Lean application and the significant role Visual Management plays in creating transparency is discussed. An important focus of the literature review is to understand why the principle of transparency is important for improving planning and control in construction and when applying the Lean concepts to construction projects. Through a synthesis of the literature on transparency, Visual Management, the deficiencies of traditional Project Management and Lean construction, gaps in application have been identified, which are addressed by this research work. This synthesis of the literature clarifies the need for broader applications of Visual Management for the planning and control of construction projects.

This chapter is organised around four specific areas: 1) Lean Production; to understand the important principles and visual tools of the Toyota Production System (TPS) from which this this research work originates and to explain why holistic thinking is important when implementing Lean 2) Visual Management; to gain an understanding of how Visual

Management is currently applied to increase transparency and to understand what challenges have been experienced when applying Visual Management to construction projects 3) the deficiencies of traditional project management; to understand how the traditional conversion model in construction contributes to a lack of transparency in projects and 4) Lean Construction; to understand the benefits and challenges that have been faced when applying the Lean concepts to construction projects. In particular, a closer look is taken at applications of the Last Planner System, one of the most widely used systems for production planning and control in construction, based on the Lean principles.

2.2 Lean production

The Toyota Production System (TPS) is the origin of lean production, which is based on five important principles: Value, Value Stream, Flow, Pull and Perfection (Womack & Jones, 1996). Liker (2004, p.7) also emphasises the importance of these principles:

> "To be a lean manufacturer, requires a way of thinking that focuses on making the product flow through value-adding processes without interruption (one-piece-flow), a pull system that cascades back from the customer demand by replenishing only what the next operation takes away at short intervals and a culture in which everyone is striving continuously to improve".

The principle of Value is the starting point for the application of Lean Thinking: determining the main characteristics of a product and what a customer is willing to pay for. This is also a first step in the identification of waste in the process. The second principle is that of the Value Stream: understanding the physical flows of material, people and information. Value Stream Mapping, which was adapted by Rother & Shook (1999) is an important tool to visualise material and information flow (Liker, 2004). The principle of *flow* refers to achieving the optimal order of process activities, by reducing variability and irregularity (such as bottlenecks) so that material and information may move in a predictable way within the supply chain. Pull (together with flow) are regarded as the core characteristics of Lean thinking and cornerstones for the elimination of waste. Toyota defines waste as any activity that does not add value for the customer (Liker, 2004). The idea of pull is to produce only as much as the following work activity needs while keeping inventory at a minimum. The principle of perfection is closely related to the idea of continuous improvement - constantly striving for perfection in processes.

These principles are applied using the tools of the Toyota Production System illustrated in Figure 2.1. Section 2.2.1 presents the tools and techniques that make up the TPS.

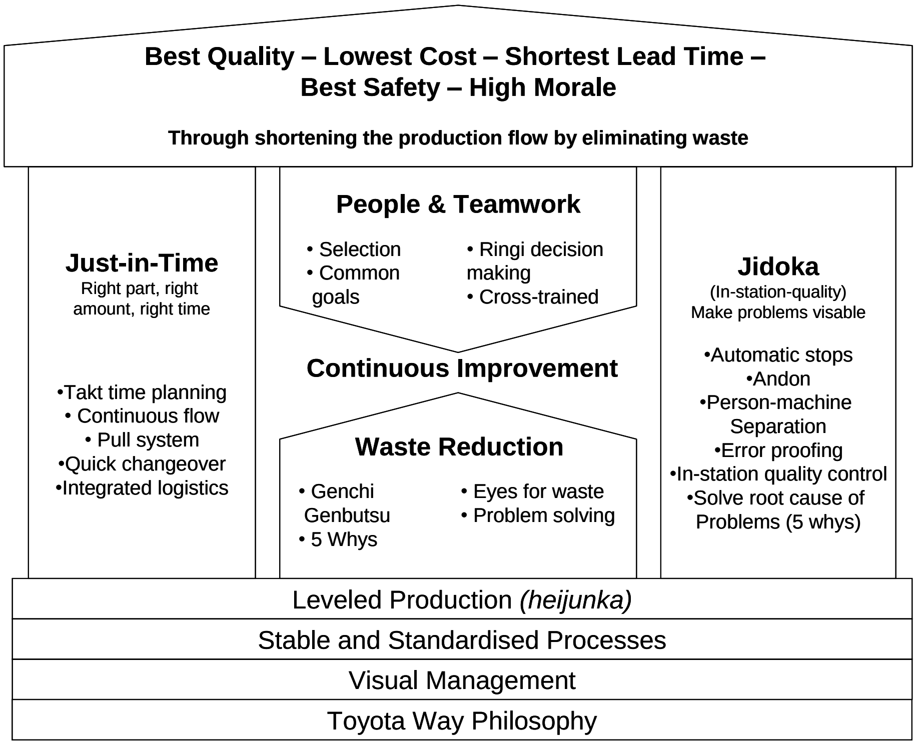


Figure 2.1: The TPS house (Liker, 2004, p. 33)

2.2.1 The TPS: tools and techniques

The TPS house (Figure 2.1) is a symbol illustrating the various tools and techniques that have been developed and practiced for decades by Toyota. It has become one of the most recognisable symbols in modern manufacturing and was created initially by Toyotas past president, Fujio Cho, working closely with former Toyota engineer and executive Taiichi

Ohno, to support the teaching of TPS to suppliers of the company. Different versions of the TPS house exist today but the core principles remain the same.

The roof of the TPS house represents the goals of an organisation: best quality, lowest cost, shortest lead-time. The two outside pillars represent the concepts of *Just-In-Time* (producing the right quantity and in time) and *Jidoka* (automatically recognising quality issues). *Just-In-Time* in turn can be achieved by applying a number of different tools:

- **Takt-Time:** is the rhythm of customer demand. It is an indicator of how much time is available to produce one part based on the operating time available and the customer demand.

- **Kanban:** is used to realise pull-production in small batches (Monden, 1998). It relays information (on cards) with the intention of influencing behaviour (only the specified quantity on the cards are delivered).

- **Continuous Flow:** enabling material and information to flow fast as well as to link processes and people together so that problems surface right away (Liker, 2004).

- **Quick Changeover:** reducing the amount of time it takes to set up a machine to produce the next part (Liker, 2004).

Jidoka can be achieved by applying (Liker, 2004):

- **Automatic stops:** a technique that allows machines to automatically stop when a problem is detected. It attracts attention when there is a problem and prevents further errors from happening by stopping the process.

- **Poke-Yoke:** a physical device that prevents mistakes or calls attention to them by stopping production (Liker, 2004). Its purpose is to eliminate product defects by preventing, correcting, or drawing attention to process errors as they occur (Robinson, 1997).

- **Andon:** is a signalling system which uses lights or flags to indicate that equipment has shut down as a result of a quality problem (Liker, 2004).

- **5 Whys:** understanding the root of the problem by asking “why” 5 times.

The two pillars of the TPS, JIT and Jidoka, are focused on creating transparency in information so that the process participants have access to the important information that they need to answer the six fundamental questions in a workplace which is what, how many, who, when, how and where (Section 2.5.1; Galsworth, 2005, p.34-5).

The tools and techniques of the TPS are applied to help identify so-called “waste” in the process. Toyota defines waste as any activity that does not add value for the customer and identifies seven different types (Liker, 2004):

- **Overproduction:** producing more than there is a demand for. Ohno considered this to be the fundamental waste, since it contributes to most of the other wastes.

- **Waiting** (time on hand): waiting for a machine, for material or information.

- **Unnecessary transport or conveyance:** carrying work in process (WIP), moving material.

- **Over processing:** taking unneeded steps to process parts.

- **Excess inventory:** excess raw material, WIP or finished goods, causing longer lead times, obsolescence, damaged goods, transportation and storage costs.

- **Unnecessary movement:** any wasted motion that employees have to perform during the course of their work.

- **Defects:** production of defective parts that need correction.

A further waste added by Liker (2004) is unused employee creativity. Employees work in the process and have a deep understanding of the nature of the work and what the root causes of problems are.

Finally, the TPS house is supported by several foundational elements, which include the need for standardised, stable and transparent processes, the performance of which is measured. Imai (1986) explained in his book on continuous improvement called Kaizen, that it is impossible to improve any process until it is standardised. It is also important to measure performance and create feedback that will lead to higher levels of improvements (Marosszeky et al., 2004). Managers tend to view measurement as a tool for controlling people's behaviour. Instead, measurement is a way of communicating goals, sharing responsibilities and learning in organisations (Formoso & Lantelme, 2000). The foundational elements of the TPS include a levelled schedule or heijunka which is necessary to keep the system stable and to allow for minimum inventory and Visual Management, which is applied to create transparency in the work environment and to easily identify problems.

The principle of transparency is key to the effective application of the TPS. Section 2.3 discusses the principle of transparency and presents some important points to consider in order to create it.

2.3 The principle of transparency

The principle of transparency is a core element of Lean Production (Formoso et al., 2002). The lack of transparency on construction sites appears to contribute to the fact that production systems in construction often operate well below their full potential (Formoso et al., 2002). Workers are often forced to use their time searching, wandering and waiting for tools, material and information instead of performing value-adding operations. This section defines what is meant by "transparency" and considers how the traditional approach to managing construction projects has contributed to a lack of transparency in the construction process.

2.3.1 What is transparency?

Formoso et al., (2002, p.38) defines transparency as: "the ability of a production process to communicate with people". The concept of transparency can also mean a separation of the network of information and the hierarchical structure of order giving (Greif, 1991). The goal is thus to "substitute self-control for formal control and related information gathering" (Koskela, 2000, p.63). Other researchers have described transparency as way to provide people with a clear understanding of different aspects of the current system performance and status, giving them feedback on performed activities and helping in making decisions, letting them recognise interdependencies and as a result, enabling higher levels of improvements (Bauch, 2004). Transparency provides insights into matters that are relevant for all parties involved in a common process who with the right information, can make well-founded decisions with regard to the transactions that they agree on with one another (Nijhof et al., 2009).

Transparent organisational entities radiate information through physical artefacts or remove the blockage for improving information flow. Some aspects of transparency such as the goal of delegation of decision making from higher to lower organisational levels and increasing information availability for individuals, coincide well with the fundamental requirements of the organisational empowerment practice (Bowen & Lawler, 1992). Lamming (2005) considers transparency in customer-supplier relationships as the mutual sharing of sensitive information for the purpose of value creation, which they call value-transparency, and suggest businesses can jointly plan which information should be clear, translucent or opaque to optimise value creation.

In a practical sense in construction, according to dos Santos et al. (1998), transparency consists of management actions that use visual tools that are able to determine the progress of a particular process thus resulting in a reduction of the interdependence between activities. It includes creating a work layout that promotes visibility of the work flows and ongoing activities, incorporation of information about production and process management, maintenance, organisation and cleaning of construction sites and other actions that improve the visibility of the production attributes through measurements and indicators (dos Santos et al., 1998). The principle of transparency represents a substantial change in the production management of construction since it aims to transform the traditional “silent” processes into ones that communicate in an active manner (de Oliveira et al., 2012).

From the definitions above, it can be concluded that a key characteristic of transparent processes is that they radiate relevant information in a physical way, facilitating communication, decision-making and promoting self-management. With the transparency of processes, trust among parties is built and value is generated.

2.3.2 Creating transparency

Koskela (1992) discusses the notion of transparency in his work and presents some ideas on how to create transparency in the construction process:

2.3.2.1 Reducing interdependence between the production units

Reducing the interdependence between processes increases transparency because it allows the separation of processes in time and space (Formoso et al., 2002). This separation reduces disruption and cluttering caused by large quantities of materials, equipment and workers moving within the same area. Reduction of interdependence may be achieved through improvements and innovations in design, production methods and by planning materials and work flow adequately (Formoso et al., 2002).

2.3.2.2 Using visual devices to enable immediate recognition of process status

If waste, abnormalities and problems were easily recognised by all involved, more meaningful improvement activities could be defined. However, in contrast to manufacturing, examples of the use of visual devices in construction are quite minimal. The discussion of transparency in construction tends to be limited to physical site operations (Kemmer 2006; dos Santos et al., 1998; Klotz & Horman, 2007) with little focus on the delivery processes. These examples tend to focus on visual Lean tools taken from manufacturing and applied to construction (Section 2.5.3). The application of other visual tools however, such as process mapping, has the potential to further improve transparency and in turn sustainable project delivery (Klotz & Horman, 2007). While there is little evidence of the benefits of process mapping for general business processes and in the construction industry, it appears that the benefits are linked to improvements that result from revising processes based on future-state process maps (Rother, 1997).

2.3.2.3 Making the process directly observable

World-class companies' emphasise the importance of making manufacturing processes as directly observable as possible through appropriate layout and signage, so that following workstations can see the root cause of problems and react accordingly. In contrast to manufacturing, in construction the product is fixed and the work stations move around it as the site develops (dos Santos et al., 1998). Measures can be taken to improve the sequence of production and layout planning so that the process becomes more observable from other areas of the site (also by using fencing that one can see through, lighting to illuminate darker workplaces and signage to show where important safety equipment is located).

2.3.2.4 Incorporating information into the processes

A self-explaining production environment can be achieved, by inserting relevant process information into the process. Defects display boards, defective storage part areas, general statistics about the process or even supplier's illustrative videos are examples of this informative role of visual communication (dos Santos et al., 1998).

2.3.2.5 Maintaining a clean and orderly workplace

By maintaining a clean and orderly workplace, a safe and effective work environment is established. People intuitively recognise that a clean, uncluttered, safe, and well-ordered workplace is a much more productive environment. However, in the construction industry it is very common to see workers spending precious time searching, wandering, or waiting for the tools, materials, and information they need in order to do their work instead of adding value. 5S is a lean tool that can be applied to achieve a clean and orderly workplace. The term 5S refers to the five housekeeping practices that are part of the daily routine of every Japanese household - Seiri: proper arrangement, organisation; Seiton: straighten; Seiso: cleanliness;

Seiketsu; standardise; Shitsuke: discipline, good conduct (Galsworth, 1997; Monden, 1993; Osaka, 1991).

2.3.2.6 Rendering invisible attributes visible through measurements

Transparency can also be improved by establishing measurements that detect the efficiency and effectiveness of the conversion and flow activities. The practice of measuring the process helps to detect the problems as they occur, or even show critical situations before they actually become problems.

Ideally, it is a combination of these points rather than an isolated application that leads to improving transparency. Reducing interdependencies between the production units alone does not improve transparency sufficiently. Being able to recognise and observe flow, waste and problems in the construction process is essential to be able to do so. In the literature, various authors (Galsworth, 1997; dos Santos et al., 1998; Formoso et al., 2002) call for the use of visual tools and methodologies to increase transparency on a construction site, reduce information processing time and human errors, add different layers of information on workplace elements and promote self-management. Koskela (2000, p.63) states that:

> "transparency is achieved by visualising the main flow of operations from beginning to end, through organisational and physical means, measurements and public display of information".

Process transparency is achieved by using information giving, signalling, limiting or guaranteeing (mistake-proofing or poke-yoke) visual tools to communicate with people so that work settings expectedly become self-explanatory, self-ordering, self-regulating and self-improving (Galsworth, 1997). A characteristic of transparent organisations is that they make information readily available via the use of visual artefacts in order to improve the information flow. When making processes transparent by using such artefacts, it is important to consider information design, information modality (visual, auditory, tactile, gustatory and olfactory) and semiotics (the study of symbols) (Lehto & Buck, 2007; Ware, 2004).

The following sections 2.4 and 2.5 expand on the concept of Visual Management as an important approach for creating transparency in the construction process. Section 2.4 explains what is meant by Visual Management and section 2.5 presents a classification of different visual tools existing and discusses how Visual Management is applied to construction today. As discussed in section 2.2.1, Visual Management is one of the core foundational elements of the Toyota Production System and some examples are discussed of how visual lean tools have been applied to construction and what challenges have been experienced during implementation.

2.4 What is Visual Management?

In general, there appears to be a lack of terminology and the absence of an explicit definition of Visual Management (Tezel, 2011). Bell & Davison (2012) identify the difficulty in defining and understanding the "Visual" as a reason for the slow response to the "Visual turn" in the field of management studies research. Bell & Davison (2012) broadly define "the Visual" to encompass a variety of forms, including pictures, graphs, film, web pages and architecture and considers how recognition is growing of these forms in management research as a counterweight to the linguistic form (where language constitutes meaning and reality). Further definitions and explanations of Visual Management are to be found in the literature and are presented in this section.

- Greif (1991) describes Visual management as an orientation towards visual control in production, quality and workplace organisation. The goal is to render the standard to be applied and a deviation from it immediately recognisable by anybody (Greif, 1991).

- According to Liker (1997), Visual Management enhances communication by making information easily accessible in a production setting.

- Ho & Cicmil (1996), refer to Visual Management as using visual aids to improve processes and communication and promote continuous improvement (Ho & Cicmil, 1996).

- Imai (1997) describes Visual Management as a way to help workers and supervisors to control and improve the workplace: “It makes abnormalities visible to all employees – managers, supervisors, employees, so that corrective action can begin at once” (Imai, 1997, p. 96).

- Tomkins & Smith (1998, p. 17) refer to Visual Management in terms of being part of the performance measurement system: “A communication and information centre for all employees to understand an organisation‘s strategic directions, performance (scoreboard) and the process of improving performance.

- Visual Management improves the availability of information, which also helps to reduce work interruptions (Chua et al., 1999).

- Koskela (2001, p. 5) refers to Visual Management as “a sheer embodiment of management-as-organising”. The Toyota Production System (Section 2.2) is essentially based on an approach known as “management-as-organising” where it is assumed that human activity is inherently situated, i.e. a response to the situation in question. Thus, the structured nature of the environment may contribute to purposeful acting. In contrast, conventional production management is based on an approach to management called management-as-planning (Johnston, 1995) (Section 2.7.1), where the central assumption is that intentional activity is based on a representation of the world. Thus, management is essentially about planning, i.e. manipulation of that representation. Koskela (2001) argues that the structuring of environment in the Toyota Production System aims at making the productive situation transparent and practices visible. Production managers become enablers through Visual Management by using visual communication for increased autonomy in practice.

- Liff & Posey (2004) refer to Visual management as a system for organisational improvement that aligns organisational vision, core values, goals and culture with other management systems, by means of stimuli (information), which directly address one of the five main senses: sight, hearing, feeling, smell and taste. Visual

Management does not only refer to the ability to see, but also all of the other core senses.

- Pries (2003, p.92) defines Visual Management as "the goal of making the performance of each work team in each work area transparent, as well as visualising the standardised operations and processes". The author explains Visual Management through its role in performance and process management. Pries (2003) claims that Visual Management is one of the superior production principles.

- In a later work, Koskela et al. (2007), refers to Visual Management as a management strategy that leads to the realisation of a visual workplace and also as "an attempt" to externalise, not only the plan of work, but also the required competence" (Koskela et al., 2007, p.8).

- Tezel (2011) refers to Visual Management as taking part in various managerial efforts in different ways and degrees, providing people with relevant information they need in a correct, easy way to understand and timely fashion, by using visual (sensory) communication (Tezel, 2011, p. 21).

It can be derived from the explanations and definitions of Visual Management presented in this section that an important goal of Visual Management application is to make information easily accessible so that process participants can act in a purposeful way (Liker, 1997; Imai, 1997; Tomkins & Smith, 1997; Chua et al., 1999; Koskela, 2001). Galsworth (2005) also reflects this view by noting that Visual Management can be applied to help answer the six fundamental questions in a workplace which is what, how many, who, when, how and where (Galsworth, 2005, p.34-35). The answers to these questions provide the necessary information that is needed to carry out work on a daily basis and to make effective decisions. Acting purposefully and effective decision making is particularly important in an industry such as construction where market forces (increased competition, increased design and construction, partnering between owners, contractors and suppliers, emphasis on innovation and research and development) shape the structure of the industry (Ahmad & Sein, 1997).

In conclusion, while various different definitions and explanations of Visual Management exist in the literature, it can viewed as a management strategy for organisational control, measurement and improvement which uses visual aids to externalise information and improve communication in the workplace by creating transparency. The working definition of Visual Management used for this research is that of Ho & Cicmil (1996): Visual Management uses visual aids to improve processes and communication and promote continuous improvement.

The following section presents important concepts when applying Visual Management and discusses how Visual Management is applied to construction today.

2.5 Application of Visual Management

When applying Visual Management, 5S is usually considered to be a first step (Galsworth, 1997). 5S is a lean tool which consists of a series of activities for eliminating waste that contribute to errors and defects (Liker, 2004). 5S stands for "Sort, Straighten, Shine, Standardise and Sustain" (Liker, 2004, p. 150; Section 2.3.2). By removing clutter, improving space utilisation and introducing standards, the workplace is visually improved. As part of the 5 S approach, standards are implemented which may be in the form of signs or labels which are a visual form of standardisation.

Different types of visual tools for application are described in the literature (Galsworth, 1997; Liker; 2004). According to Galsworth (1997, p. 309), a visual tool (or device) is:

> "a mechanism, gadget, or apparatus that is intentionally designed to make workplace information vital to the task at hand available at a glance – without speaking a word. Its purpose it to influence, direct, limit, guarantee or otherwise impact human behaviour relative to a specific performance process or outcome".

Section 2.5.1 presents the different types of visual tools identified by Galsworth (1997), which are applied to support daily operations by making information transparent, reducing waste and motion and improving space utilisation.

2.5.1 Visual tools identified by Galsworth

Galsworth (1997) identifies different visual tools that are consciously designed to structure human behaviour when implementing Visual Management. According to Galsworth (1997), Visual Management is realised by visual systems that consist of one or more these visual tools. Four types of visual tools are identified by Galsworth (1997): 1) visual indicators 2) visual signals 3) visual controls and 4) visual guarantees.

2.5.1.1 Visual indicators

The visual indicator relays information with the intention of influencing behaviour. There is no guarantee that this information will be taken on board and thus, the human control of disobedience is high. Usually, consequences as a result of disobedience are minimal. Some examples of visual indicators in use in the Lean environment are: team boards, charts, photos, value stream maps etc. When these are used more for control purposes, then usually they would include an expected state to be achieved and / or a control indictor to measure progress. Reasons for deviation may be noted and actions to be taken defined in a template (Greif, 1991). Visual indicators are a useful way to communicate important information from management to operational level. Difficulties in communicating such important information in construction are apparent with reports indicating that only 20% of information passed down from management might reach the construction site because of information overload, lack of openness and filtering (Bateman & Snell, 1999).

2.5.1.2 Visual signals

A visual signal enforces much more human control than the visual indicator described above (Galsworth, 1997). A traffic light is an example of a visual signal. A visual signal attracts attention by using visual stimuli[2]. It is designed to encourage people to pay attention and directs behaviour. An example of a visual signal in the lean production system is the Andon

[2]A visual stimuli provokes a response to the eyesight so that one has the ability to interpret the surrounding environment.

board, which visually and audibly calls the team leader in case of an abnormality on a line or at a workstation (Monden, 1998).

2.5.1.3 Visual controls

This type of visual tool enforces almost complete human control. It limits human response in terms of height, size, quantity, volume, weight, width, length and breadth. Parking and road lines are an example of this kind of visual element. In the lean production system, colour-coding, production and maintenance Kanban, markings, display of safety regulations etc are all examples of visual control in use. Liker (2004) uses the term ―"Visual Control Systems" and explains that they are communication devices that tell people how things should be done and show the deviations at a glance, helping people see immediately how they actually perform their jobs. These Visual Control Systems are all integrated into the process related elements (e.g. the process itself, equipment, and inventory etc.).

2.5.1.4 Visual guarantees

A visual guarantee, also known as a mistake proof, fail-safe or Poke-Yoke device, is designed to make sure that only the right thing can happen. Prevention information is designed into the device (Galsworth, 1997). This type of visual tool strives to eliminate human error and exercises the most human control. All information needed is built in mechanically or electronically into the machine (e.g. petrol pumps that stop automatically when the tank is full).

Many of the Lean tools of the Toyota Production System presented in Figure 2.1 and Section 2.2.1 are visually based and conform to the different types of visual tools identified here by Galsworth (1997).

2.5.1.4.1 Galsworth's Visual Management application framework

In addition to a classification of visual tools, Galsworth (2005, p.99) also proposes an application framework for Visual Management (Figure 2.2), starting from the bottom level and working upwards. The visual order at the bottom level refers to the systematic standardising and cleaning of the workplace, materials, tools, warehouse etc (application of the concept of 5 S). The next level, visual standards involves providing people with visual standards and visual displays to use for their tasks (for example, written specifications, procedural standards etc). Another aspect of this level is applying various visual tools which make information readily available so that process participants can answer the core questions of where, what, when, who for effective decision making. Visual metrics for management, sub-contractors and suppliers should be made transparent for all to see. This includes showing a comparability (then and now) highlighting abnormalities and involves corrective action (Greif, 1991; Galsworth, 1997). The top level refers to Poke-Yoke or mistake proofing devices (Section 2.2.1) which are used to minimise human error.

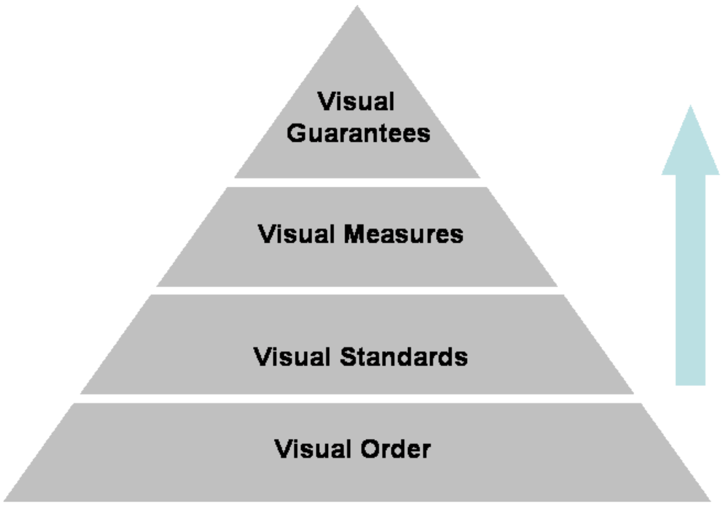


Figure 2.2: Glasworth's (2009) application framework for Visual Management

2.5.2 Visual Management research in construction

Research in the area of Visual Management in construction has increased in recent years due to an increased awareness of the concept of transparency (Tezel, 2011). Formoso et al., (2002) investigates the application of the principle of transparency in construction focusing on the ideas for creating transparency (Section 2.3.2) proposed by Koskela (1992). Formoso's et al., (2002) study identified important points that hinder transparency such as, a high interdependence of production units which lead to several gangs working in the same area, leaving it cluttered and disorganised. Formoso's et al (2002) research concluded that further research areas should focus on developing new visual tools and technologies for construction. An example of new visual technologies for use in construction is the implementation of ICT (Information and Communication Technologies - automation) to aid transparency. Akinci et al. (2002), presents a 4D application for work space requirements that can automatically identify space conflicts when planning for stable work. Fard et al., (2009) aim to improve transparency by applying visual tools such as 4D colour-coded images on site photographs while Sacks et al., (2009) discusses improving transparency of workflow by proposing a BIM (Building Information Modelling) integrated workflow visualisation, showing past, present and future work status.

2.5.3 Visual tools from the TPS applied to construction

Kanban is a visual indicator (Section 2.5.1.1) since it relays information (on cards) with the intention of influencing behaviour. It is also a visual signal (Section 2.5.1.2) since certain types of Kanban systems use visual stimuli to attract attention (i.e: an empty container signals more material / parts are needed for example). *Andon* is a visual signal (Section 2.5.1.3) which uses lights (or flags) to indicate that there is a problem. Autonomation is a visual signal (Section 2.5.1.2) since it attracts attention when there is a problem and prevents further errors from happening by stopping the process. A *heijunka* board can also be compared to a visual indicator (Section 2.5.1.1) since it relays information of what quantities should be produced when so that production is levelled and inventory is kept at a minimum. Poke-Yoke is also a type of visual guarantee (Section 2.5.1.4) since it draws attention to process errors by preventing mistakes from happening. Its purpose is to eliminate product defects by preventing, correcting, or eliminating process errors (Robinson, 1997).

The literature reveals that many examples of the application of visual tools to construction are based on the Lean tools from the Toyota Production System (Figure 2.1, Section 2.2.1). Arbulu et al., (2003) demonstrates an application of Kanban in material supply while Jang & Kim (2007) demonstrate an application of the Kanban system in production control and safety within the Last Planner System. The applicability of the concept of Poke-Yoke in the construction environment is discussed by dos Santos & Powell (1998) and Tommelein (2008) also provides some mistake-proofing examples in design, construction and maintenance. Saurin et al., (2008) also dealt with the application of Poke-Yoke in construction safety. Kemmer et al., (2006) presents the application of the andon concept and the heijunka board in a high rise building construction project.

2.5.3.1 Tezel's Taxonomy

Tezel (2011) developed an in-depth study on Visual Management in construction which included research visits to Brazil and Finland to investigate how Visual Management is applied on construction sites. Tezel (2011) also provided evidence of many examples of visual tools originating from the Toyota Production System and applied to construction sites such as 5S, Kanban, standardisation, the heijunka board, Andon and Poke-Yoke. As part of his work, Tezel (2011) compiled a Visual Management taxonomy which is a classification of the different Visual tools and methods observed in practice. The visual tools described in this taxonomy represent isolated examples of Visual Management that were identified on 9 different construction sites. Each visual tool had its own specific purpose and it was not clear if and how these tools related to one another and indeed, if better results could be achieved if they did. This taxonomy is important for this research since the LCM model demonstrates how a large number of these tools can be applied either directly or indirectly collectively as part of one Visual Management Model (Chapter 8, Section 8.4.4). The individual elements of the Visual Management Taxonomy as composed by Tezel (2011) is explained in more detail below.

2.5.3.1.1 Site Layout and Fencing

The main function of these items was to create transparency by making processes observable (Koskela, 1992) and enabling flow. Glass as a translucent material was used for increased transparency on the perimeter walls and doors of the site office buildings investigated by Tezel (2011). Likewise, the fencing types that were observed in this research work permitted seeing and being seen through, along with providing a safe enclosure such as a chain link or welded wire fences.

2.5.3.1.2 Standardisation of the workplace elements

According to Tezel (2011), the standardisation of a number of site elements make up an important portion of the Visual Management activities in construction for e.g. people, materials, machines, carts, tools, workstations, temporary mobilisation units, transportation routes, temporary storage, process areas etc. It is also the fundamental concept of the Toyota Production System (Liker, 2004; Galsworth, 1997). One example Tezel (2011) presented included the identification of people onsite (workers, foremen, group leaders, site managers and visitors) through the use of coloured helmets. A further example was the transportation routes for frequently used materials such as brick and tile were clearly marked with different colours and separated from the walking routes for the flow of these materials (Tezel, 2011).

2.5.3.1.3 In the warehouse

In Tezel's (2011) case study, various examples of visual elements were found in the warehouse. The supply items (consumables) in the warehouse were classified and stored in specific bins/racks. Necessary information (e.g. material name, technical specifications, picture etc) were attached to these bins/racks as tags, stickers or badges. A consumables control board that displayed the stock level of commonly used materials and tools (e.g. nails, cement bags, gloves etc.), provided elementary information for everyone who did not work at the warehouse on the site. A large matrix-like tool/equipment control board showed the names of the workers on the left and hand tools/equipment (e.g. drills, saws, shovels etc), which may have high circulation between workers and can be used by different work groups, at the top.

2.5.3.1.4 5S

According to Tezel (2011) some companies systemised their site cleaning, order and standardisation within the systematic housekeeping effort, known as 5S (Section 2.4). The 5S effort was displayed, underlined and reinforced with some visually attractive communication aids (e.g. mascots, tablets, 5S boards etc.) in these companies. 5S teams were created to sustain the effort. 5 S is an important Lean tool of the TPS and Galsworth (1997) identifies this as the first step in implementing Visual Management (Section 2.5).

2.5.3.1.5 In the Elevators

Entrances of different elevators for the transport of people and material were identified with name tags on each floor. Their specified weight limit was clearly displayed with necessary warnings, showing a picture of each material and its corresponding weight including the transportation barrow or the number of people allowed.

2.5.3.1.6 Pull production through Kanban

Pull production can be achieved by using simple cards and this was also an important visual Lean tool (Section 2.2.1) classified by Tezel. The Kanban cards generally contained a picture of the ordered material, the identity of the production unit issuing the order and the amount to be transported to the production unit. Material transport was not allowed unless a Kanban order was issued by the production workers to the transportation workers.

2.5.3.1.7 Production levelling through a Heijunka board

A further visual Lean tool that Tezel (2011) observed on the sites in Brazil was the use of a *heijunka* board (Section 2.2.1) to level the production of concrete. The production levelling at site mixers was critical when a project was highly dependent on the mixer for different concrete mixes. In Tezel's case studies, the *heijunka* board enabled workers to manage the levelling on their own and managers to track the actual production.

2.5.3.1.8 In-Station quality (Jidoka) through Andon

Examples of *Andon* (Section 2.2.1) were also observed. Tezel (2011) mentioned different forms, sometimes being evident in the form of a panel, particularly in high rise building constructions. A green light on the control panel installed at the site management office would turn on for every floor. The green light indicated that all materials, information, project details and labour force were in place to start production. Later in the day, should problems occur, a group leader would press the yellow button and correspondingly a yellow light would turn on, calling management attention at the site office. The *Andon* system did not necessarily have to be electrical or complicated at all (coloured cards sometimes being used to indicate abnormalities).

2.5.3.1.9 Prototyping

Prototyping was in place in some of the construction companies and was used to help people do their jobs better and more easily through complete visualisation of the end product (Tezel, 2011). In prototyping, a standard part of the end product (e.g. a piping system of a toilet that would have to be constructed many times) was put on display for workers and management.

2.5.3.1.10 Sampling

Sampling was used to couple materials with their location of use and equipment with their corresponding work groups. It was used to match different production elements (material/space or equipment/personnel) by using a real sample of the material and/or equipment in question. For example a tile board displaying a sample of each tile type with its corresponding area of use in the project (Tezel, 2011).

2.5.3.1.11 Visual signs

Tezel's (2011) research shows, some visual posters or signboards, which contain company specific mascots or characters, were used to emphasise the preferred practices (e.g. ―use your helmets, do not waste material, put on your earmuffs etc.). More general information, like a 5S poster or company politics, was located in the shared areas (e.g. entrances, warehouses, dining halls etc) so that their coverage was wider.

2.5.3.1.12 Visual Work Facilitators

There were visual elements that had been designed essentially to facilitate the jobs of several workers (worker gangs) (Tezel, 2011). Process charts of current work and visual step by step sketches of how to perform certain important construction tasks (e.g. concrete mixing and casting, reinforced concrete steel works, bricklaying, facade works etc.) were located around the communal areas on the site (e.g. dining areas, entrance to the management site office, changing rooms etc.). Some visual aids were specifically designed for management level to facilitate their role (i.e. a designated area for the collection of all legal documents with an index at the top of the collection) and production management visual aids (e.g. colour coded projects showed the concreting sequence and area or tiling plan of a floor, balanced production maps, a building plan showed the types of work and coloured line of balanced charts, real and planned durations of different tasks and so on) posted on a board in the managerial room.

2.5.3.1.13 Improvisational Visual Management

There were many examples of how information was integrated into the environment on the sites studied by Tezel (2011) e.g. writing a big "OK" on a brick wall to indicate that it complies with the quality standards, putting a tick on a wall with a chalk to indicate that electrical fixtures have been located correctly or incorrectly, writing a big "NO" on a ceiling to communicate that it is not supposed to be painted are some of the simple examples of this improvisation.

2.5.3.1.14 Performance Management through Visual Management

Different performance figures were displayed on boards for different reasons e.g. a construction progress board in bar chart format was used, showing the dates of the final completion and the last update. The board, which can easily be seen from outside the construction site, was mainly for potential customers and was put on display for marketing purposes. The evaluation of the suppliers' performance by different metrics (e.g. quality, security, contract compliance etc) was put on display either at the entrance for anyone on the construction site or at the sides of the site aimed at observers from outside.

2.5.3.1.15 Distributing System Wide Information

In order to enhance transparency, system wide information, whether it was directly related to construction production or not, was put on display for everyone working on the site. Some examples of production related system wide information were visual diagrams showing the dates and amounts of past concreting in a high rise building construction, a table which displayed the delivery situation of an expected material in the building (ordered for the 2nd floor, waiting for the 15th floor etc) to name a few.

2.5.3.1.16 Human Resources Management

Many Visual Management practices were observed with regard to Human Resources Management. For example, a) workers and work groups were identified by their helmets b) their planned location on the site was communicated to them with highly visual boards and signs, c) the standard salaries of workers were on display, d) company events were organised and the pictures from these events were distributed throughout the site, e) information related to worker health and well-being was posted all through the site.

2.5.3.1.17 Health and Safety Management

Safety performance was also visualised. An overall indicator of safety and project wide information was put on display (e.g. information on the number of days without accident, the safety politics, the identification of responsibility for safety, the safety procedures etc).

2.5.3.1.18 Poke Yoke

Examples of Poke Yoke (Section 2.2.1) were also observed e.g. inserting two nails on pipe heads to ensure they would not shift while concreting. However, according to Tezel (2011), there is still room for research and application in this field, as indicated by dos Santos & Powell (1998) and Tommelein (2008).

2.5.3.1.19 On-site Prefabrication

On-site prefabrication was also documented (Tezel, 2011). Some examples included 1) the prefabrication of the mortar at a specifically designed station to guarantee homogeneity for a high quality mixture and 2) the prefabrication of the electrical hardware (the junction box) within bricks before brick laying to reduce the interdependencies between tasks.

Section 2.5.3 presented examples of Visual Management, originating from the TPS and applied to the construction process to improve transparency. The following sections 2.5.4 and 2.6 discuss the problem of a lack of transparency in the construction process and how the deficiencies associated with traditional project management contribute to this.

2.5.4 Transparency and the traditional conversion model

The traditional conversion model of understanding production systems as a set of conversions of inputs to outputs (Koskela, 1992) has contributed to a lack of transparency in construction projects (dos Santos et al., 1998). The traditional method of cost estimation is at the heart of this view, where the outputs of each conversion are associated with the costs of the inputs (dos Santos et al., 1998). The building (or other structure) is divided into its constituent elements, and for each element, the costs of needed materials and labour (conversion of input to output) are estimated (Koskela, 1992). In the conversion model, it is assumed that the total production process consists of a set of sub processes which convert an input to an output, and which can be realised and analysed in isolation from each other **(**Koskela, 1992). This view of production in construction is the basis for traditional managerial concepts applied to projects (Koskela, 1992). Since it is assumed, that sub processes can be realised independently of one another, the importance of the need for transparency between these sub processes is not recognised.

In his work, Koskela (2000), proposes the TFV (Transformation-Flow-Value) theory, which places a strong emphasis on the transformation process in construction and not just on the transformation of inputs to outputs of the individual parts, which is typical of construction. Koskela argues that in production management that the management needs arising from the three concepts should be integrated and balanced. This work argues that the traditional approach to Project Management has led to a functional view of the construction process with little transparency of information on interdependencies between the different interfaces.

2.6 The traditional approach to Project Management

Since the construction industry is organised around projects, current production theory and practice are heavily influenced by the concepts and techniques of project management (Ballard, 2000). The "Project Management Body of Knowledge" (PMBOK) describes the sum of the knowledge within the profession of project management (Duncan, 1996). The PMBOK guide, issued by the Project Management Institute (PMI), documents the practices, tools and techniques describing the generally accepted sum of knowledge within the profession of Project Management. The PMBOK was first developed in the mid 1980's. The first PMBOK guide was first published in 1996, with updated versions issued in 2000, 2004, 2009 and 2013.

According to the PMBOK guide, a project is a temporary endeavour undertaken to produce a unique product or service." Projects involve two types of processes: 1) processes that create the product, service or project results and 2) managerial processes as illustrated in Figure 2.3 (PMBOK, 2004). The five managerial processes are the initiating, planning, execution, controlling and closing processes (Figure 2.3). Each process includes a series of activities which generally have a sequential relationship. The process activities can be viewed as conversions of the inputs to outputs (Koskela, 1992).

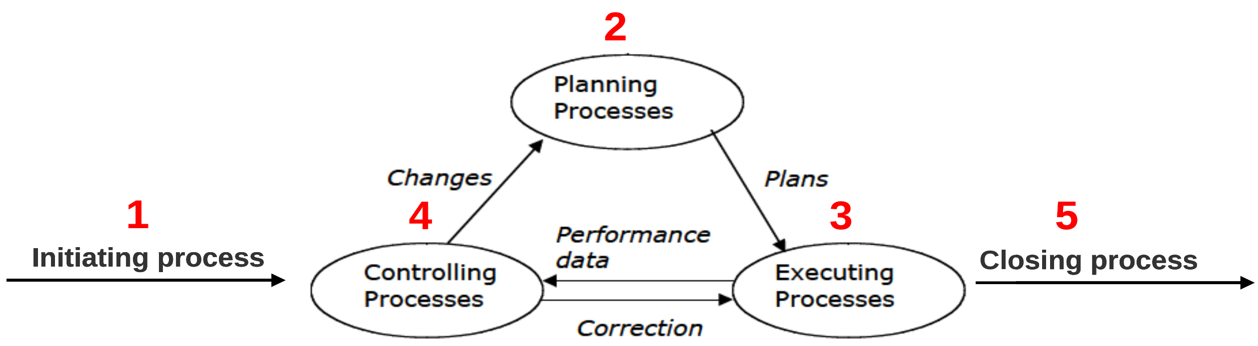


Figure 2.3: The closed loop of managerial processes in project management according to the PMBOK Guide (adapted from Koskela & Howell, 2002).

2.6.1 The initiation process

The initiation process defines and authorises the start of a project. The initial scope is defined and initial financial resources are committed. Internal and external stakeholders are identified and the Project Manager is selected (PMBOK, 2009).

2.6.2 The planning process

The planning processes define project objectives and plans of actions to achieve these. In the PMBOK guide, the function of planning is the most detailed and well explained process. It is structured into core processes and facilitating processes: scope management, time management, cost management, procurement management, quality management, communications management, risk management and integration management (Figure 2.4).

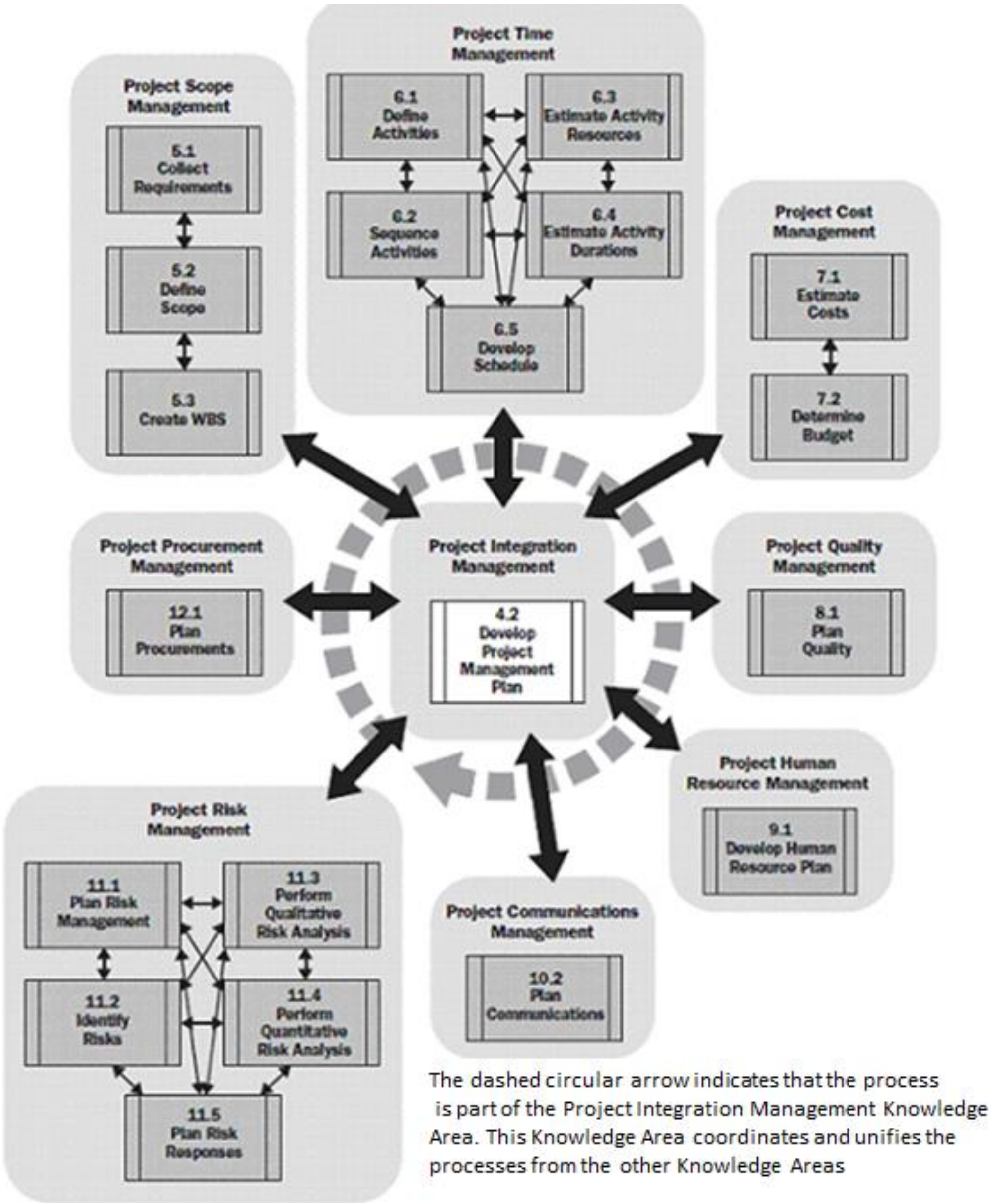


Figure 2.4: The planning process (PMBOK 2009)

2.6.3 The execution process

The executing processes are focused on the co-ordination of people and resources and the integration and implementation of project activities to complete work defined in the Project Management plan. The PMBOK guide provides generic information about the execution process under the sub headings of Human Resource Management, Communications Management, Procurement Management, Quality Management (Figure 2.5). The relationship between planning and execution is described in a simplistic way: “during execution, results may require planning updates and e-baselining” (PMBOK, 2009). It is explained that any variances potentially affecting the project management plan would require detailed analysis and development of appropriate Project Management responses. “From the analysis, requests can be triggered and the project plan may be modified” (PMBOK, 2009).

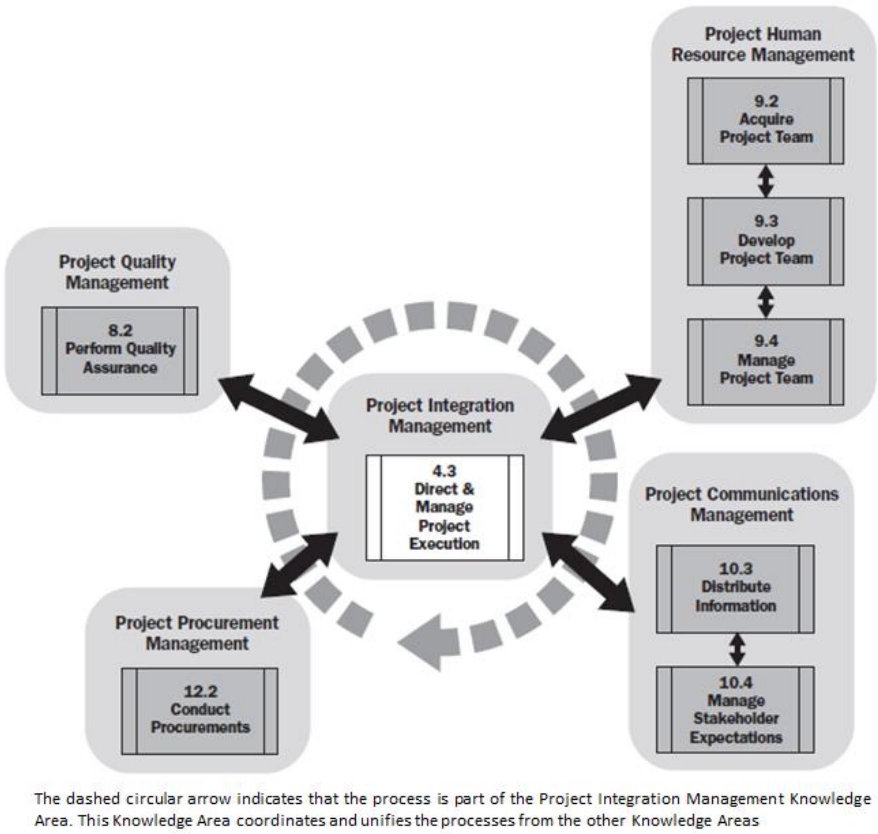


Figure 2.5: The execution process (PMBOK 2009)

2.6.4 The monitoring and controlling processes

The monitoring and controlling processes track, review and regulate the progress and performance of the project; identify any areas to which changes to the plan are required and initiate the corresponding changes (PMBOK, 2009). The processes evident are the control of cost, time, quality, scope and reporting on performance (Figure 2.6). Performance reporting corresponds to the cybernetic model of management control (the thermostat model) that consists of the following elements (Hofstede, 1978): there is a standard of performance; performance is measured at the output; the possible variance between the standard and the measured value is used for correcting the process so that the standard can be reached (Howell & Koskela, 2002c). Therefore control is reactive, only corrected after deviations from plan are evident. There appears to be no proactive means to avoid problems.

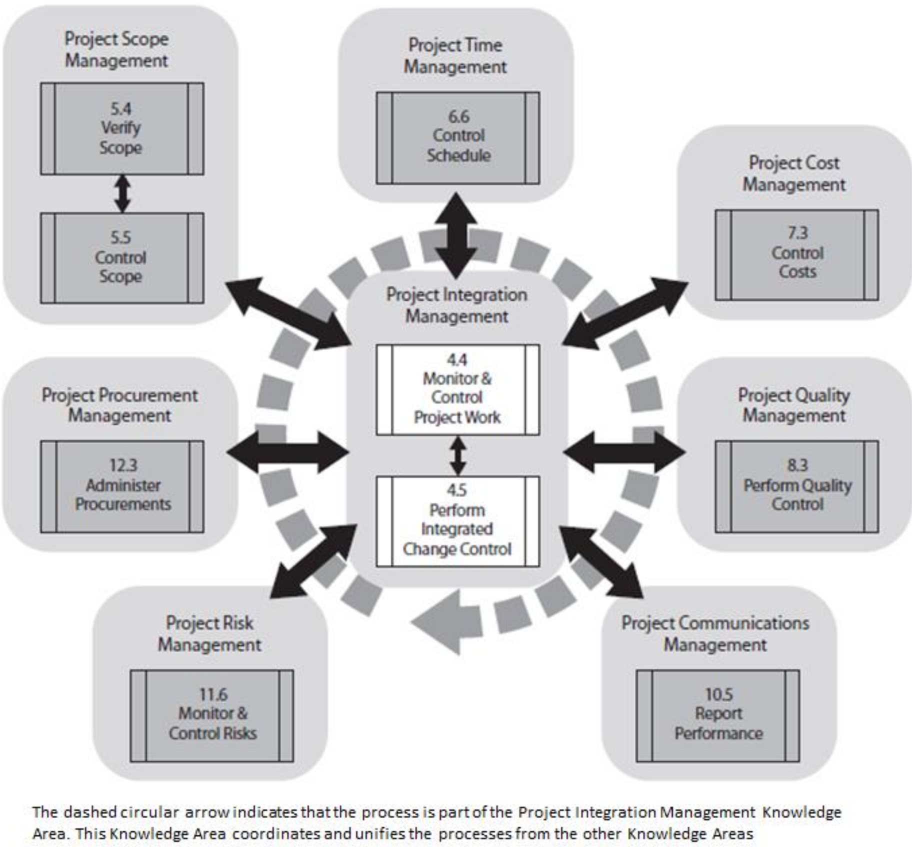


Figure 2.6: The control process (PMBOK 2009)

2.6.5 The closing processes

The closing process finalises all processes in overall Project Management Process Groups to complete the project, phase or contractual obligations. It formalises the acceptance of the product, service or result and completes the project. These processes are considered to be completed sequentially, but can overlap in some project situations.

2.7 The deficiencies of the traditional approach

The literature reveals deficiencies in the traditional approach to project management described in Section 2.6 (Laufer & Tucker, 1989; Koskela, 1992, 1999, 2001; Johnston & Brennan, 1996; Howell & Koskela, 2000; Koskela & Howell 2002a, 2002b, 2002c) which lead to frequent project failures (Kharbanda & Pinto 1996), lack of commitment towards project management methods (Forsberg et al., 1996) and a slow rate of methodological renewal (Morris, 1994).

Literature on the critiques of Project management theory, (Koskela, 1999; Howell & Koskela, 2000; Koskela & Howell, 2002a, 2002b, 2002c) suggest that it is based on three theories of management: management–as planning, the dispatching model and the thermostat model. Sections 2.7.1-2.7.3 discuss the deficiencies that have been identified in each.

2.7.1 Deficiencies in planning: "management-as-planning"

The creation, revision and implementation of plans dominate the management activity in "management-as-planning". This approach assumes a clear connection between the actions of management and outcomes of the organisation. The process and outputs of planning are not questioned and it is assumed that what is planned can be carried out. This assumption has been criticised in the literature (Johnston & Brennan 1996) since it is not generally possible to maintain a complete and up-to-date representation of the current circumstances and the plan to change them. A further criticism is the clear separation between planning and execution (Koskela & Howell, 2002a) which does not adequately correspond to organisational reality. While the advice of the traditional Project Management guidelines (PMBOK) suggests that the three functions of management form a closed loop (Figure 2.3), it is argued in the literature that the empirical evidence provides for a very different view. In practice there is evidence to suggest that there are disconnects at the critical interfaces between these functions: a weak link between the planning and execution functions in particular is evident (Howell & Koskela, 2000). As a result of this separation, the plans push tasks to execution without taking the status of the production system into account. There is a sense from the literature as a result of these aspects that the traditional approach leaves the task of management essentially uncoupled from everyday activity (Johnston & Brennan 1996).

All of these factors contribute to a function of planning which is carried out for other reasons, except for the smooth running of the execution phase. There is no transparency of information flow between planning and execution, which could help anticipate problems in execution earlier. The motivation for planning is often control and comes from outside sources: legal considerations and owners requirements, rather than from the production process. Planning becomes more about explaining what has happened, rather than constraint removal in execution, thus there is almost total degeneration of the role of this function (Laufer & Tucker 1987): the role of planning is transformed from initiating and directing action before it takes place (as suggested by theory) to influencing and regulating operations while in progress (as intended in practice) and to follow-up and status reporting (as realised in practice) (Koskela & Howell, 2002 a).

2.7.2 Deficiencies in execution: "the dispatching model"

As explained in section 2.7.1, one clear deficiency of traditional project management approach is that the planning processes dominate the scene with little offered on the execution process (Koskela & Howell, 2002a). It is not clear how and who manages the "production" of construction (Ballard, 2000) which often leads to an execution phase, characterised by delays, rescheduling and large amounts of waste, since work is "pushed" into execution assuming an unproblematic completion. Unlike in transparent processes, the production process in construction is unable to communicate with participants. Little consideration is given to the actual status of the production system and the lack of transparency is evident – it is difficult to anticipate problems in execution, interdependencies are not recognised, there is no feedback on performed activities and higher levels of improvements cannot be achieved. In addition, there is little understanding of the flow of work onsite and problems are recognised just as they occur.

The concept of *"flow"* (Section 2.2.1) is an important Lean principle which refers to achieving the optimal order of process activities, by reducing variability and irregularity (such as bottlenecks) so that material and information may move in a predictable way within the supply chain (Womack & Jones, 1996). According to the flow model, production includes processing, waiting, inspecting and transporting activities (Koskela, 1992). Processing generates the main value adding element in a production system (Shingo, 1989). All other elements of flow can be classified as non-value adding activities. Thus the aim of the production manager is to eliminate or reduce non-value adding activities while increasing efficiency of the main value-adding activity (processing) (Koskela, 1992). Bertelsen et al., (2006, p. 3) define the types of flows for construction as:

> "The flows comprise physical flows in the traditional sense, such as flow of materials and equipment, but also flow such as information, crew, space and external conditions (weather, authorities 'approvals, etc). In short: Construction Physics deals with the flow of all the prerequisites which make the process sound and it considers these flows as equally important to the soundness of the process. Construction Physics also looks at the interaction between flows, such as how the flow of materials influences the flow of space".

As a result of the deficiencies of the managing-as-planning approach discussed in section 2.7.1, execution commences on the basis of several assumptions that are incorrect. These assumptions appear to substitute the need for transparency in the processes between planning and execution. One assumption of the dispatching model, is that planned tasks can be executed by a notification of the start of the task to the executor. This assumes that the inputs to a task and the resources to execute it are ready at the time of authorisation, which often is not the case. As discussed in section 2.7.1, it is very difficult to maintain an up-to-date plan, and thus the tasks pushed by the plan often do not correspond to reality, i.e. their prerequisites in terms of other inputs, do not necessarily exist (Koskela & Howell, 2002b).

A further assumption which has been criticised is that once a task is authorised, it is thought to flow, in a linear way from the time of authorisation. It is assumed that the task is fully understood and that it can commence and be completed according to the plan once authorised. In this way, it is assumed that one way communication of information is adequate and no feedback on feasibility or real world circumstances is relevant for execution. This view has been challenged by Winograd & Flores (1986) who argue that the work in organisations is coordinated through making and keeping commitments. The commitment cycle begins with an offer or a request, followed by a promise, performance and declaration of completion. Thus action is coordinated by the commitments people make rather than by central control acting through commands. This perspective reveals two basic shortcomings of the dispatching model. Firstly, in dispatching, there should be two-way communication between the controller and the executors. Secondly, it is necessary to consider the commitment of the executor; a job will actually be started and completed only if the executor is committed to realise it (Koskela & Howell, 2002b).

As a result of the deficiencies in planning, the plans for execution are less meaningful since they are not tested against reality. This has given rise to an informal system of behaviours and management to work adequately (the Tavistock Institute, 1966) since the formal system (contracts, plans, approvals etc.) does not recognise the uncertainty of and interdependence between the operations of the building process. The informal system of management is geared towards handling uncertainty and interdependence, but it produces a climate of endemic crisis, which becomes self-perpetuating (Koskela & Howell, 2001).

2.7.3 Deficiencies in control: "the thermostat model"

The criticism of control in traditional project management theory is that it leads to negative impacts on execution, rather than correction (Koskela & Howell, 2002c). Since tasks enter the execution phase on the assumption that they can be completed which is not the case, targets are often not met. Supervisors therefore are distracted from today's and tomorrow's tasks in order to produce a historical record of yesterday's problems and a justification for what happened (Laufer & Tucker 1987). There is no room for understanding the root cause of problems in the construction process and therefore no opportunity for prevention or continuous improvement.

Some of the deficiencies of traditional project management are addressed by the Last Planner System (Ballard, 2000), which is a system for production planning and control in construction based on the Lean concepts. Section 2.8 discusses the application of the Lean concepts to the construction industry and Section 2.9 presents various techniques for production planning and control in construction, focusing in particular on the Last Planner System and the challenges which have been experienced in implementation so far.

2.8 Lean in construction

The term 'Lean Construction' was coined by the International Group for Lean Construction at its first meeting in 1993 (Howell, 1999) and refers to the application of the Lean concepts originating in manufacturing, to construction processes. Koskela (1992), served as a catalyst for research on applying the Lean concepts to construction by first introducing the idea of understanding construction as a production system (Salem et al., 2005). Koskelas (1992) report first considered the idea of applying the new production philosophy based on the concepts of the Toyota Production System (TPS) to construction. Since the 1990's, the literature reveals many examples of applying the Lean principles to construction using different tools such as the Last Planner System (Ballard, 2000), visualisation (Moser & dos Santos 2003), daily huddle meetings (Mastroianni & Abdelhamid 2003), first run studies (Ballard & Howell 1997) and poke-yoke (Milberg & Tommelein, 2003). The Last Planner System appears to be the most widely used system based on the Lean concepts in construction (Salem et al., 2005). Despite an increasing focus on the adaptation and application of Lean tools to construction since the 1990's, reports in the UK appear to suggest that the construction industry has generally been slow in taking up these ideas (Johansen et al., 2002).

The following section discusses the benefits and highlights the challenges of Lean Construction.

2.8.1 Benefits of Lean Construction

Lean Construction has the goal of better meeting customer needs while using less of everything. This is achieved by placing an emphasis on the flow and value generation view of processes in addition to the conversion view of conventional engineering and production. The flow view is crucial in production for focusing on waste elimination and in engineering the value view is highly significant (Koskela & Huovila, 1997). Four main benefits of applying Lean to construction can be established from the literature review: 1) to identify and remove waste (Koskela & Huovila, 1998; Howell & Ballard, 1994) 2) to minimise variation (Howell et al., 2001) 3) to embrace uncertainty (Howell, 1999) and 4) to promote team work (Howell, 1999).

2.8.1.1 Identify and remove waste

An important focus of Lean application is to reduce waste. Waste in construction stems from the same “activity-based” thinking (Section 2.5.4) as in mass production. This activity based thinking makes it difficult to identify waste and to see the interdependencies between these activities, making it difficult to manage dependence and variation. The seven areas of waste identified by Toyota (Section 2.2.1), can also be found in construction processes. Koskela (2004) identifies a further area of waste in construction: making-do. Making-do as a waste refers to a situation where a task is started without all its standard inputs, or the execution of a task is continued although the availability of at least one standard input has ceased. The term input refers not only to materials, but to all other inputs such as machinery, tools, personnel, external conditions, instructions (Koskela, 2004). The consequences of making-do are classified as technical and behavioral (Grosfeld-Nir & Ronan, 1998). From a technical perspective, making-do leads to an increase in processing time and variability. Increased variability leads to more work in process or longer lead times. The increased processing time leads to a decline in productivity and to more operating expenses. Increased work-in-process necessitates increase in complexity of controls. A further consequence of making do is poor quality and more rework (Koskela, 2004).

2.8.1.2 Minimises variation

Another benefit of applying the lean concepts to construction is to assure that variation in work flow is minimised and to decouple what cannot be controlled. Lean works to isolate the crew from variation in supply by providing an adequate backlog or tries to maintain excess capacity in the crew so they can speed up or slow as conditions dictate (Howell et al., 2001).

2.8.1.3 Embraces uncertainty

Lean construction embraces uncertainty in supply and employs production planning to make the release of work to the next crew more predictable. Collaboration between work crews is improved as is an understanding of the causes of variation.

2.8.1.4 Promotes team work

Lean supports the development of team work and a willingness to shift burdens along supply chains. Partnering relationships coupled with lean thinking make rapid implementation possible. Where Partnering is about building trust, Lean is about building reliability (Howell et al., 2001).

The literature also reveals some challenges that are experienced when applying the Lean concepts to construction projects which are concerned with 1) the unique circumstances of construction (Howell, 1999; Koskela, 2000; Ballard & Howell, 1998) 2) the complexity of construction projects (Williams, 1997; Bertelsen, 2003; Salem, et al., 2006) 3) activity-based approach (Miller, et al., 2003) and 4) difficulty in justifying research and training (Banik, 1999). A more detailed discussion on the challenges faced when applying the Lean concepts to construction and overcoming these challenges can be found in Appendix A.4.

As mentioned in Section 2.8, the Last Planner System is the most widely used system for production planning and control of construction projects, based on the Lean concepts. The LPS was developed by Ballard (2000) to broaden the view of the construction process by providing a better link between planning and execution and a way to cope with the critical situation of production control. The idea behind the Last Planner System, is to focus on the "last planner" on the hierarchical chain of planners at the interface to execution, so that feasible work assignments are pulled into the system rather than pushed. Tasks can only enter into the execution phase if they have met all prerequisites and it is not assumed that tasks are ready from the start of authorisation as is the case in traditional project management. The Last Planner System combines central elements of task management and flow management to address the deficiencies of traditional Project Management (Koskela, 1999).

The following section takes a closer look at the Last Planner System and identifies challenges experienced during implementation.

2.9 Production planning and control in construction

In the literature, various techniques for production planning and control in construction can be found and are briefly described below (Armor & Jardim-Goncalves, 2003):

2.9.1 The critical path method (CPM)

This is a mathematically based algorithm for scheduling a set of project activities and is used in construction for preparing proposals, managing personnel and resources, tracking delays and change orders, instituting as a basis for progress payments, and co-ordinating with subcontractors (Jaafari, 1984). However, the CPM has been widely criticised in terms of its inability to cope with non-precedence constraints and difficulty to evaluate and communicate interdependencies (Pultar, 1990; Jaafari, 1996; Choo et al., 1999).

2.9.2 The line of balance method

This involves repetitive sequences of activities such as high rise buildings, tunnels, roadways, and pipeline construction. The basis of the method is to find the required resources for each stage of construction so that the following stages are not interfered with and the target output is achieved (Harris & McCaffer, 1989). However, in large and complex projects, there is a problem to show all information on one chart especially when monitoring progress.

2.9.3 Simulation method

Since the 1960s, construction simulation has been developed as a definitive tool for resource optimisation and productivity improvement. Examples of popular tools are CYCLONE (Halpin & Riggs, 1992) and STROBOSCOPE (Martinez, 1996). However, the types of operations that can be simulated need to be cyclical or repetitive in nature and the construction industry has also been reluctant to adopt this method in their planning (Halpin & Martinez, 1999).

2.9.4 Visualisation methods

Started in mid 1990s, construction research has employed the advancement of visualisation technologies to enhance capability of communication and evaluation of the construction plans. Two major approaches including 4D CAD (3D+time) and Virtual Reality (VR) have been successfully applied to aid evaluation of physical constraints i.e. technological dependency (McKinney & Fischer, 1998; Koo & Fischer, 2000; Kähkönen & Leinonen, 2001), space (Akinci et al., 2002; Dawood et al., 2002), and safety (Hadikusumo & Rowlinson, 2002). However, the method has not been used to detect information and resource constraints.

2.9.5 Critical Chain Scheduling

Critical chain scheduling is an application of the theory of constraints (TOC) to project management (Goldratt, 1990). The critical chain method encourages a reduction of contingencies through optimistic estimation of task duration and insertion of aggregated buffers. Furthermore, the method attempts to avoid the inefficiency of multi-tasking by taking into account the limitations of resources when developing the project schedules (Herroelen & Leus, 2001).

In addition, the Last Planner System is a widely used approach for production planning and control which aims to improve the link between planning and execution and the deficiencies described in Section 2.7. The following section gives an overview of the Last Planner System and in particular looks at the challenges experienced during implementation.

2.9.6 The Last Planner System (LPS)

A large number of papers of the annual IGLC conferences over the years report the use of the Last Planner System, providing evidence that this system has been successfully implemented in a large number of projects in different countries, such as USA, Brazil, Chile, Ecuador, England, Finland, Denmark, among others (Viana et al., 2010). It also highlights the need for a focused means of planning in construction, since this industry is characterised by 1) particular complexity factors owing to industry specific uncertainties and interdependences, and 2) inefficiency of operations (Dubois & Gadde 2002).

"The Last Planner System of production control is a philosophy, rules and procedures, and a set of tools that facilitate the implementation of those procedures" (Ballard, 2000). It is a system for creating predictable and reliable workflow using a technique known as "Pull Planning" which is key Lean principle (Section 2.2). Ballard (2000) describes pull planning as "working from a target completion date backwards which causes tasks to be defined and sequenced so that their completion releases work" (Figure 2.7). Pull Planning maximises value generation and eliminates waste of over production, one of Ohnos seven areas of waste (Ballard, 2000). The Last Planner is the person or group accountable for production unit control, that is, the completion of individual assignments at the operational level (Ballard, 2000). The two main components of the Last Planner System are production unit control and work flow control.

2.9.6.1 Production unit control

The goal of production unit control is to make progressively better assignments to direct workers through continuous learning and corrective action (Ballard, 2000). The concept of continuous improvement is central to Lean thinking. The goal of continuous improvement is to strive towards perfection in processes. The principle of perfection is one of the key Lean principles (Section 2.2). The failure to use workers valuable knowledge for solving problems and continuous improvement has been identified as a further area of waste: unused employee creativity (Liker, 2004). Production unit control is focused on the co-ordination of the execution of work e.g.: construction crews and design squads. This addresses deficiencies associated with traditional project management, by emphasising the need to question the feasibility of work in the execution and test plans against reality (Section 2.7). In order to control the work at production unit level, a measurement called the PPC (Percentage Plan Complete) is used. The PPC is the number of planned activities completed divided by the total number of planned activities. By gathering data on the PPC performance, an analysis of the reasons for non-conformity can be carried out so that improvements can be made.

2.9.6.2 Work flow control

The goal of work flow control is to proactively cause work to flow across production units in the best achievable sequence and rate (Ballard, 2000), rather than assuming the work flows automatically as is characteristic of the traditional model (Section 2.6). Flow is another key Lean principle (Section 2.2.1 and 2.7.2).This focuses on co-ordinating the flow of design, supply and installation through production units (Ballard, 2000). Work flow is controlled by the lookahead process in the Last Planner System (Figures 2.7 and 2.8). The objective of the lookahead process is to form a backlog of sound work that can be executed realistically by eliminating constraints. It focuses on a time period of 3-12 weeks (depending on the project characteristics and the reliability of the planning process) and activities enter into the look ahead window approximately 6 weeks before planned execution, depending on the project type.

According to Ballard, 2000, this lookahead process aims to do the following:

- Shape work flow sequence and rate
- Match work flow and capacity
- Decompose master schedule activities into work packages and operations
- Develop detailed methods for executing work
- Maintain a backlog of ready work
- Update and revise higher level schedules as needed.

2.9.6.3 The look ahead process of the Last Planner System

The aims listed above are achieved through a number of different processes as part of the overall look ahead process in the Last Planner System (Figure 2.7). They include: activity definition, constraints analysis, pulling work from upstream production units, and matching load and capacity. Before the lookahead process is carried out, the master plan is broken down to "a level of detail appropriate for assignment on weekly work plans, which typically yields multiple assignments for each activity" (Ballard, 2000, p.3-7). Once the master plan has been broken down into suitable weekly assignments, each assignment is then subjected to a constraints analysis to determine what must be done to make it ready for execution. Only activities that can be made ready for completion on schedule are allowed to advance into the lookahead window and to advance from week to week within the lookahead window (Ballard, 2000). There is an emphasis on the creation of sound assignments before execution which contrasts to the traditional approach where tasks are assumed to be ready for completion upon authorisation. If the Last Planner is not confident that the constraints can be removed, the potential assignments are postponed to a later date.

As also mentioned above, the objective of the lookahead process is to form a backlog of sound work that can be executed realistically. Weekly work plans are then formed from workable backlog, thus improving the productivity of those who receive the assignments and increasing the reliability of work flow to the next production unit.

PROJECT: Pilot	5 WK LOOKAHEAD				
ACTIVITY	1/13/97 M T W T F S	1/20/97 M T W T F S	1/27/97 M T W T F S	2/3/97 M T W T F S	NEEDS
Scott's crew					
"CUP" AHUs-10 CHW, 2 HW	X X X X X	X X X X X	X X X X X		CHW delivers 1-8-97 thru 1-13. HW delivers 1-20.
Punch, label, & tag AHUs			x x x		Materials on site
Ron's crew					
DI Steam to Humidifier	x x x				Materials on site
DI Steam Blowdown	x x				Check material
DI Steam Cond. to coolers (13)		x x x x x	x x x x x	x x x	Material on site
Charles' crew					
200 deg HW 1-"H"	x x x				Matl delivery 1-8-97
200 deg HW 1-"B" & 1-"D"		x x x x x	x x x x x		Release matl for 1-15-97
1st flr 200 deg HW guides & anchors	x x x x x		x x x x x		Material on site. Need West Wing flr covered.
Richard's crew					
2-"A" HW & CHW	x x x x x				Control valves for added VAV coils
CHW in C-E-G tunnels	x x x x x	x x x x x	x x x x x		Need tunnels painted & release materials
Misc FCUs & cond. drains in "I", "J", & "K" 1st flr		x x x x x	x x x x x		Take off & order materials
Punch, label & tag		x x x x x	x x x x x		Material on site

Construction Lookahead Schedule[14]

Figure 2.7: The lookahead window in the LPS, Ballard (2000)

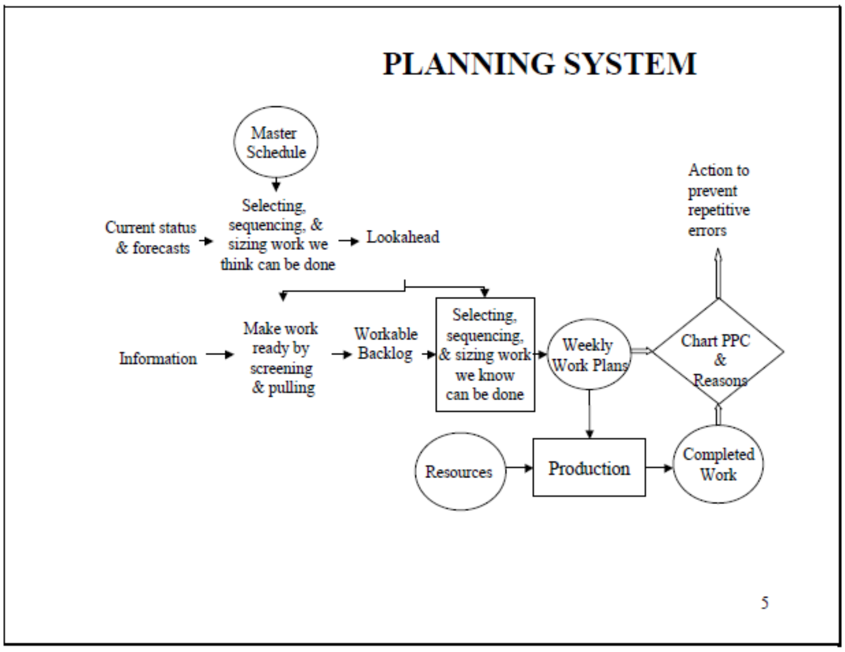


Figure 2.8 The Last Planner System with lookahead process highlighted, Ballard (2000)

2.9.7 Barriers to Last Planner implementation

A literature review on some of the reports on past implementations of Last Planner was carried out as part of this research. As part of the review, over 83 construction projects where the LPS was implemented were focused on (a survey was carried out on these projects the results of which are presented in Table 2.1: Aslesen & Bertelsen, 2008; Alsehaimi et al., 2009; Conte 1998; Kalsaas et al., 2009; Friblick et al., 2009). The projects cover a variety of different types of construction, from low and high rise buildings, heavy industrial projects, heavy civil construction projects, light industrial construction, educational facilities to shipbuilding. Evidence of the positive effects of Last Planner implementation is provided through notable improvements in PPC and lead time on projects (Table 2.1). While it is possible to measure the positive effects of LPS, the experiences gathered during implementation also provide valuable insights into some of the challenges faced when implementing the system. Some of the challenges noted were:

2.9.7.1 Weak communication and transparency

While the LPS required regular meetings with the project team to plan work and visualise important key information on post-its, it tended to lack a more visual perspective at the actual area of work. Alarcón et al., (2005) describes weak communication and transparency as a barrier to progress. Since with the Last Planner system, information is exchanged and discussed in regular meetings, it is often not possible for all participants and construction workers to be aware of important details if they were not present at the meeting. A lack of good communication was also highlighted as a barrier on the Saudi Arabia projects, (AlSehaimi et al., 2009), which led to misunderstandings and non-compliance.

2.9.7.2 Minimum involvement of construction workers

Minimum involvement of construction workers was perceived to have been a barrier on some projects; especially those carried out in Sweden, (Friblick et al., 2009). Also, the inadequate involvement of sub-contractors in the Last Planner process hindered its effectiveness.

2.9.7.3 Inadequate preparation and training of participants

In some cases, a lack of preparation and training before implementation meant there was little understanding of what the system was and why it was needed. In the Chilean construction projects, (Alarcón et al., 2005), one barrier was the lack of training of those involved in the use of LPS and the lack of understanding of LPS concepts. In the Last Planner projects in Sweden (Friblick et al., 2009), the lack of knowledge of what the system is and how it works on behalf of construction workers was a major obstacle.

2.9.7.4 Lack of role definition

Other barriers were experienced as a result of a lack of role definition. In some cases, important project participants did not feel obligated to work according to the terms of Last Planner. In the Seoul and Busnan Subway projects, (Kim & Jang, 2005), the foreman was not adequately involved in the planning and scheduling process. Other difficulties were experienced as a result of team structure. For example, work was structured and scheduled not by engineers in a construction team but by those in a project control team. Problems arose since engineers in the project control team were not very aware of site constraints such as the progress of pre-requisite work. The role of top management and commitment to promises are also mentioned as critical success factors for implementation during the construction projects carried out in Saudi Arabia, (AlSehaimi et al., 2009).

2.9.7.5 Information not adequately used

Information was collected in meetings but it was found in the Chilean projects, (Alarcón et al., 2005) that this information was inadequately used and administered to create a learning cycle. In the Havlimyra case (Norway), (Kalsaas et al., 2009), the information was not fully adequate as it was felt that there was a missing link between the production schedule and the phase schedule (in order to remove constraints and create a backlog of workable tasks). This raises the question of how information can be better managed and linked during LPS implementation, so that constraints are removed effectively.

2.9.7.6 Lack of time for implementing improvements

Lack of time for implementing improvements was also mentioned as a barrier during the Chilean projects, Alarcón et al., (2005). It is difficult to create time for improvements during construction so focusing on less complicated and feasible solutions, that save more time than they cost is necessary.

2.9.7.7 Lack of integration of production supply chain

At the construction of a library in Sao Paulo state, (Conte, 1998) the most difficult part of implementation of the LPS was linking the areas of supply, execution and integrated financial control. In the Havlimyra case (Norway), (Kalsaas et al., 2009), a difficult challenge was the dysfunctional relationship between the architect, general contractor and the owner which made co-operation difficult. There was also insufficient support from the general project manager for the lookahead process.

Table 2.1: Overview of Last Planner implementations

	PROJECT TYPE	PROJECT DESCRIPTION	WHAT WAS ACHIEVED?	HOW WAS THIS ACHIEVED?	BARRIERS	IGLC PAPER
1	**Chilean construction projects**	Database of 77 projects focusing on LPS implementation	PPC improved from 63% to an average of 71 % within a 3 year period.	1) Through the learning process 2) Experience accumulated by the GEPUC team 3) Adaption of support tools 4) Top management involvement	1) Poor use of info. 2) Lack of time and training 3) Organisation 4) Lack of self criticism 5) Inadequate administration 6) Inadequate communication	ASSESSING THE IMPACTS OF IMPLEMENTING LEAN CONSTRUCTION, IGLC 13, 2005.
2	**Two construction projects in Saudi Arabia**	2 LPS projects carried out at educational facility in Saudi Arabia.	Increase of PPC in both projects from 69% and 56% in the first week to 86% and 82% in the last week.	Implementation in four phases - an evaluation being made after each. PPC monitored and reasons for non-completion gathered.	1) Management support 2) Committment 3) Administration 4) Communication	LAST PLANNER SYSTEM: EXPERIENCES FROM PILOT IMPLEMENTATION IN THE MIDDLE EAST, IGLC 17, 2009.
3	**Construction of a library in Sao Paulo State**	The construction of a library in the city of Campinas.	Ontime completion. Reduced costs by 42%.	Weekly preparation of medium term schedule (lookahead). Elaboration of weekly work plan with exact details. New function for foreman.	1) Lack of integration of all areas	LAST PLANNER, LOOK AHEAD, PPC: A DRIVER TO THE SITE OPERATIONS, IGLC 6, 1998
4	**Shipbuilding project**	LPS project in Norwegian shipyard.	Throughput improved.	Mapping of shipyards organisational challenges. Formation of "change group". Focused weekly work plans and lookahead plans.	1) Standard not fully suitable 2) Interpretation unclear	LAST PLANNER IN A SOCIAL PERSPECTIVE – A SHIPBUILDING CASE,IGLC 16, 2008,
5	**Havlimyra case (Norway)**	LPS project by general contractor, Skanska.	A further improvement in PPC of 65% in 2009 is expected	Active involvement of technical sub-contractors. Measuring of PPC and a more focused approach to solving issues.	1) Difficult relationships 2) Inadequate information	IMPLEMENTATION OF LAST PLANNER IN A MEDIUM-SIZED CONSTRUCTION SITE, IGLC 17, 2009.
6	**Last planner projects in Sweden**	LPS survey on construction projects in Sweden.	Amount of time spent on non value adding activities decreased.	The survey didn't go into details about actual implementation	1) Lack of involvement 2) Lack of training and communication	PROSPECTS FOR IMPLEMENTING LAST PLANNER IN THE CONSTRUCTION INDUSTRY, IGLC 17, 2009.

From the examples of Last Planner implementation analysed (Table 2.1), it appears that the barriers experienced during the LPS implementation, stem from two key sources: one is a lack of commitment which results from the improper implementation of the system and the second is concerned with a lack of clear communication and adequate use of information. The barriers stemming from the latter indicate a process and environment that lacks transparency (Section 2.3.1). While the lean principles of Value, Value stream, Flow, Pull, and Perfection can be applied by using the Last Planner system, the literature (Alarcón et al. 2005; AlSehaimi et al., 2009; Kalsaaas et al., 2009) also reveals that barriers in the process of implementation are experienced due to a lack of transparency. Visual Management (Section 2.4-2.5) is an important concept for making information transparent and in turn improving communication and use of information. This work argues that by using Visual Management, transparency in the production planning and control of projects can be improved.

2.10 Summary and discussion of literature review

In this section, a summary and discussion of the findings from the literature are presented. This chapter discussed the importance of the principle of transparency (Section 2.3) and the significant role Visual Management plays in creating it (Section 2.4-2.5). The problems faced in the planning and control of construction projects were discussed and it was established that the nature of the traditional approach to Project Management in construction contributes to a lack of transparency in the overall process (Section 2.5.4 and 2.7). It was explained how important concepts from other alternative approaches such as Lean Production can benefit construction projects (Section 2.8-2.9). Three main findings from the literature can be summarised as follows and are discussed in Section 2.10.1-2.10.3: 1) there is a need for broader solutions for Visual Management application in construction 2) there is a need for transparency in the construction process and 3) Visual Management can be applied to create transparency in production planning and control.

2.10.1 There is a need for broader solutions for VM in construction

It is evident from the literature review that examples of VM application to construction tend to focus on the application of individual tools in an isolated way to parts of processes, leading to poor implementations of the Lean concepts and Visual Management (Tezel, 2011; Picchi, 2004). While these isolated applications provide valuable contributions, it is argued that a more comprehensive approach could lead to a deeper understanding of Visual Management in construction and broader results. Tezel (2011, p. 96) highlights, Visual Management is not being applied as part of an overall system on sites:

> "the wider discussion needs to show different Visual Management practices and their connections on a construction site and /or company in a holistic manner".

Much of the literature on the TPS, recognises that the application of individual tools and techniques to isolated areas of an organisation or process does not contribute to its effective functioning (Appendix A.1). It is also important to include the participation of all levels in the hierarchy and to introduce the principles not only in the shop-floor level but also in the company culture and organisational structure (Özbayrak & Papaadopoulou, 2004).

A broader approach is essential for Visual Management application, considering the interrelationship of all practices in order to improve overall levels of quality, productivity, integration and waste reduction over all functional areas and along the supply chain (Boyle, et al., 2010). Broader Visual Management solutions which facilitate a holistic view when optimising processes are needed to:

2.10.1.1 To truly understand waste

By focusing on the whole system, a true perspective of waste in processes is established. For example, based on Taylor's view[3] it is unproductive if a machine is not running or if there is some waiting time. In contrast, based on a holistic view of processes that are directly linked to customer demand: it might be better to leave a machine idle, or rearrange worker capacity if it

[3]Frederick Taylor's "scientific management" at the beginning of the 20th century focused on eliminating every second of inefficient motion.

meant reducing producing products that are not required by the customer (over-production). This is illustrated in Figure 2.9. If the whole process is observed from the moment a product is ordered by the customer until it is received by the customer, a better understanding of the value added time of this process (green) compared to the non-value added time (white) is achieved. This could indicate that it would be better to focus on optimising other areas of the process (rather than the value added processes) to achieve a greater reduction in waste.

A holistic view achieved through broader solutions, enables a better understanding of value, of the flow of work and how to create pull and truly eliminate waste. Without a holistic view of the overall process, it is difficult to see the opportunities for reducing waste by getting rid of non-value added steps and to determine what effect these opportunities might have on the whole process (Figure 2.9).

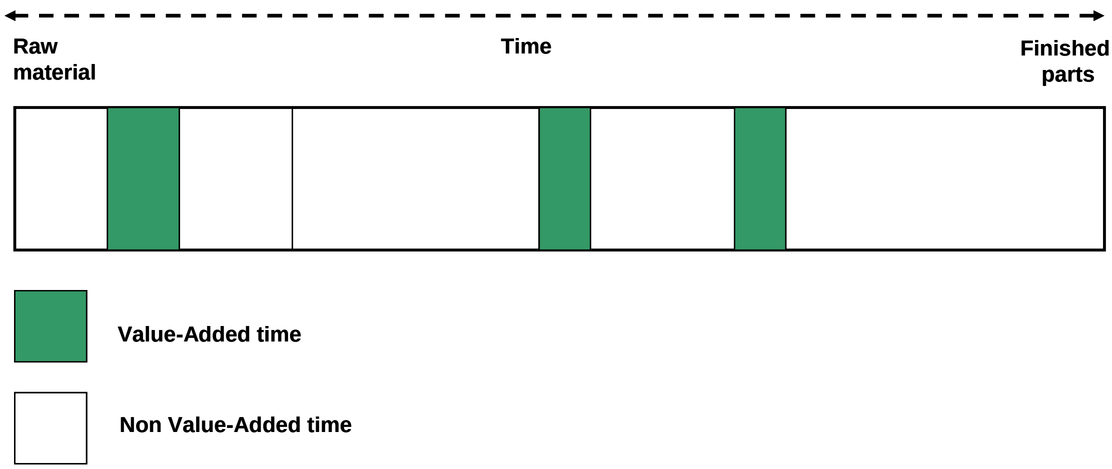


Figure 2.9: A holistic understanding of waste

2.10.1.2 Involvement of participants at all levels

Broader solutions involve process participants at all levels, encouraging communication and creating a continuous improvement culture that extends beyond individual processes. Toyotas continued success at implementing the tools of the TPS stems from a deeper business philosophy and holistic strategy, based on its understanding of people and human motivation (Liker, 2004, p.6). Ultimately, Toyotas success is based on its ability to use these tools and techniques in a holistic way, to cultivate leadership, teams and culture, to devise strategy, to build supplier relationships and to maintain a learning organisation (Liker, 2004, p.6).

2.10.2 Challenges in achieving a holistic view through broader solutions

The holistic system, as applied by Toyota, is for many companies easier said than done. According to the literature (Atkinson, 2010; Hines et al., 2008; Sim & Rodgers, 2009, Ransom, 2001) less than 10 per cent of UK organisations have accomplished successful Lean implementation, despite the huge influence of the Lean movement. Furthermore, it can be noted that few manufacturers have managed to imitate Toyota successfully – even though the company has been extraordinarily open about its practices (Spear & Bowen, 1999). The failure of lean in many organisations has led researchers to question lean's applicability across all industries and why full adoption has not occurred for many. Cooney (2002), for example, highlights that Lean may not be universally desirable and provides examples from luxury automotive and speciality manufacturing where craft and batch remain viable approaches to production. This work argues that the problem lies elsewhere: in the inability of organisations to achieve a level of holistic thinking and strive for continuous perfection that is necessary for a lean transformation.

2.10.2.1 Misunderstanding of Lean systems approach

In the literature, while there is a growing appreciation of the importance of holistic thinking when applying the Lean concepts, there is evidence to suggest that organisations fail to demonstrate the appreciation of a Lean systems approach and its extendedness in practice, which has led to less than universal practitioner success in achieving anticipated outcome performance from Lean implementation efforts (Boyle et al., 2010). In addition, it has been found that often organisations fail to view lean as a continuous and never ending process (Saurin et al., 2011; Lewis, 2008; Atkinson, 2010), that is a fundamental part of day to day operations and not just carried out in "spurts" as referred to by Fujio Cho, past President of the Toyota Motor Corporation .

Liker (2004) supports this argument by recognising that organisations tend to confuse “Lean thinking” with the application of a tool or a set of tools in practice, with companies focusing heavily on individual concepts such as 5S and just-in-time without understanding lean as an entire system, which must permeate an organisations culture (Liker, 2004) (an example of this can be found in Appendix A.2). Liker (2004) points out that most companies are just focusing on implementing tools at the process level, without considering all aspects of the Lean system (Figure 2.10). It is predicted that by doing so, these companies will continue to lag behind those companies that adopt a true culture of continuous improvement. Spear & Bowen (1999) also present this misconception in their work, indicating that visitors to Toyotas plants actually confuse the tools and techniques they observe on those plant visits, with the system itself. According to the authors this makes it impossible for them to resolve an apparent paradox of the system – namely, that activities, connections and production flows in a Toyota factory are rigidly scripted, yet at the same time Toyotas operations are enormously flexible and adaptable (Spear et al., 1999).

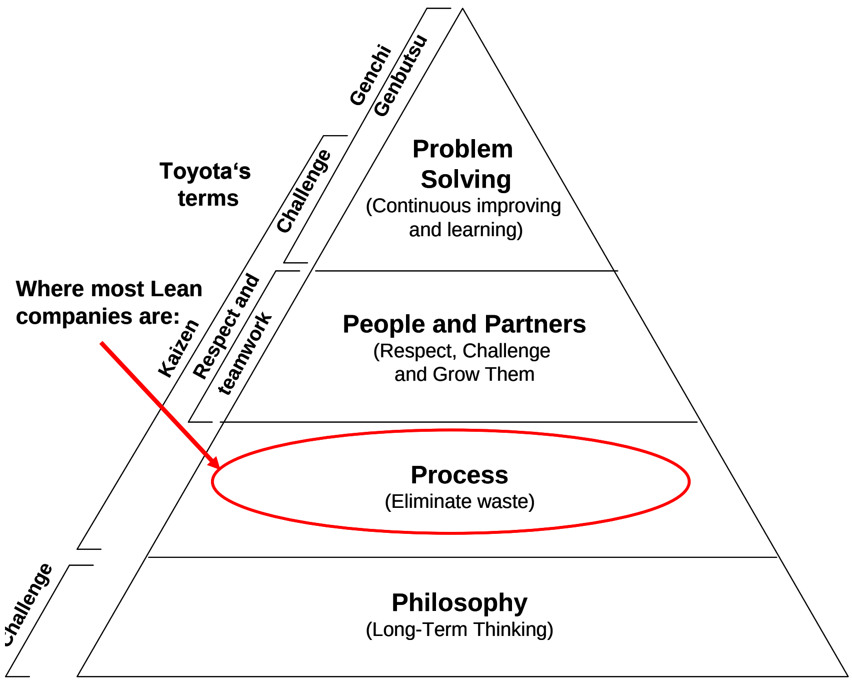


Figure 2.10: Misunderstanding of Lean application (Liker, 2004)

Despite the difficulties in achieving such a holistic approach, the literature demonstrates a growing appreciation of its importance when implementing Lean (Özbayrak et al., 2004).

2.10.3 There is a need for transparency in the construction process

The principle of transparency plays a key role in enabling a holistic view of the construction process. As discussed in Sections 2.3 and 2.4, the principle of transparency and the use of Visual Management to create transparency, play a significant role in achieving a holistic view of the process. In construction, the deficiencies associated with the traditional approach to project management have been heavily criticised for contributing to a lack of transparency and hindering effective communication between organisations involved in the procurement process. These deficiencies, occurring as a result of assumptions made in the traditional model (Section 2.7), are disguising the need for transparency between the functions of planning, execution and control. There is evidence in practice however to show that assumptions such as a) uncertainty is low, b) relationships between activities are simple and sequential, c) activity boundaries are rigid, d) control against standards will assure outcomes and e) production management is not a concern of project management (Howell & Koskela, 2000) are incorrect.

These assumptions result in the creation of plans that are not tested against reality, causing work to be pushed into execution without taking the current status of the production system into account. More meaningful, lower level plans are needed that can be adapted according to the current status of the production system. Without transparency in processes however, it is difficult to observe the current status of the production system. In addition, one way communication occurring to execute plans is not sufficient, since no feedback is allowed on the feasibility of those plans. Two-way communication is needed to create sound commitments (Winograd & Flores, 1986) but this is only feasible if there is transparency of information and structures in place to support the two-way communication process.

This work argues that there is a need for transparency to deal with the uncertainty that exists in construction, to better understand the complicated relationship between activities and interfaces, thus anticipating and resolving problems earlier. Transparency of the construction process is necessary for three main reasons: 1) to enable a holistic view of the entire process and to implement flow 2) to support continuous improvement and 3) to build trust and motivate process participants.

2.10.3.1 To facilitate a holistic view of the entire process and to implement flow

Alternative models to the traditional model see production as a system composed of 'operation flows' (machine or man) and 'process flows' (Gilbreth 1922, Shingo 1989, Koskela 1992). To observe the construction process as a flow of activities and to achieve a holistic view of the overall process, a high capability of handling vast amounts of information is required. This is in part due to the fact that many factors that before were considered unimportant come to the surface and become very important to the production effectiveness. This surplus information may be quite off-putting for construction managers, as they may be unable to understand and control this additional information. Thus the flow of information must be easily understood, or construction managers and workers may prefer to return to the traditional conversion model view as soon as they are exposed to the enormous amount of information related to the flow model. In order to overcome the difficulties associated with this additional information, production activities in construction must become more transparent. The transparency of information is also important to facilitate a common understanding among process participants of the construction process, so that the "right" activitity is carried out. Common understanding has been proposed as an important additional flow in construction which needs to be defined, developed and nurtured across the project execution (Pasquire, 2012).

The application of the principle of transparency is a key point to make viable the flow model (dos Santos et al., 1998). Achieving a holistic view of the entire process and considering the interrelationship of the individual parts, is a key step when striving to achieve a Lean organisation (Section 2.10.1).

2.10.3.2 To support continuous improvement

In order to identify higher level of improvements and understand what effect those improvements have on the overall process, it is necessary to make the process and information flow between the different interfaces transparent, so that a clear understanding of the order of work is achieved (Figure 2.11, right side). This gives rise to more meaningful optimisations than those typical of the traditional model, where improvements are aimed at the minimisation of cost of each of the individual conversion activities (Koskela, 1992) and an explanation of what has happened, rather than anticipating and preventing what could happen.

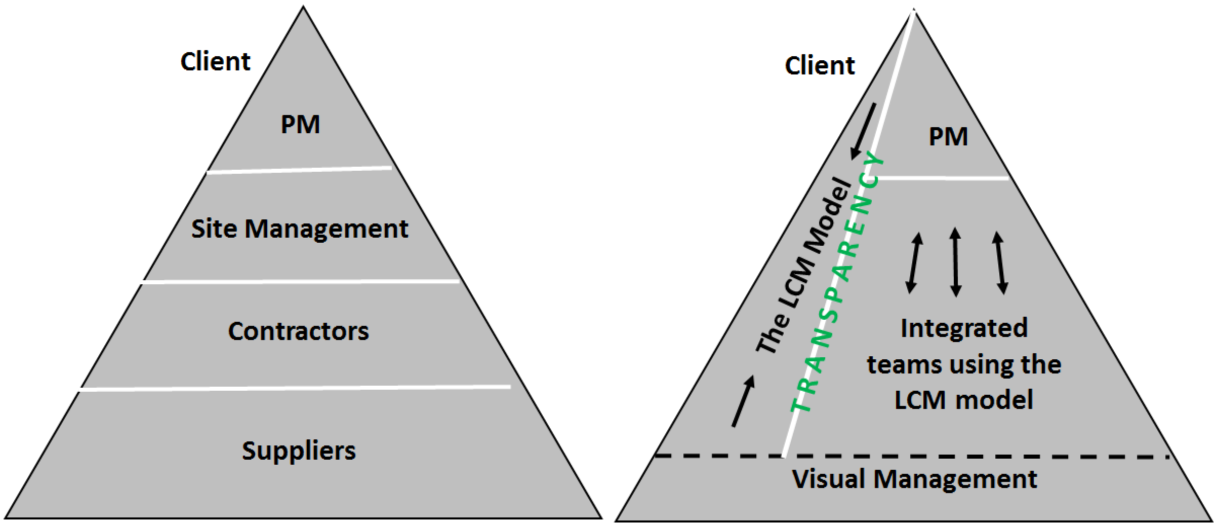


Figure 2.11: Functional orientated structure of projects (with little transparency and one-way communication, left) versus process orientated structure (using Visual Management to open up interfaces, create transparency and support two-way communication, right).

2.10.3.3 To build trust and motivation

Another reason why the principle of transparency is needed in construction is to support change by building trust and motivation. Construction companies usually have few visual mechanisms to inspire, instruct or motivate workers to carry out their jobs more effectively, efficiently and safely (dos Santos et al., 1998). A construction project is a complex organisation that is subject to frequent change and challenging times. This situation requires a different approach to management and planning, which is aimed at motivating and maintaining trust through volatile times. Transparency is important to deal with the fluctuations and complexity associated with construction projects as it is essential for maintaining trust: by being clear on what information is gathered and how decisions are being made (Crumpton, 2011). It is crucial that the trust and confidence of all parties in the construction project is maintained. Latham (1994) identified a lack of trust between organisations in construction as being a major barrier to improving its performance. By communicating even bad news in a transparent way, emotional uncertainty can be kept from creating more negative actions (Crumpton, 2011). Transparent communication on decision making helps to reduce uncertainty, which could otherwise lead to negative action.

The principle of transparency can also be applied to enable a clear understanding and alignment of individual goals with an organisation's over-arching strategy which is fundamental to driving the execution of that strategy. Research shows that organisations lose forty percent of the potential financial value of their strategies due to poor performance and talent management of their employees (Mankins & Steele, 2005). Unless employees are motivated, the alignment of organisational and individual goals will not optimise the organisation's overall performance (Sirota et al., 2005). It is critical then, to understand what will motivate an individual to achieve the goals that contribute to the execution of the organisation's strategy. Berggren (2007) argues that transparency within an organisation reduces inefficiencies in strategy execution, and is a key factor in attracting and retaining high performers in the labour market.

In summary, the principle of transparency is important for construction for three main reasons: 1) to achieve the level of understanding of the entire process that is needed to implement flow and identify critical interdependencies 2) for the definition of higher levels of improvements and 3) to motivate and create trust among participants. It also stimulates informal contact between the different interfaces, supporting the recognition of interdependencies between sub processes and initiating discussions on the consequences of actions. It promotes well rounded decision making and builds trust, by providing clear insights into matters that are relevant to all parties involved and reduces emotional uncertainty. It promotes self-management and leads to the early recognition and solution of problems.

2.10.4 The downside to transparency

While many authors recognise positive effects of transparency such as the access to the expertise, experience, stored knowledge of another (Hansen, 1999), thereby creating the potential to increase the quantity and quality of knowledge transfer (Argote et al., 2000), shared understanding (Bechky, 2003), acceleration of organisational learning curves (Adler & Clark, 1991, Pisano, 1994), a downside to the principle is also recognised. There are two main negative effects of the principle of transparency to be found in the literature: 1) using transparency to serve personal interests and in some cases transparency in operations could lead to a 2) reduction in overall worker performance.

2.10.4.1 Serving personal interests

Transparency is thought to be used as a weapon to serve personal interests (Thorne et al., 2012). According to Thorne et al., (2012), the functions of the narratives “light and dark”, the “seen and unseen” the visible and the invisible” is to validate the supremacy of one economic/ideological position over another (Thorne et al., 2012).

2.10.4.2 Reduction in worker performance

Bernstein (2012) argues that transparency of processes at operational level, could also reduce worker performance rather than improve it. In his study on the implications of transparent organisational design on worker productivity at a mobile manufacturer in China, Bernstein (2012) identified the notion of the transparency paradox whereby maintaining observability of workers may counter intuitively reduce their performance by inducing those being observed to conceal their activities through codes and other costly means. It was noted during Bernstein’s (2012) study that the operators went to great lengths to hide their most innovative techniques from management so as not to “bear the cost of explaining better ways of doing things” or alternatively “get in trouble” for doing things differently (Bernstein, 2012, p. 188).

New workers were trained by peers how to act whenever a customer, manager or line leader came around. When observed, the new workers were trained in the art of appearing to perform the task the way it was "meant" to be done according to the codified rules posted for each task. When unobserved, the new workers were shown "better ways" of accomplishing tasks, and "a ton of little tricks that kept production going" and enabled "faster, easier and / or safer production" (Bernstein, 2012, p. 188). Many examples of this type of behaviour were noted such as carrying out a quality check on two phones at the same time (instead of a quality check on one) and allocating varying numbers of workers to different work stations to reach daily targets etc. The transparency created by making the work process observable appeared to keep operators from getting their best work done rather than enabling performance.

A similar type of hiding behaviour is reflected in a different way by Welch & Rothberg (2006). The authors (Welch & Rothberg, 2006, p. 938) question the effect of a company's strategy being completely transparent:

> "Do managers, with full knowledge that their strategy will be "open and notorious," water down or temper their strategy because of a concern that it might be misinterpreted, used to the advantage of competitors, or worse – if it fails – the managers might be identified as the provider of a failed strategy? Does that, in turn, cause managers to choose strategies which "regress to the mean" so they will not be blamed, in retrospect, if matters go wrong? Stated another way, does this add to the pressure for management to be risk averse, given the requirement for openness and transparency?"

While the literature does reveal some downsides to transparency (Roy, 1952; Dalton, 1959; Burawoy, 1979; Hamper, 1986; Welch & Rothberg, 2006; Bernstein, 2012) the value and usefulness of the principle is not challenged by the authors. Instead, they merely raise the question of how much transparency is good and necessary and what other factors motivate the need for transparency, other than improved communication and common understanding.

2.10.5 VM creates transparency in production planning and control

The Last Planner System was designed to broaden the view of the construction process by providing a better link between planning and execution and a way to cope with the critical situation of production control. However, as discussed in Section 2.9.7, two recurrent barriers experienced during LPS implementation were a lack of transparency and weak communication leading to an inadequate use and flow of information which is needed both for daily operations and the overall interaction between the different roles involved (Alarcón et al., 2005; AlSehaimi et al., 2009; Kalsaas et al., 2009; Conte, 1998). Visual Management (Section 2.4) is an important concept for making information transparent and in turn improving communication and use of information. This work argues that by using Visual Management, transparency in the production planning and control of projects can be improved with positive effects on communication and the decision making process.

2.10.6 Conclusions from the literature review informing this research

In summary, the main conclusions from the literature review informing this research are as follows:

2.10.6.1 Lack of broader Visual Management solutions

There is a lack of broader Visual Management solutions existing, to apply to construction projects in order to create transparency and clarity in production planning and control of the execution process (Section 2.10.1).

2.10.6.2 Lack of transparency in construction projects

The principle of transparency is poorly demonstrated in construction projects (Section 2.10.3). There is a need to improve transparency in execution since it is evident from practice that a) work cannot be completed as planned without taking real world circumstances into consideration and b) that work does not flow automatically from the time of authorisation. More meaningful, lower level plans need to exist and become more transparent, as current plans are not tested against reality (Section 2.7.1-2.7.2). The principle of transparency in the construction process is essential to support a holistic view of the process so that waste is clearly identified, higher levels of improvements are achieved, communication is improved and trust among all parties is built (Section 2.10.3).

2.10.6.3 Lack of transparency in production planning and control

There is also a need to improve transparency and communication in current systems of production planning and control in construction such as the Last Planner System (Section 2.9.7 and 2.10.5).

2.11 Chapter summary

This chapter discussed the relevant literature for this research. First, the Lean concepts were presented as the origins of this research work. The principle of transparency was presented as an important element of Lean application and Visual Management was presented as a key approach used to create transparency. Visual Management application in construction was discussed, showing that many examples found in construction are based on the Lean concepts. The problem of a lack of transparency in the construction process was expanded on, explaining how the traditional conversion model of understanding production systems as a set of conversions of inputs to outputs has contributed to a lack of transparency in the construction process. Following this, the need for the principle of transparency in construction was explained. Finally, the application of the Last Planner System for production planning and control in construction based on the Lean concepts was presented. The chapter concluded with a discussion on the main findings of the literature review which are that 1) there is a need for broader solutions for Visual Management application in construction 2) there is a need for transparency in the construction process and 3) Visual Management can be applied to create transparency in production planning and control.

The next chapter presents and analyses the research method applied for this work.

3 Research method

3.1 Introduction

The basic purpose of scientific research is theory, i.e. to understand and explain phenomena (Kerlinger, 1977). A theory presents a systematic view of phenomena by specifying relations among variables, with the purpose of explaining or predicting (Kerlinger, 1977). The research method represents the logic of development of the research process used to generate theory (Kerlinger, 1979). Research method refers to the procedural framework within which the research is conducted (Remenyi et al., 1998).

This investigation adopts a Design Science approach. Section 3.3-3.4 presents an overview of Design Science and a justification for why this approach was chosen to guide this investigation. Section 3.5 presents the outcomes and steps taken during a Design Science investigation and Section 3.6-3.10 explains the research process.

3.2 Choice of method

When carrying out good quality research, it is important that certain criteria are met (Buckley et al., 1975):

- it be an orderly investigation of a defined problem;
- appropriate scientific methods are used;
- adequate and representative evidence is gathered;
- logical reasoning, uncoloured by bias, is employed in drawing conclusions on the basis of the evidence;
- the researcher is able to demonstrate or prove the validity or reasonableness of their conclusions;

- the cumulative results of research in a given area yield general principles or laws that may be applied with confidence under similar conditions in the future.

There are many factors to consider when choosing an appropriate research method, with the topic to be researched and the specific research question being primary drivers (Remenyi et al., 1998). The choice of research method varies depending on the aim of the research and the scientific discipline. Van Aken (2004) determines 3 categories of scientific disciplines and what their missions are:

- The *formal* sciences, such as philosophy and mathematics: the formal sciences are ‘empirically void’. Their mission is to build systems of propositions whose main test is their internal logical consistency;
- The *explanatory* sciences, such as the natural sciences and major sections of the social sciences. The mission of explanatory science is to describe, explain and possibly predict observable phenomena within its field. Research should lead to ‘true’ propositions, i.e. propositions which are accepted by the scientific forum as true on the basis of the evidence provided. The typical research product of explanatory science is the causal model, preferably expressed in quantitative terms; and
- The *design* sciences, such as the engineering sciences, medical sciences and modern psychotherapy. The mission of design science is to develop knowledge for the design and realisation of artefacts, i.e. to solve *construction problems*, or to be used in the improvement of the performance of existing entities, i.e. to solve *improvement problems* (Van Aken, 2004, p. 224). Architects and civil engineers deal predominantly with construction problems while medical doctors and psychotherapists deal mainly with improvement problems.

This research aims to solve a practical problem in construction rather than to explain a particular phenomenon and is within the scientific discipline of the design sciences. Section 3.4 discusses in more detail why the Design Science approach was adopted for this research work. The following section presents the Design Science approach, its outcomes and the necessary steps to be taken when conducting a Design Science research study.

3.3 The Design Science approach

Various authors (March & Smith, 1995; Lukka, 2003; Hevner et al., 2004; Van Aken, 2004; Venable, 2006) describe Design Science as a research approach applied to develop innovations that solve an existing problem in practice and which also make a contribution to knowledge. Lukka (2003) refers to Design Science as a research approach for producing innovative constructions, intended to solve problems faced in the real world and by that means, to make a contribution to the theory of the discipline in which it is applied. Venable (2006) argues that Design Science is an inventive problem solving activity which focuses on developing and producing artefacts and artificial systems with desired properties. March & Smith (1995) refer to Design Science as attempting to create things that serve human purposes and Henver et al., (2004) describes Design Science as being a rigorous process to design artefacts to solve observed problems, to make research contributions, to evaluate designs and to communicate the results to appropriate audiences.

The Design Science approach originates in the field of Information Technology (March & Smith, 1995; Lukka, 2000; Vaishnavi & Kuechler, 2007). It has been widely used in the technical sciences, mathematics, engineering and clinical medicine (Kasanen et al., 1993; Peffers, et al., 2007) and has become an important activity in fields like Architecture, Engineering and Urban Planning. In construction, some examples of Design Science studies that have been carried out are by da Rocha (2011); for developing a framework to be used in defining customisation strategies for housing and Rooke (2012); for the development of guidelines for improving way finding in hospital environments. Other examples include those carried out by Barker et al., (2004) who focuses on the development of a time compression model for construction projects and a study carried out by Oyegoke (2011) focusing on highlighting the need for constructive research and illustrating this need through the development of a Specialist Task Organisation (STO) procurement approach. This is used as a demonstrative example to show the rigour and application of the Design Science research approach. As is the case in these examples, rather than producing general theoretical knowledge, design scientists produce and apply knowledge of tasks or situations in order to create effective artefacts (Van Aken, 2004).

The core features of the Design Science approach require that it (Lukka, 2003):

- focuses on solving real-world problems;
- produces an innovative artefact meant to solve the initial real-world problem;
- includes an attempt for implementing the developed construction and thereby a test for its practical applicability;
- implies a very close involvement and co-operation between the researcher and practitioners in a team-like manner, in which experiential learning is expected to take place;
- is explicitly linked to prior theoretical knowledge; and
- pays particular attention to reflecting the empirical findings back to theory.

A Design Science study is experimental by nature: the developed and implemented new artefact should be regarded as a test instrument in an attempt to illustrate, test, or refine a theory, or develop an entirely new one (Lukka, 2003). The Design Science research approach is based on the belief, brought from the pragmatist philosophy of science that by a profound analysis of what works (or does not work) in practice, one can make a significant contribution to theory (Lukka, 2003).

The following section presents the justification for the choice of this research approach.

3.4 Justification for the choice of research method

Typically, research in construction management has followed a descriptive and explanatory approach (AlSehaimi et al., 2013) using quantitative surveys or case studies (Azhar et al., 2009). However, this approach has been criticised in recent times as being inadequate for solving persistent managerial problems experienced in construction (AlSehaimi et al., 2013). The main problem with existing approaches to research in construction is that research findings tend to fall short of providing clear recommendations for the improvement of Construction Management practice (AlSehaimi et al., 2013). The majority of recommendations are general and not devoted to solving the problems observed in practice. Studies often find planning and control to be ineffective, yet solutions to this problem are not recommended and while some studies do recommend solutions, they do not identify the necessary tools needed to facilitate those (AlSehaimi et al., 2013). While theory building, theory testing and explanation undoubtedly remain indispensable, a deeper focus on discovery and problem solving in the form of Design Science research to complement existing approaches is needed (Simon,1969 & 1996; Simon, 1973; Klahr & Simon, 1999; Holmström 2009).

According to Peffers et al., (2007), Design Science can be adopted for a research study in various ways depending on the circumstances of the research; ie whether it is a problem-, an objective- or a design centered research project or if the research study was initiated from a client-context situation (Section 3.5.5). Thus, Design Science was adopted for this research to fit the unique circumstances of how this work was initiated in practice in a client-context situation. In her role as a consultant with a company specialising in the area of project management and optimisiation of real estate projects, the researcher developed the first version of the LCM model on a construction site, to resolve issues experienced in the daily planning and control of construction work onsite. This client context situation was a first attempt to apply the Lean concepts to a construction project using Visual Management, based on the researcher's previous experience and knowledge of application in other industries (Section 1.4). Positive improvements in daily planning and communication were noted after the first implementation of the model in practice, which initiated its further study and development within the context of this PhD work. Peffers et al., (2007) states that typically a Design Science researcher would start with a problem and then work from there, but a research study could also be initiated by the development and application of a solution that worked in practice as is the case with this research. The researcher is in a sense "working backwards" to apply rigor to the process. *Design science can result from the existence of an artefact that had not yet been formally thought through* (Peffers et al., 2007, p.14), as is the case with the LCM model. Through the course of the research, the development process of the LCM model is presented, analysed, evaluated and further developed to determine its contribution to practice and theory using the Design Science approach. This need to apply rigour to the initial design process of the LCM model is also an important reason for applying Design Science.

As mentioned at the beginning of this section, research in construction tends to fall short of providing clear recommendations and solutions to improve construction management practice (AlSehaimi et al., 2013). A further important reason for adopting Design Science is due to nature of the aim of the research, which is to provide a clear solution that can be applied to improve current practice in production planning and contol and to clarify the theoretical significance of this solution (March & Smith, 1995; Lukka, 2003; Hevner et al., 2004; Van Aken, 2004; Venable, 2006). Design Science is prescriptive in nature, creating artefacts that embody those prescriptions (March & Smith, 1995) and this research intends to change the real world by proposing a solution to solve a practical problem and to add to existing knowledge about the world by establishing the theoretical significance of the problem and its solution.

The practical problem posed in this work is a lack of transparency in the construction process, which leads to difficulties in communication, decision-making and general progress in daily work. This research work also addresses the problem of a lack of solutions to be found in the literature that demonstrate the systematic application of Visual Management to improve transparency. Rather than merely attempting to understand reality as is the aim of research in natural science, Design Science is applied in this case to provide a solution[4] and demonstrate how this solution can be applied to facilitate construction managers to plan and control the process by making information transparent. In this way, Design Science also complements explanatory research (Holmström & Ketokivi, 2009) by producing artefacts that can be used for evaluation research. Design Science goes beyond the capabilities of merely descriptive

[4] Of course, Design Science does attempt to understand reality, but in order to change it.

and/or explanatory approaches, providing a clear, practical way to improve transparency in construction. The artefact can be used for future research to develop and test new theories.

Through the application of Design Science, this work also intends to bridge practice to theory, rather than theory to practice as proposed by Holmström & Ketokivi (2009). They present four phases of research, the first two being exploratory (solution incubation and solution refinement) followed by two phases of explanatory research (establishing theoretical relevance and development of formal theory). According to the authors Holmström & Ketokivi (2009), typically, problem solvers in industry will likely stop at phase II once the solution is refined and the solution design has met its goal. However, solving a managerial problem does not constitute a scientific contribution. Through the course of the research, the initial phases I and II as described by Holmström & Ketokivi (2009) are linked to phase III by generalising the findings and demonstrating a theoretical contribution. Holmström & Ketokivi (2009) conclude that the successful bridging of managerial relevance and theoretical contribution lies in the ability to bridge Phase II and Phase III types of research. Design Science intends to make academic research more relevant to practitioners and extends practical solutions by seeking more thorough theoretical understanding and contribution. Design Science better aligns the theoretical and research interests of this work with the interests of managerial practice (Holmström & Ketokivi, 2009; Lukka, 2003). Despite ambitious efforts in various fields of research over the years, the goal of making academic research relevant to the practitioner remains elusive (Holmström & Ketokivi, 2009).

Furthermore, a key part of Design Science is the evaluation and testing of the solution (Kasanen, 1993; Lukka, 2003; Vaishnavi & Kuechler, 2007 & Peffers et al., 2007) and an important focus of this research work is to determine whether the solution provided utility for the task and the market intended (Kasanen, 1993). Design Science can be combined well with other traditional approaches to research such as case studies, which are an important method of investigation in this research.

Sections 3.5 presents the outcomes of Design Science research and Section 3.5.1 discusses the most important steps involved when adopting this approach.

3.5 Design Science outcomes

Design Science outcomes are of four types (March & Smith, 1995): Constructs or concepts, Models, Methods and Instantiations. The four outcomes and the relationship between each are defined as follows (March & Smith, 1995):

3.5.1 A construct or concept

A construct or concept forms the vocabulary of a domain. They constitute a conceptualisation used to describe problems within the domain and to specify their solutions. Such constructs may be highly formalised as in semantic data modelling formalisms (having constructs such as entities, attributes, relationships, identifiers, constraints, as proposed by Hull & King, 1987) or informal as in cooperative work (e.g. consensus, participation, satisfaction, as proposed by Kraemer & King, 1988);

3.5.2 A model

A model is a set of propositions or statements expressing relationships among constructs. A model can be viewed as either a description or a prescription, that is, as a representation of how things are, or a statement of how things should be;

3.5.3 A method

A method is a set of steps, e.g. an algorithm or guideline, used to perform a task. Methods are based on a set of underlying constructs (language) and a representation (model) of the solution space (March & Smith, 1995). Methods can be tied to particular models in that the steps take parts of the model as input. Furthermore, methods are often used to translate from one model or representation to another in the course of solving a problem;

3.5.4 An instantiation

An instantiation is the realisation of an artefact in its environment. Instantiations operationalise methods. However, an instantiation may actually precede the complete articulation of its underlying constructs, models, and methods.

Vaishnavi & Kuechler (2007) propose a fifth output, better theories, and explain that Design Science research can contribute to better theories in two ways: 1) since the artefact developed is an object for theorising for many communities (e.g. how to build more maintainable software), the construction phase of a Design Science research effort can be an experimental proof of method or an experimental exploration of method, or both and 2) the artefact can expose relationships between its elements, through better understanding and making them more visible, thus potentially falsifying or elaborating on previously theorised relationships (Vaishnavi & Kuechler, 2007).

Furthermore, Van Aken (2004) identifies a further outcome of Design Science as a technological rule. According to Van Aken (2004) a technological rule is "a chunk of general knowledge" (Van Aken, 2004, P. 228), linking an intervention or artefact with a desired outcome or performance in a certain field of application.

3.5.5 Design science steps

Design scientists strive to create concepts, models, methods and instantiations that are innovative and valuable. A number of steps to conduct Design Science are presented in the literature and are summarised in Table 3.1. March & Smith (1995) state that the Design Science research process has two fundamental activities: creating things that serve human purposes and evaluating their performance in use; "Design Science consists of two basic activities, build and evaluate. Building is the process of constructing an artefact for a specific purpose; evaluation is the process of determining how well the artefact performs" (March & Smith, 1995, p. 254).

Other authors; Kasanen et al. (1993); Lukka (2003); Vaishnavi & Kuechler (2007) and Peffers et al. (2007) propose a detailed sequence of steps towards a Design Science strategy which are similar to what Van Aken (2004) refers to as the problem solving cycle (problem identification, name and frame, plan intervention, apply and evaluate).

Table 3.1 shows the three common steps for Design Science, i.e. 1) identifying a problem; i.e. finding a problem that is practically relevant which also has potential for a theoretical contribution (Kasanen et al.,1993; Lukka, 2003; Vaishnavi & Kuechler, 2007 and Peffers et al., 2007), 2) developing a solution; i.e. creating a solution that solves the problem at hand (Kasanen et al., 1993; March & Smith, 1995; Lukka, 2003; 2007 and Peffers et al., 2007) and 3) evaluating that solution; demonstrating that it works and analysing its theoretical contribution (Kasanen, 1993; Lukka, 2003; Vaishnavi & Kuechler, 2007 & Peffers et al., 2007).

Table 3.1: Different approaches to Design Science (Kasanen et al., 1993; March & Smith et al., 1995; Lukka, 2003; Vaishnavi & Kuechler, 2007; Peffers et al., 2007)

	Kasanen et al., (1993)	March & Smith (1995)	Lukka (2003)	Vaishnavi & Kuechler (2007)	Peffers, et al., (2007)
1. Identify problem	Find a problem with practical relevance that also has research potential		Find a practically relevant problem with potential for theoretical contribution	Awareness of the problem	Problem identification and motivation
			Assess the liklihood for longstanding research collaboration with the target organisations		
	Obtain an understanding of the topic		Obtain an understanding of the problem from a practical and theoretical perspective		
2. Develop solution	Construct a solution	Create things that serve human purposes	Innovate a solution idea and develop a solution that solves the problem at hand	Suggestion of design	Define objectives for a solution
					Design and develop
3. Evaluate	Demonstrate that the solution works	Evaluate the performance of things in use	Implement the solution and test how it works	Further development of the design and implementation	Demonstrate
				Evaluation of the design against previously defined criteria	Evaluate
	Present ist connection to theory and the research contribution				
	Assess the scope of application of the solution		Identify and analyse ist theoretical contribution	Conclusion	Communicate

Peffers et al. (2007) proposed a process model for Design Science application in response to the lack of a set of steps serving as a commonly accepted framework for Design Science. The same authors (Peffers et al., 2007) further argue that this may have contributed to the slow adoption of Design Science. Peffers et al. (2007) process model for Design Science incorporates principles, practices, and procedures consistent with prior literature to provide 1) a nominal process for the conduct of Design Science research 2) a mental model for presenting and evaluating Design Science research.

Peffers et al. (2007) process model was chosen as a guide for this research as it was found to be most suited to the nature of the research and provides a clear structure identifying the different stages of the Design Science process. Peffers et al. (2007) model includes six steps which do not always follow a sequential order: 1) problem identification and motivation, 2) definition of the objectives for a solution, 3) design and development, 4) demonstration, 5) evaluation, and 6) communication.

3.5.5.1 Step 1: Problem identification and motivation

The authors (Peffers et al., 2007) argue that a thorough definition of the problem and justification of the value of a solution is essential for the development of effective artefacts. Since the problem is used as basis for the solution, it is necessary to analyse the problem adequately so that the solution can capture its complexity. Justifying the value of the solution is important for motivating the researcher and the audience of the research to pursue the solution and to accept the results and helps to understand the reasoning associated with the researcher's understanding of the problem (Peffers et al., 2007).

3.5.5.2 Step 2: Define the objectives for a solution

The second step infers the objectives of a solution from the problem definition and knowledge of what is possible and feasible (Peffers, et al., 2007). The objectives can be quantitative (how a solution is better than current ones) or qualitative (how a new artefact is expected to support solutions to problems not addressed until this point). The objectives should be inferred rationally from the problem specification and the resources required for this include knowledge of the state of problems and current solutions, if any, and their efficacy (Peffers, et al., 2007).

3.5.5.3 Step 3: Design and development

The third step focuses on the creation of the artefact. Such artefacts are potentially concepts, models, methods, or instantiations. This activity includes determining the artefact's desired functionality and its architecture and then creating the actual artefact. Resources required moving from objectives to design development include knowledge of theory that can be brought to bear in a solution (Peffers et al., 2007).

3.5.5.4 Step 4: Demonstration

The fourth step is concerned with the demonstration of the use of the artefact to solve the problem. Demonstration can be in the form of experimentation, simulation, case study or other appropriate activity. Resources required to carry out the demonstration stage include effective knowledge of the use of the artefact to solve the problem.

3.5.5.5 Step 5: Evaluation

The evaluation of the artefact is concerned with the observation and measurement of how well the artefact supports a solution to a problem. This activity involves comparing the objectives of a solution to actual observed results from use of the artefact in the demonstration. It requires knowledge of relevant metrics and analysis techniques (Peffers et al., 2007). The evaluation can take many forms; it could include comparing the artefacts functionality with the solution objectives or include quantifiable measures of system performance, such as response time or availability (Peffers et al., 2007). An important part of the evaluation is also to determine the theoretical significance of the artefact.

3.5.5.6 Step 6: Communication

In the final step the problem and its importance, the artefact, its utility and novelty, the rigour of its design, and its effectiveness is communicated to relevant audiences such as researchers and practising professionals (Peffers el al., 2007). Communication can take the form of scholarly research papers and reports.

3.5.5.7 Discussion

While the six steps above are presented in a linear fashion, Peffers et al., (2007) explains that the process is not linear and may evolve in different ways (Section 3.4). Typically, a problem-centred approach would be taken where a researcher would start with a problem and begin at step 1. Research may proceed in this sequence if the research resulted from observation of the problem or from suggested future research from a research project already carried out (Peffers et al., 2007).

The process could also begin at step 2 if it were an objective centred solution. This could occur through the definition of a research or industry need that can be addressed by developing an artefact. A research idea could also be initiated from the existence of an artefact that has not yet been formally thought through as a solution for the explicit problem domain in which it will be used. This is considered to be a design and development-centred approach (Peffers et al., 2007).

Finally, a research need could arise from a client / context initiated solution whereby a solution was developed in practice and it was observed that the practical solution was effective (Peffers et al. 2007), as is the case in this research work. In the case of this research process, the researcher is in a sense "working backwards" to apply rigor to the process (Peffers, et al., 2007, p. 14).

> "A problem-centred approach is the basis of the nominal sequence, starting with activity one. Researchers might proceed in this sequence if the idea for the research resulted from observation of the problem or from suggested future research in a paper from a prior project. An objective-centred solution, starting with activity two, could be triggered by an industry or research need that can be addressed by developing an artefact. A design and development-centred approach would start with activity three. It would result from the existence of an artefact that has not yet been formally thought through as a solution for the explicit problem domain in which it will be used. Such an artefact might have come from another research domain, it might have already been used to solve a different problem, or it might have appeared as an analogical idea. Finally, a client/context initiated solution may be based on observing a practical solution that worked; it starts with activity four, resulting in a DS solution if researchers work backwards to apply rigor to the process retroactively. This could be the by-product of a consulting experience".

3.6 Research process

The research process is divided into three parts (Figure 3.1 and Table 3.2), which follow the Design Science research steps as proposed by Peffers et al. (2007). Part 1 is concerned with the definition of the problem and a deepening of its conceptual understanding through a synthesis of the literature (step 1), the definition of objectives for a solution (step 2), design and development (step 3), demonstration (step 4), evaluation (step 5) and communication (step 6). Data gathered from the first development and instantiation of the model in case study 1 (1A), is used as basis for carrying out these steps. Each instantiation represents the implementation of the model to one specific project. Yin (2003), defines the case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". A case study's unit of analysis is the phenomenon under study. This can be persons, groups, organisations or non-human objects (eg: products, policies, processes or programs) (Yin, 2009). In this situation, the phenomenon under study is the version of the model and the aim is to explain how the first version was developed and applied in case study 1, by looking back at the original practical evidence and applying the Peffers (2007) model to add rigour to this process.

Part 2 and 3 are concerned with the further development and application of the LCM model to two different types of construction scenarios and follow steps 3-6 of Peffers et al. (2007) model for Design Science: (further) development (step 3), demonstration (step 4), evaluation (step 5) and communication (step 6). In part 2, data from case study 2 which involves two instantiations of the model (2A and 2B), is used as basis for carrying out these steps. In addition, part two also involves an observational study carried out on construction sites in Brazil to establish if similar models are evident on sites there and to compare the LCM model to existing Visual Management practices observed. In part 3, data from case study 3 which involves five instantiations of the model (3A-3E), is used as basis for applying steps 3-6 of Peffers et al. (2007) model.

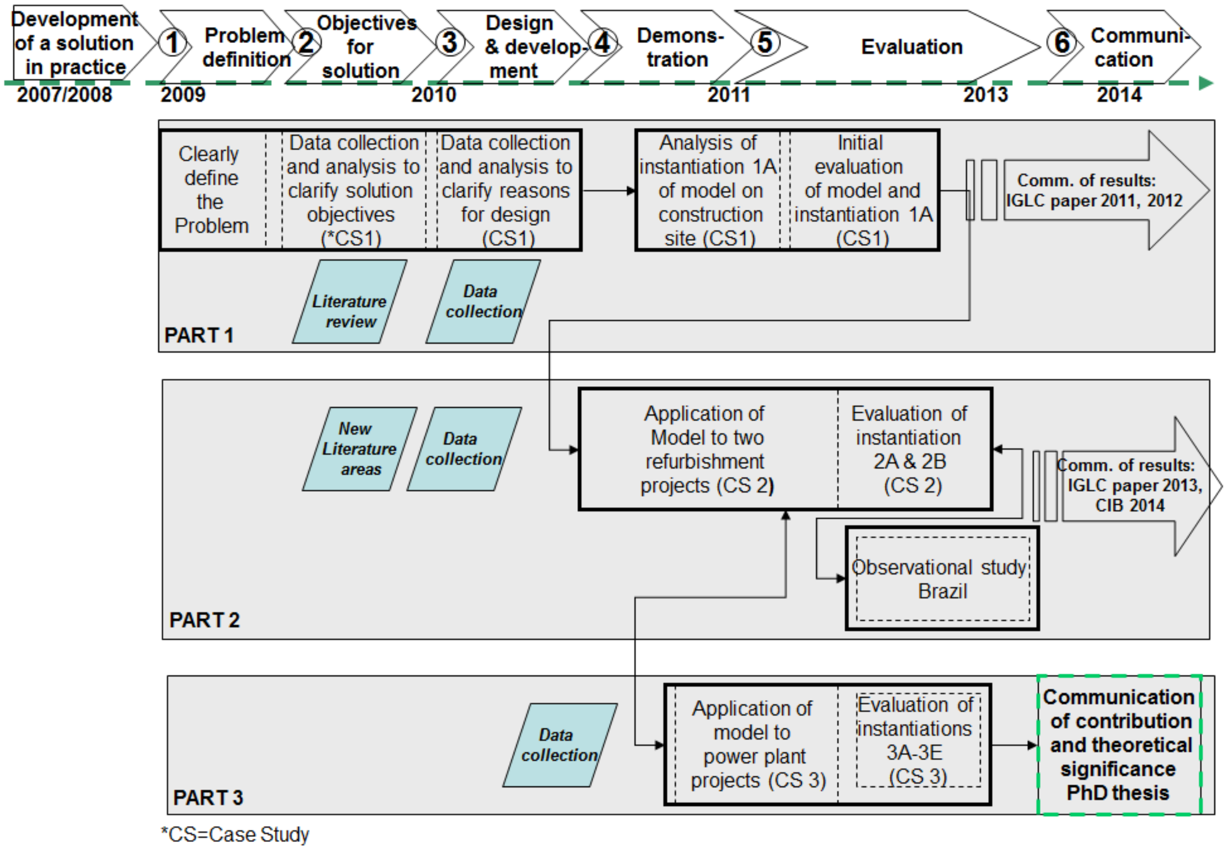


Figure 3.1: Research process

Table 3.2: Overview of research process

	AIM	BASIS FOR DATA	DESIGN SCIENCE STEPS (Peffers, et al., 2007)	DATA GATHERING
PART 1	**Initial development of the LCM model**	**1 instantiation to new residential building (1A)** **Literatre review**	**Steps 1-6:** 1) definition of the problem 2) the definition of objectives for a solution 3) design and development 4) demonstration 5) evaluation and 6) communication	Documentation analysis
PART 2	**Further development, application, evaluation and comparison**	**2 instantiations to two refurbishment construction projects (2A & 2B)** **Observational study** **Literature review**	**Steps 3-6:** 3) (further) development 4) demonstration 5) evaluation and 6) communication	Semi-structured interviews Documentation analysis Participant observation Direct observation Focus groups
PART 3	**Further development, application and evaluation**	**5 instantiations to five power plant construction projects (3A-3E)**	**Steps 3-6:** 3) (further) development 4) demonstration 5) evaluation and 6) communication	Semi-structured interviews Documentation analysis

In total, three different versions of the LCM model are presented during this research process. The first version represents the original version of the model after its initial development, prior to the commencement of this PhD, and is the focus of part 1 of the research, focusing on the first instantiation of the model (1A). The second version of the model represents how it was further developed and adapted to refurbishment construction in part 2, focusing on 2 instantiations of the model to two refurbishment construction projects (2A & 2B). This is also typically how the model is applied in practice today and was used as basis for comparison when carrying out the observational study in part 2. The third version of the model, which is the focus of part 3, represents a further adaptation of the model to suit the specifics of power plant construction, focusing on five instantiations of the model to five power plant construction sites (3A-3E). The three different versions of the LCM model are illustrated in Figure 3.2.

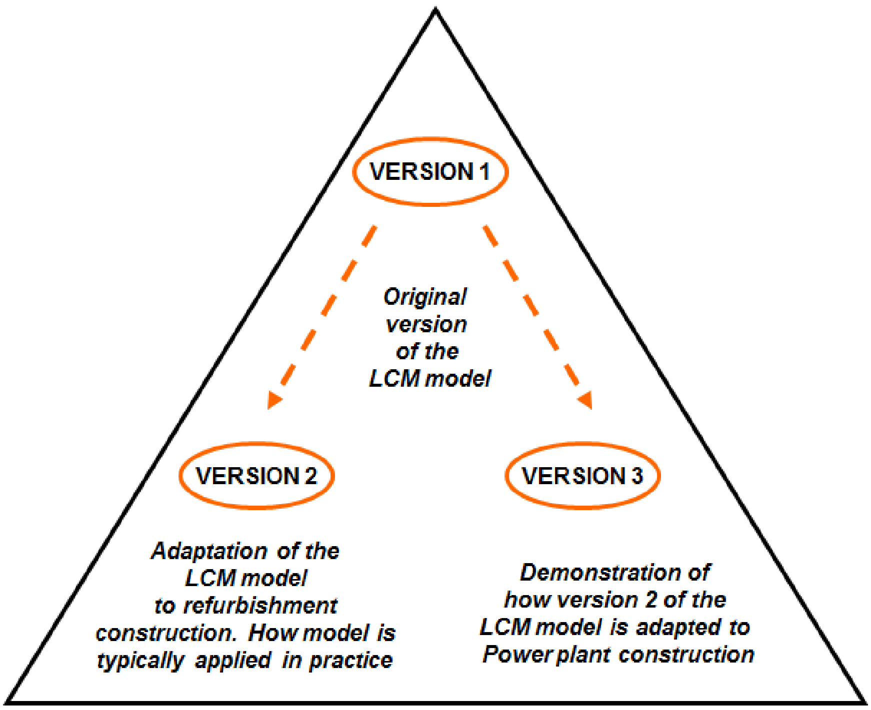


Figure 3.2: Three different versions of the LCM model applied to different project environments

3.7 Data collection

The main data collected during the research process is from 1) documentation 2) semi-structured interviews and 3) direct and participant observation.

3.7.1 Documentation

Documents are important sources of data in research and their range might include diaries, letters, agendas, minutes of meetings, personal notes, field notes and reports, images, sounds and objects and computerised records (Bryman, 2001; Yin, 2003; Finnegan, 2006). According to Yin (2003), documents can provide other specific details to corroborate information from other sources and additionally, related inferences can be made from documents.

3.7.2 Semi-structured interviews

According to Berg (2001, p.70), a semi-structured interview involves the implementation of a number of predetermined questions and/or special topics. These questions are typically asked of each interviewee in a systematic and consistent order, but the interviewers are allowed freedom to digress; that is, the interviewers are permitted (in fact expected) to probe far beyond the answers to their prepared and standardised questions. The purpose of the interviews is to gather relevant data for the evaluation stage.

3.7.3 Observation

O'Leary (2004) defines observation as a systematic method of data collection that relies on a researcher's ability to gather data through his or her senses. It is a technique that can be used when data collected through other means can be of limited value or it is difficult to validate (Hancock, 1998). There are two ways in which observation can be conducted: direct (non-participant) and participant observation (Hussey et al., 1997; Saunders et al., 2007). The purpose of direct observation is to observe and record what people do in terms of their actions and their behaviour without the researcher being involved (i.e. a field visit to the case study). Participant observation is a method of collecting data where the researcher is not just a passive observer. Instead, he/she is involved and may play a variety of roles in the event being researched (Yin, 2003; Easterby-Smith et al., 2002; Bryman, 2001).

A detailed description of the data collected during each part of the research in presented in each of the case study Chapters 4, 5 and 7 (Section 4.2, 5.2 and 7.2).

3.8 The research process in part 1

Part 1 is structured around the six steps for conducting Design Science proposed by Peffers et al., (2007). Part 1 was carried out between April 2009 and June 2011. An important focus of part 1 was clearly defining the problem identified in practice and deepening the knowledge of this problem through a synthesis of the literature. This also included a reflection on the first instantiation (1A) of version 1 of the LCM model in case study 1, to one construction project to access if an improvement in transparency was achieved and to identify further improvements to the model. Instantiation 1A was selected since it was the setting where the LCM model was originally developed and first applied in 2007. It was also important to explain how the objectives for the solution and elements of the model were defined.

3.8.1 Case study 1: Background

The project, which is the setting for the first development and instantiation (1A) of the LCM model, involved the construction of a block of 32 residential apartments situated in a small town in south-east Germany in July 2007. During this time (2007-currently), the researcher was employed as consultant by a company focusing on the project management and optimisation of real estate projects. The project was managed by a construction management company, which is a sister company of the firm where the researcher was then employed. Five main subcontractors were responsible for the majority of the construction work. It was hoped that through better coordination between the planners and the construction companies, the project could be completed without additional amendments, quality problems and ultimately, with a reduction in cost for the customer through an optimised planning and building process. The researcher, together with a consultant from an external company (which was working together with the researcher's company on this project), was given the task of conducting an analysis at the building site in question, to determine any potential to reduce waste as defined in the Toyota Production System and to optimise the building process.

Case study 1 represents the first stage of the research, beginning where a solution had been developed in practice (by the researcher) and the researcher starts by "working backwards" to apply rigor to this process (Peffers et al., 2007). The initial development of the model is analysed and reflected upon by building a description and explanation of the process by applying the following steps:

3.8.1.1 Step 1: Definition of problem

The research process began with an initial solution to a problem perceived in practice which was a lack of transparency in the construction process onsite leading to difficulties in communication, decision-making and general progress in daily operations. Part of this step of the research was to gain a deeper understanding of the practical problem in case study 1 and to clarify the problem from a theoretical perspective. A synthesis of the literature was carried out to gain this deeper understanding of the problem and of the theoretical background that could provide basis for addressing it. The literature review focused on the principle of transparency, Visual Management, Lean Production, Lean Construction and the deficiencies of Project Management.

In addition to the literature review, an important activity of this step was reviewing and analysing data gathered (Chapter 4, Table 4.1) on the practical problem by the researcher during the initial development stage in her role as a consultant. Data from a report from the subcontractors on problems onsite was reviewed. Data gathered on site such as photos, information on inventory and problems experienced in the flow of daily work were also reviewed. The literature findings helped to established that the problems onsite were related to a lack of transparency in daily operations.

3.8.1.2 Step 2: Defining objectives for the solution

An important part of step 2 was the definition of the objectives of a solution that addressed the problem identified in step 1. This step involved the review and analysis of data gathered (Chapter, 4, Table 4.1) to explain how the objectives for a solution were defined based on the problems observed in practice, a review of important concepts in the literature and the researchers practical experience of the application of Lean tools and Visual Management previously (prior to LCMs development in 2007).

Seven objectives of the Visual Management Model were defined at this step which had not been formally clarified during the development in practice (Chapter 4, Section 4.4).

3.8.1.3 Step 3: Design and development

Based on the objectives for a solution and a knowledge of visual tools used in practice when optimising processes i.e.: process maps, Kanban systems, Andon, Poke-Yoke, the researcher in her role as a consultant developed the first concept of the LCM model. An important part of this step was to clarify the steps to be taken to achieve the defined objectives and to clarify which visual tools should be used.

3.8.1.4 Step 4: Demonstration

An important part of this step was to explain, based on the data collected (Chapter, 4, Table 4.1), how the model (and its individual elements) was applied for the first time in practice. The main data was drawn from the researchers personal experience of the application process and all information gathered during that process (i.e: photos, descriptions of process, examples of visual tools used, templates for visual tools, notes from discussions with foreman and companies during implementation, KPI information gathered etc.). The different visual elements making up the model are described and their relationship to each other and use in practice explained. This step was important to determine the different elements of the model.

3.8.1.5 Step 5: Evaluation

An important outcome of the evaluation stage of Design Science is to establish whether a real-world problem has been solved (and to what extent) by the implementation of a new artefact and what are the practical and theoretical contributions of this solution (Lukka, 2003). Kasanen (1986) proposes weak, semi-strong and strong market tests to validate the utility of new artefacts which are viewed as products competing in the market of solution ideas (Kasenan, 1993, p. 253). A weak market test is based on the willingness of any manager responsible for the results of his or her business unit or project to apply the artefact; a semi-strong market test is based on how widely the artefact has been adopted by companies and a strong market test is based on how results have been improved by those companies systematically applying the artefact, compared to those who are not. The evaluation of the model during each part of this research serves two main purposes: to contribute to the models overall further development and to establish the applicability and effectiveness of the model, i.e: the market testing of the artefact. In this way both formative and summative evaluation is used. The main concern of formative evaluation is to "form" or develop a program or solution to help achieve a specific goal and summative evaluation intends to provide an "end-of-term report" indicating what the program or solution has achieved (Robson, 2004, p.51).

In evaluating what a solution has achieved, a difficulty often lies in determining when a solution is complete. Henver et al., (2004) states that a solution is complete and effective when it satisfies the requirements and constraints of the problem it was meant to solve. An important part of the evaluation of the LCM model is to establish whether it contributed to an improvement in transparency in the planning and control of daily operations and to clarify its contribution to knowledge and practice. In order to carry out the summative evaluation, it was first of all necessary to develop an evaluation framework. The development of the evaluation framework and the evaluation process is a significant part of the overall research design.

3.8.1.5.1 Evaluation framework

Three important steps were taken to develop a suitable framework for the evaluation:

- **Step 1: definition of evaluation criteria**

  The first step involved the definition of evaluation criteria. In the literature, a number of important criteria can be found that should be considered when evaluating an artefact using the Design Science approach. Hevner et al., (2004) point out that utility, quality, and efficacy are parameters for evaluating a solution. March & Smith et al., (1997), state that research in the build activity should be judged based on value or utility to a community of users. Likewise, Kasanen argues that artefacts should be validated based on their utility and applicability in the market (Kasenen, 1993). Van Aken (2004) refers to evaluating the effectiveness of a certain rule in the original context while Lukka (2000) emphasises the need to "ponder the scope of applicability of the solution" or translating the rule to other contexts. Lukka (2003) also emphasises the need for the researcher to explicate the theoretical contribution of the artefact during the evaluation by reflecting the findings back to prior theory. From these ideas, high level criteria were identified as basis for the evaluation framework. They are: usefulness, applicability and theoretical importance (Figures 3.4 and 3.5).

While the applicability of the model could be evaluated based on its adaptability to different types of construction scenarios, in order to establish criteria for evaluating utility a deeper understanding of the aims of the model and its outcomes according to Design Science was needed.

- **Step 2: classification of LCM elements**

  The LCM model was analysed and its elements classified according to the outcomes of Design Science: concepts, models, methods and instantiations (Section 3.5). This is an important step, to fully understand the artefact and its aims to determine what is understood by utility of the LCM model. The foundational concepts of the LCM model are based on the idea behind the Lean principles of value, value stream, flow, pull and perfection (Womack & Jones, 1996) and a need to improve transparency in the construction process onsite.

  A total of 16 different elements as part of the LCM model were identified which are based on these concepts (see Figure 3.3). Five of the elements (1. Overall Process Map 2. Process Planning tool 3. Overall Process Analysis action list 4. Process Planning action list and 5. The Stability of Process Planning Metric PP metric) aim to focus on the principle of value by ensuring that the optimal process is fully understood and that there is a common understanding of what the value of the process is. Six further elements of the model (6. The Planning board 7. The construction cards 8. The problem cards 9. The logistic board 10. Logistic cards 11. Visualised colour-coded site layout and 12. Material database (power plant) aim to implement flow and pull in the construction process onsite and in the wider processes. Finally, four elements of the model (13. Apartment clock / colour-coded plans 14. Visualised action plans in LCM area 15. Metric for On-Time-Performance and 16 metric for quality) aim promote continuous improvement and the principle of perfection in the process. How these elements are applied together in a specified way is the method. Each application of LCM represents an instantiation.

	TRANSPARENCY		
	VALUE & VALUE STREAM	FLOW & PULL	PERFECTION
CONCEPTS	1) Focus on value 2) Common understanding of overall process 3) Identify and remove constraints 4) Measure process stability	1) Visualise optimal process 2) Definition and visualisation of daily work packages based on optimal process (pull). Reduce buffer. 3) Visualise constraints and improvements 4) Visualise and optimise use of logistic resources and organisation of material: Just-In-Time	1) Daily quality checks 2) Visualise and track constraint removal 3) Measure on-time completion of work and quality 4) Two-way communication
ELEMENTS OF LCM MODEL	1. Overall Process Map 2. Process planning tool 3. Overall process planning action list 4. Process planning action list 5. SPP (stability of process planning)	6. Planning board 7. Construction cards for each company 8. Problem cards 9. Logistic board 10. Logistic cards 11. Visualised, colour-coded site layout 12. Material database linked to LCM (power plant cases)	13. Complete cards visualised on "apartment clock" to be checked (or visualised on plans) 14. Visualisation of constraint on actionplan in LCM area 15. Metric for daily work completion 16. Metric for quality
	Original development	Models: 1,3,4,6,7,8,11,13,14,15,16	
	Further development by third parties	Models: 2,5,9,10,12	

Figure 3.3: The outcomes of LCM

- **Step 3: definition of low level evaluation criteria based on aims of model**

Ultimately by applying the LCM model the aim was to improve the process of planning and control in construction, to enable the early identification of constraints, to reduce waste and to measure performance through increased transparency (Figures 3.4 and 3.5). Low level criteria were established according to the aim of the model (ie.: the effectiveness of the model in stabilising daily planning, identifying constraints, reducing waste, measuring improvements and performance and improving transparency). Questions were defined that were used as a basis for the semi-structured interviews with the LCM manager and the client. The data gathered from these interviews would help determine whether the criteria were fulfilled.

		LCM ELEMENTS							
		1. Overall process map	2. Process planning tool	3. Overall process planning action list	4. Process planning action list	5. Stability metric	6. Planning board	7. Construction cards	8. Problem cards
1.USEFULNESS	Daily planning	Q1. Did these elements improve daily planning and / or site logistics and if so, how?							
	Constraint removal	Q2. Could constraints be identified removed and monitored using these elements?							
	Waste	Q3. Did the use of these elements lead to the identification and removal of waste?							
	Transparency	Q. 4 Was comunication and a better common understanding achieved? Could information be easily accessed?							
	Measureability	Q.5 Was it possible to measure improvements? ie number and types of constraints, improvements implemented, stability of promises.							
2.APPLICABILITY	Adaptability	Q. 6 Can these elements be adapted to different types of projects?							
3.IMPORTANCE	Theoretical contribution	Q.7 How does the LCM model contribute to theory? Q.8 How different is it from previously used systems? Q.9 What new ideas does it contribute to the body of Lean Construction literature?							
		further development in practice by third parties							
		original development							

Figure 3.4: Evaluation framework for the LCM model (elements 1-8)

		LCM ELEMENTS							
		9. Logistic board	10. Logistic cards	11. Visualised colour-coded site layout	12. Material database linked to LCM	13. Complete cards visualised on "apartment clock" (now on plans).	14.Visualised action plan in LCM area	15. Metric for daily work completion	16. Metric for quality
1.USEFULNESS	Daily planning	Q1. Did these elements improve daily planning and / or site logistics and if so, how?							
	Constraint removal	Q2. Could constraints be identified removed and monitored using these elements?							
	Waste	Q3. Did the use of these models lead to the identification and removal of waste?							
	Transparency	Q. 4 Was comunication and a better common understanding achieved? Could information be easily accessed?							
	Measureability	Q.5 Was it possible to measure improvements? ie number and types of constraints, improvements implemented, stability of promises.							
2.APPLICABILITY	Adaptability	Q. 6 Can these elements be adapted to different types of projects?							
3.IMPORTANCE	Theoretical contribution	Q.7 How does LCM model contribute to theory? Q.8 How different is it from previously used systems? Q.9 What new ideas does it contribute to the body of Lean Construction literature?							
		further development in practice by third parties							
		original development							

Figure 3.5: Evaluation framework for the LCM model (elements 9-16)

During part 1 of the research, the researcher used these questions as basis for reflection on the first application of the model to the construction project in case study 1 (instantiation 1A). An initial evaluation of instantiation 1A of version 1 was carried out to access if an improvement in transparency was achieved. In addition, recommendations are made regarding future application of the model and improvements to the model are proposed. This evaluation was carried out as part of the research, approximately four years after the instantiation took place. For this reason, there were limitations in the data available for the evaluation such as the incompleteness of KPI data and inability to carry out formal interviews.

3.8.1.6 Step 6: Communication

Finally an important part of this step of the research was the communication of the initial findings of the research, the importance of the research problem and the artefact to improve this problem. This included two papers published in 2011 and 2012 at the IGLC conferences and various presentations of the research work that were held for fellow PhD students, academics and practitioners.

3.9 Research process in part 2

Part 2 represents the second stage of the research (Figure 3.1) where the LCM model is further developed and applied to two refurbishment projects (instantiation 2A & 2B) in case study 2. Part 2 began in July 2011 and continued until June 2013. Part 2 follows steps 3-6; i.e. design and develop, demonstrate, evaluate and communicate.

The objective of step 3, design and development, is to show how the LCM model was further developed. The objective of the demonstration (step 4) is to form an explanation of how the version 2 of the LCM model was applied based on two instantiations of the model to two refurbishment construction projects. A key focus of this stage of the research is also an evaluation of the utiliy of the model (step 5) and its application and adaptation by both third parties and the researcher to the two refurbishment projects (instantiations 2A & 2B).

3.9.1 Case Study 2: Background

Case study 2 in part 2 of the research focuses on the further development of the LCM model and its application to refurbishment construction. It focuses on 2 instantiations (2A & 2B) of the LCM model (version 2) to refurbishment construction. The process of application is the same for both instantiations – the model was adapted during instantiation 2A and applied in the same way to instantiation 2B. Instantiation 2A of the LCM model to refurbishment construction was carried out by a third party. The building had 5 floors; 3 levels of offices and 2 technical levels. The renovation of a further company building was in the pipeline and should the results of this application be successful, it was planned to apply the model to a further project within the same company. Since the first instantiation (2A) to refurbishment was carried out successfully, the decision was made to apply the model to a similar, but more complicated refurbishment. It was more complicated as it was a larger building with many rooms that had unique specifications. The building had 9 floors; 6 levels of offices and 2 technical levels. It was an important strategic building for the client as it was the company headquarters and achieving the completion target was of utmost importance. Instantiation 2B of the LCM model to a commercial refurbishment project was carried out by the researcher. over the course of 14 months.

3.9.1.1 Application of evaluation framework

The goal of the evaluation of the LCM instantiations 2A & 2B to refurbishment projects by third parties and by the researcher was to establish how the model was further developed and to determine whether it was applicable and useful when adapted to a different type of construction scenario. Evidence on the applicability of the model to refurbishment construction is provided by both instantiations of the model to the refurbishment projects.

Version 2 of the LCM model represents a more formalised and improved application in practice to version 1, demonstrated in case study 1. In case study 2, the proposed recommendations and guidelines for implementation had been applied. In case study 2, during instantiation 2A of the model, the researcher takes a step back from the initial development of LCM (version 1) and observes how the suggested improvements have been applied and how it has been further adapted and modified to a new project situation. The key question here according to Lukka (2000), is to analyse the results of the process and its preconditions. According to Lukka (2000) it is important to observe to what extent and with what case by case modifications the artefact is transferable to other organisations (Lukka, 2000).

The usefulness of the model is evaluated based on five lower level criteria: 1) improvement in daily planning, 2) constraint identification and removal, 3) waste identification and removal, 4) improved transparency and 5) measurability of performance (Figures 3.4 and 3.5). The interviews with third parties involved in the LCM instantiations (Chapter 5, Table 5.2) provided a valuable source of data on the perceived effects of the increase in transparency for the evaluation (Chapter 5, Section 5.5). The questions used as basis for the interviews with the LCM manager are shown in Figure 3.4 and 3.5. The questions used as basis for the interview with the foreman and client during instantiation 2 B can be found in the Appendix B.3.

KPI data on On-Time-Performance was also gathered to determine how sound the subcontractors commitments were (i.e if they committed to x number of daily work packages, how many were completed?). The constraints removal was measured by making the number of constraints identified transparent and establishing if these constraints were removed or not (Chapter 5, Section 5.4; Chapter 7, Section 7.4). It was difficult to measure the exact level of waste reduction on both cases studies (walking, searching, movement, transport etc from a number of different crews was difficult to document). However, it was possible to measure the effect the increased transparency had on optimising the buffer times between construction activities, which were made transparent on the planning board (Chapter 5, Section 5.4.2). In both instantiations of the model to refurbishment construction (2A & 2B), it was possible to note positive effects in the stabilisation of daily planning, constraint removal and some areas of waste through the increased transparency (Section 5.5.2). However, there are limitations to the data since no previous data existed to compare these effects to. While the data in most cases show stability in On-Time Performance and quality during the observation period, the data itself is not conclusive. However, this data forms a basis for possible future comparisons.

During part 2, the researcher also conducted a field trip to Brazil to carry out an observational study for three weeks in March 2013. This observational study was part of a triangulation strategy of research validation in order to overcome bias and to observe different perspectives of Visual Management application. Triangulation refers to the "observation of the research issue from at least two different points" (Flick, 2000, p. 178) thus limiting personal and methodological biases and enhancing a studys generalisability and validity (Black, 1993). The researcher was aware of reports of advanced applications of Visual Management at some Brazilian companies and the opportunity arose for her to personally visit some of these companies and sites.

The aim of the observational study was to compare Visual Management practices observed on three construction sites in Brazil to the LCM model. Two of the construction sites were residential projects and one site was the construction of a commercial distribution centre. Visual tools used to plan and control the construction process were observed onsite and from the documentation gathered. This comparison of Visual Management practices observed to the LCM model, would help to determine if similar models of Visual Management application were evident on the sites in Brazil and if the LCM model could contribute to existing practices. Another purpose of the observational study was to verify findings from the literature review that indicated that Visual Management application tended to focus on the application of individual tools rather than the use of systematic models of application (Arbulu et al., 2005; Picchi et al, 2004; Kemmer et al., 2006; Jang & Kim, 2007; Tommelein, 2008; Saurin et al., 2008); Tezel, 2011). This observational study was carried out in part 2 of the research since version 2 of the model represents how it is typically applied in practice and therefore a suitable basis for comparison.

Finally, the research was communicated (step 6) in this phase of the research through the publication of a further IGLC paper in 2013, a CIB paper in 2014 and further presentations of the work to academics and practitioners.

3.10 Research process in part 3

Part 3 represents the final stage of the research (Figure 3.1) where the LCM model is further developed and applied to five power plant construction projects, which represent five further instantiations of the model (instantiations 3A-3E). These instantiations are the focus of case study 3.

While conducting this research work, the researcher was aware that the LCM model had been successfully adapted and applied to 9 power plant construction sites for the same client worldwide. The adaptation and application of the LCM model to these power plant construction sites provided a rich source of data on a further unique type of instantiation of the model. In addition, it provided further evidence of the models utility and applicability. Since data was not available on all 9 instantiations, five instantiations were selected based on the quality and availability of data. In addition, it was also possible to gather further information on the instantiations by interviewing the two LCM managers and the project manager from the client side, who were involved in all five instantiations selected. A list of the data gathered is shown in Chapter 7, Table 7.2 and 7.3.

The first instantiation to power plant construction (instantiation 3A) is important to understand how the LCM model was further developed (version 3) to suit power plant construction. This version of the model was then used as a standard and applied to eight further power plant projects, data from four of which is used as part of the evaluation. These remaining instantiations are important for the evaluation of the model since they focus on analysing the effects of LCM application that could be observed, based on data gathered on crane utility and On-Time-Performance. However, as is the case with data gathered in part 2 of the research, there are also limitations to this data since no previous data existed to compare these effects to.

Part 3 began partially parallel to part 2 in June 2012 and continued until November 2013. Part 3, like part 2 is mainly structured around steps 3-6; further development, demonstrate, evaluate and communicate. The further development, demonstration of applicability to a further type of construction and the evaluation of the effectiveness and utility of the model are an important focus of part 3.

3.10.1 Case Study 3: Background

Case study 3 focuses on the further development of the LCM model (version 3) and its application to power plant construction. It focuses on five instantiations of the model (3A-3E) to power plant construction, during which the researcher was not personally involved. Version 3 of the LCM model is developed during instantiation 3A and this version is applied to a further 4 power plant sites (3B-3E). Of the five instantiations, three of these power plants were located in Germany, one in the Czech Republic and one in the Netherlands. The common goal of the instantiations of the LCM model on all of the power plants was to optimise buffer times, crane utility and to reduce overall lead time for execution. According to a company manager, there was a general lack of transparency on all power plant sites and a missing standard approach to manage and organise the site operations. An important objective of the case study is to demonstrate the applicability of the LCM model to a specialised type of construction like power plant construction. An important focus was also to present findings to establish what effects the increased transparency had on the project, demonstrating the usefulness and effectiveness of the model. The main focus of instantiations 3B-3E was as basis for the evaluation of the utility of the model.

3.11 Chapter summary

This chapter presented the data that was collected and analysed in the three parts to this research. The chosen approach for this research, Design Science, was presented along with a justification for this choice. The research process was presented, which follows the six steps of Peffers et al., (2007) process model for Design Science application: 1) problem identification and motivation, 2) definition of the objectives for a solution, 3) design and development, 4) demonstration, 5) evaluation, and 6) communication. In addition the research activities carried out during each part of the research process were explained.

The next chapter presents case study 1 as part of this research, where the LCM model is initially developed and applied to a residential construction project, representing version 1 of the model.

4 Development of the LCM model: Case Study 1

4.1 Introduction

This chapter focuses on the first development and instantiation (1A) of the LCM model and is structured around five main sections according to the steps of Peffers et al., (2007) process model presented in Chapter 3 (Section 3.5). The sections are: 1) problem identification, 2) definition of the objectives for a solution, 3) design and development, 4) demonstration and 5) evaluation. As part of the sixth step, 6) communication (of artefact to relevant audiences such as researchers and practising professionals) IGLC papers on the research were published in 2011 & 2012). The objective of case study 1 is to describe how the first version of the LCM model was developed. The objectives of this chapter are:

- to gain a deeper understanding of the need for improving transparency in the construction process by clarifying the problems that were observed.
- to explain how the first version of the LCM model was developed in practice based on the observations gathered, thus identifying the early foundational concepts of the model (output of Design Science, Chapter 3, Section 3.5).
- to explain and describe the visual elements that make up the LCM model itself (output of Design Science, Chapter 3, Section 3.5).
- to explain how the model was applied for the first time to a construction project (explanation of the model and the 1st instantiation, 1A).
- to establish the effects of instantiation 1A.

4.2 Data collection

Since the first development and instantiation 1A of the LCM model occurred in 2007 before the research began in 2009, consequently much of the data presented in case study 1 is documentation gathered from this initial project.

Data was gathered from notes taken from informal discussions with the subcontractors and the foreman and from reports provided by the project manager from the construction management company, who had documented issues experienced in the construction process over a time period of 8 weeks. In addition, further data was gathered in the form of photos, reports, presentations, pie charts and other illustrations. A summary of evidence collected is shown in Table 4.1.

Table 4.1: Data gathered for instantiation 1A

DATA GATHERED FROM FIRST DEVELOPMENT AND INSTANTIATION 1A				
Type of data	**Project description**	**Type of data**	**Description**	**Timeframe**
Case study 1: Instantiation 1A	**LCM development and first instantiation to newly built residential project**	**Document analysis**	1) Masterplan 2) Contracts and letters 3) Presentations 4) Reports on problems 5) List of inventory on site 6)) Notes on discussions with project management, sub-contractors, construction management 7) Photos from site 8) Photos of application of method 9) LCM implementation plan 10) Copies of flipcharts from LCM workshops 11) Reports from LCM implementation workshop 12) Action plans 13) Documentation of Kaizen improvements 14) Electronic construction cards used 15) Overview of areas for planning board 16) Partial KPI data on companies (On Time Performance and quality) 17) Logistics documentation (overview of storage areas) 18) List of companies involved in implemenation 19) Documentation from planning meetings 20) Documentation of LCM method description 21) Documentation on quality issues	April 2009-June 2011

4.3 Step 1: Clarification of the problem

The project, which is the focus of this case study, involved the construction of a block of 32 residential apartments situated in a small town in south-east Germany in July 2007 (Figure 4.1). The researcher, in her role as a consultant, was given the task of developing a solution that would improve coordination between the planners and the construction companies so that ultimately the project could be completed without additional amendments, quality problems and a reduction in cost for the customer through an optimised planning and building process.

The researcher was involved in this project for four months from July 2007 until October 2007.

Figure 4.1: Construction of residential building in south Germany

This section presents the main findings related to the problems experienced onsite. A report summarising the issues the five main construction companies faced was reviewed by the researcher. This report was produced by the sister company of the firm where the researcher is employed. The main issues experienced from the perspective of the five construction companies' onsite were classified into four main areas: 1) communication issues in daily operations, 2) inefficient decision making 3) poor process orientation and 4) no worker involvement in continuous improvement or standard for quality.

4.3.1 Communication issues in daily operations

Lack of communication between the construction companies onsite led to additional work. For example, there was no communication or information on work co-ordination on a day to day basis, which meant workers, would have to relocate at short notice to different areas of the site when it wasn't possible for them to carry out work in the area originally planned. This caused waiting time and additional moving around of people, materials and equipment needed to do the job.

In addition, the interface between planning and the executing companies was not satisfactory. No communication took place and there was a lack of information available on alternative work when planned work could not be carried out. Changes were often made in planning and communicated at a late stage, which resulted in rework and additional work. There were no defined structures in place to communicate information as soon as it was available.

4.3.2 Inefficient decision making

As a result of the difficulties in communication, no clear responsibilities or co-operation on decision-making were evident. For example, companies depended on the site manager who was not always present to decide where they should carry out work if it was not possible in the intended area. Companies stored their material where they found space, often hindering other companies in their daily work. There were also no consequences if companies did not adhere to instructions with regard to material storage, work procedures and repeated quality issues.

4.3.3 Poor process orientation

It could also be established from the feedback from the companies in the report, that there was a lack of process-orientation onsite. This lack of process-orientation was evident since work was not carried out in any particular logical order onsite (there was no *"flow"* (Chapter 2, Section 2.7.2 and 2.2). Companies aimed to meet their individually defined schedule and were only concerned with their activity. This meant that the companies often hindered each other from beginning work and sometimes work areas were left in an unsatisfactory way making it difficult for other crews to continue.

4.3.4 No worker involvement in continuous improvement

According to the feedback from the companies, there was no evidence of continuous improvement onsite. Since companies were focused on their own specific task, there was no incentive for improvements in the overall process. No feedback on problems in execution was received from the construction workers involved in the process and different perceptions of quality of work were evident. This led to quality issues and lack of a standard for continuous improvement.

Data was gathered in the form of photos portraying the first impressions (Figures 4.2(a)-4.2(g) show some examples), a list of inventory onsite of the amount of material lying around (Table 4.2), a pie chart showing the difference between the actual work being carried out and the planned work from the master schedule (Figure 4.3) and an illustration showing the lack of flow of work in the process and the effect this had (Figure 4.4). The following conclusions could be drawn from the data:

4.3.5 The site was disorganised and cluttered

The site appeared to be very cluttered, with no obvious process for organising and storing material. Material was stored throughout the site and in the building, in different rooms, on the rooftop, on the site and in corridors blocking crews from navigating the building easily (Figures 4.2 (a)-4.2 (f)). This created extra work for construction workers since they had to move and remove material and it took longer to find the material they actually needed at a particular time. The material itself was partly damaged due to bad weather (Figure 4.2 (e)).

Figure 4.2(a): Chaotic storeroom

Figure 4.2(b): Material located in different rooms

Figure 4.2(c): Inventory stored onsite making it difficult for workers to make their way around

Figure 4.2(d): Storing large amounts of material onsite led to extra work for the construction workers who had to move it about

Figure 4.2(e): Material damaged after rainfall

Figure 4.2(f): Disorganised storage of material onsite

Figure 4.2(g): Time intensive process of unloading large quantities of material that are not immediately needed

4.3.6 Waste in the form of high levels of inventory was evident

High levels of inventory were noted throughout the construction site, which took up space and made it difficult for the crews to move around. Table 4.2 presents a snapshot of the material stored throughout the building and the areas of waste evident on one particular day. In addition to the high levels of inventory stored through-out the site (drywall, mortar, doors, shutters, windows), other areas of waste were evident. Additional movement and transport of material was evident, since the material needed was often not stored near the area of work. Overproduction was noted in some areas, where work was being carried out that was not necessary at that time. In contrast, other apartments were vacant and "waiting" where crews had not showed up to carry out assigned work.

4.3.7 Work was not carried out as planned

Data was reviewed during the research, which had been gathered as part of the initial analysis onsite. This data compared the actual work that was being carried out onsite over a period of a week to work that was actually planned for that time (based on the master schedule). It was found that only 14% of the activities that were completed onsite, corresponded to those scheduled in the master plan (Figure 4.3).

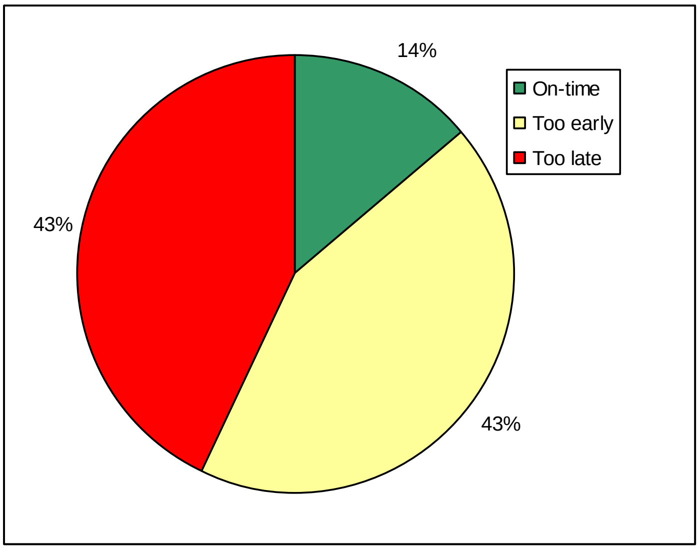


Figure 4.3: Percentage of activities on-time (green), too early (yellow) and too late (red)

Table 4.2: Snapshot of waste observed onsite

*BS 1= Building section 1 and BS 2=Building section 2		
	Type of waste	**Inventory on analysis date**
BS1 Ground floor	**1. Inventory** **2. Transport** - the parts need for the lifts are situated in the the apartments which is quite a distance away from where they are needed **3. Rework** - sub contrators need to return to improve work carried out on doors, dry wall, sanitation and electric	1. 50 rails, dry wall 2. electrical cable 3. morter * 180 kg
BS1 First floor	**1. Inventory**	1. 10 rails 2. 40 sheets dry wall
BS1 Second floor	**1. Inventory** **2. Lack of 5 S - remainder plaster not disposed of**	1. Drywall * 35
BS1 Third floor	**1. Inventory** **2. Lack of 5 S - remainder plaster not disposed of** **3. Movement -** Electrical work started but not finished resulting on repeated trips back to finish	1. Drywall * 40 2. 50 rails / profiles
BS1 Fourth floor	**1. Inventory** **2. Overproduction -** two sub contractors working on days of analysis even though this work was not planned	1. Drywall * 40 2. Rails * 20
BS2 Ground floor	**1. Inventory** **2. Waiting -** work planned for two subcontractors in two apartments but companies not present	1. 120 stück * drywall @ 5 m 2. Plastic piping * 40 3. Insulation * 10 4. Balcony doors *10 5. Large shutters * 8 packets 6. Small shutters * 35 packets 7. Windows * 6 8. Window frames *15 packets
BS2 First floor	**1. Inventory** **2. Overproduction - One subcontractor working in apartment 12 which is not planned**	1. Plaster *150
BS2 Second floor	**1. Inventory**	1. Plaster *204 kilo 2. Large shutters * 3 packages 3. Small shutters * 5 packages 4. Rails for shutters 5. Plaster * 48 Kilo 6. Large shutters * 2 packages 7. Small shutters * 1 package 8. 15 Sacks of concrete @ 40 kg 9. Plaster * 156 kilo
BS2 Third floor	**1. Inventory**	1. Plaster *204 kilo 2. Large shutters * 2 packs 3. Small shutters * 5 packs 4. Rails for shutters * 4 5. Plaster * 48 Kilo 6. Large shutters * 2 7. Small shutters * 1 8. Concrete * 15 Sacks @ 40 kg 9. Plaster * 156 Kilo
BS2 Fourth floor	**1. Inventory**	1. Plaster *204 Kilo 2. Large shutters * 3 packs 3. Small shutters * 5 packs 4. Rails for shutters 5. Plaster * 48 Kilo 6. Large shutters * 3 packs 7. Small shutters * 3 packs 8. Concrete * 15 Sacks @ 40 kg 9. Plaster * 156 Kilo
BS2 Fifth floor	**1. Inventory**	1. Plaster *170 Kilo 2. Concrete * 16 Packs @ 40 kg 3. 264 sheets dry wall 4. Plaster * 204 Kilo 5. Concrete * 16 Packs @ 40 kg

4.3.8 There was no flow of work in the construction process onsite

Data from the master plan from a two-week period was reviewed, noting where companies were planning to work and establishing if they were able to carry out that work as planned. It was found that on only two days in the two week period, crews were able to carry out the work they were scheduled to do, when they were scheduled to do it. On review of this data, it was found that the work that appeared to flow on the master plan, did not in reality (see Figure 4.4). Crews (shown as numbers 1-3 in Figure 4.4) would show up at the area of work, only to find another company was working there or they could not complete their work until certain activity was finished first. There was no sense of flow in carrying out the daily work onsite and subcontractors tended to work in areas where it was possible, rather than where they should work. According to the site manager, in order to manage the daily operations onsite and the co-ordination of the crews, a great deal of coordination, flexibility and rearranging of activities was needed to ensure work could be carried out each day. What looked straightforward on the master plan (see left side of Figure 4.4), caused great confusion in practice (see right side of Figure 4.4).

Figure 4.4: Flow of work on a daily basis (master plan left, physical work being carried out right)

4.3.9 There was no measurement of performance

There was no data gathered on the On-Time-Performance or the quality of work of the construction companies. While it was observed that work could not be carried out as planned on a daily basis and that different levels of quality were evident, it was not possible to quantify this.

4.3.10 Clarification and summary of the practical problem

Based on the data gathered from the feedback from the companies involved in the construction work and the observations and data gathered onsite (section 4.2), the issues identified can be summarised as follows:

- **There was a lack of clarity and communication between interfaces** in planning and daily operations and no clear responsibilities which led to ineffective decision making.

- **There was no flow of work** recognisable in the process onsite. The different areas or work needed to be visited numerous times in order to complete a job.

- **There was no feedback on feasibility of work in execution** and of the problems faced.

- **Material organisation and storage** was a huge issue onsite leading to searching, waiting, damaged material and quality issues.

- **There was no system of quality control** of work onsite and different perceptions of quality were evident.

- **No data existed on performance** with regard to On-Time-Performance of companies and levels of quality.

- **There was no evidence of continuous improvement** onsite as companies focused on their own individual tasks and were not concerned with other aspects of the process.

4.3.11 Discussion: a process lacking in transparency

Section 4.3 presented the issues that were evident on the construction site in case study 1. The communication and decision-making issues reviewed in the initial report and described in section 4.3.1 and 4.3.2, are indicative of a process that is lacking in transparency. The ability of a construction process to communicate with people is an important characteristic of transparent processes (Chapter 2, Section 2.3). If information is readily available and communicated when needed and there is a clear understanding of the different aspects of the construction system, companies themselves can make better informed decisions (Chapter 2, Section 2.3).

Lack of process orientation is also indicative of a process that is lacking in transparency, since in order to achieve a process view, transparency of that process is needed to deal with the vast amounts of information that is required to do so (Chapter 2, Section 2.10.1).

The data reviewed from the observations carried out during the initial analysis are further evidence of a process that lacks transparency since no logical flow of daily activities were evident and sufficient information was not available to enable companies to make informed decisions on how to proceed when work could not be carried out. In addition, it was not clear where and how much material could be stored which led to a cluttered site, damaged material, extra movement and transport. A key characteristic of transparent processes is that they display relevant information in a physical way, facilitating communication, decision-making and promoting self-management, which was not the case on this site.

Indeed, many of the issues observed on this construction site are also indicative of some of the deficiencies identified in production planning and control (Chapter 2, Section 2.7). It was observed on this site that the execution process was not unproblematic and linear as is assumed in traditional Project Management. Scheduled work often couldn't be carried out as planned since important prerequisites were not met. Only a small number of activities (14%) being carried out corresponded to those specified on the master plan, confirming that the process is not linear. The difficulties in one way communiation observed, as is characteristic of the traditional approach to Project Management, highlighted the need for better structures to enable timely feedback on why work cannot be carried out during execution. The assumption that work can be carried out as planned was confirmed on this site to be untrue since time was spent daily rescheduling work and relocating crews and equipment from areas where work could not be executed as planned.

4.4 Step 2: Definition of objectives for the solution

During the first development of the model in practice, some important objectives for the first concept of the LCM model became clear. Based on the problems discussed in Section 4.3 and summarised in Section 4.3.9.1, it was established that a solution should make the daily work more transparent so that the issues in production planning and control could be improved. Through the increased transparency, an important objective of the model was to achieve a better understanding of the interdependencies in the process, the measurement of performance (quality and On-Time-Performance) and the effective removal of constraints. As part of step 2 during this research work, the objectives of the solution are more clearly defined based the problems identified during the analysis and findings from the literature review on Lean application to construction. This section presents the objectives of the solution on which the first concept was based. The solution should:

4.4.1 Improve the overall transparency of the construction process

The first problem, as summarised Section 4.3.9.1 was concerned with the lack of clarity and communication between interfaces involved in planning and daily operations and no clear responsibilities which led to ineffective decision making. This problem was verified during the observations onsite and further discussions with the site management who stated that a great deal of the construction managements time was spent co-ordinating and placing the crews in areas where they could work. It was not clear to the crews what work needed to be carried out when or where, so often they would work where they could instead of where they should.

To achieve overall transparency in the construction process, the concepts of transparency and value stream are important. Transparency provides people with a clear understanding of different aspects of the current system performance and status, giving them feedback of performed activities and helping in making decisions, letting them recognise interdependencies and as a result, enabling higher levels of improvements (Bauch, 2004). The value stream, is concerned with understanding the physical flows of people and information (Liker, 2004). In order to achieve transparency in processes, Visual Management plays a key role. Section 4.5.1, explains how a visual tool called "the Overall Process Map" is used to make the overall process transparent in the early stages of the project.

4.4.2 Ensure the flow of levelled work and a holistic view of the process

This objective addressed a further problem (Section 4.3.9.1) which was that no flow of work was recognisable in the process onsite (Figure 4.4). This led to subcontractors preventing each other from carrying out their work, since too many crews were scheduled to work in the one area at the same time. It also led to large amounts of material onsite, which was hindering progress and getting damaged due to bad weather. This is also evidence of one of the deficiencies of traditional project management (Chapter 2, Section 2.7), where work is assumed to flow from the point of authorisation.

The concepts of flow and pull form the basis of achieving this objective. Flow and pull are core principles of the Toyota Production System (Chapter 2, Section 2.2) and are important for bringing problems to the surface and avoiding overproduction. Flow refers to achieving the optimal order of process activities, by reducing variability and irregularity (such as bottlenecks) so that material and information may move in a predictable way within the supply chain (Womack & Jones, 1996). The idea of pull is to produce only as much as the following work activity needs while keeping inventory at a minimum (Liker, 2004). If processes are organised in a logical way, problems become more transparent and solutions can be identified more easily. It requires a shift in the way work is carried out, from focusing on large quantities of work in certain areas to rethinking how the work flows through the building. Section 4.5.2 and 4.5.3 explain the steps taken when developing the visual tools of the LCM model that aim to implement flow and pull in the construction process (e.g. the construction cards and the planning board).

4.4.3 Involve the construction worker more in the whole process

This objective addressed the problem concerning the lack of involvement of the construction worker, with regard to giving feedback on feasibility of work in execution and of the problems faced (Section 4.3.9.1). As discussed in Chapter 2 (Section 2.2), in the Toyota Production System, it is the people who bring the system to life: working, communicating, resolving issues and growing together.

An important concept as basis for achieving this objective is the concept of two-way communication (Winograd & Flores 1986). Winograd & Flores (1996) argue that the work in organisations is coordinated through making and keeping commitments. These commitments are formed first of all by an offer or a request, followed by a promise, performance and declaration of completion. The new solution should involve both levels: the management and construction worker level to benefit from the important feedback from the site regarding feasibility, work requirements and quality issues. Section 4.5.3-4.5.4 and Section 4.6 describe the elements of the model that were developed with the aim of facilitating two-way communication in order to create sound commitments (e.g., the planning board, construction cards, apartment clock, action plans, KPI's etc.).

4.4.4 Improve the logistics of the site

This objective addresses the problem of material organisation and storage (Section 4.3.9.1) which led to other areas of waste such as searching, waiting, damaged material and quality issues (Figures 4.2(a)-4.2(g)). An important concept as basis for fulfilling this objective is Just-In-Time. Just-In-Time (Chapter 2, Section 2.2) is concerned with having the right amount of material, in time when needed (Liker, 2004). A new solution should consider not just the work to be carried out onsite but also how the site logistics, in particular the storage and management of material can be improved. Elements of the model that facilitate this concept are the planning and logistics board and are explained in Section 4.6.

4.4.5 Implement a simple quality control system

This objective addresses the observed problem that there was no system of quality control of work onsite and different levels of quality were evident (Section 4.3.9.1). From the discussions with the site management it was found that the subcontractors had different perspectives on what constituted a finished piece of work. There was no quality check as such; the site management usually randomly discovered quality issues on his rounds through the site. This often caused further delays since the subcontractor might have already left the site at the time the quality issue was discovered. For this reason, it was considered important that a regular, planned quality check was carried out daily onsite so that the subcontractor could resolve the problem as soon as possible so that it wouldn't be "transferred" to other areas. It was also hoped as a result that a clearer common idea on quality would emerge through the definition of standards.

The concept as basis for this objective is the idea of striving for perfection in processes (Liker, 2004). The principle of perfection is closely related to the idea of continuous improvement (Section 2.2.1), which is about constantly striving to identify and solve problems in processes and continuously improving them. The idea is to closely involve the worker level, to identify problems and to work together to develop solutions (Liker, 2004). Important elements of the

LCM model developed to achieve this are explained in Section 4.5 (eg. construction card, problem card, apartment clock, KPI's).

4.4.6 Introduce a visual way of measuring performance

This objective addresses the problem of the lack of data existing on performance (Section 4.3.9.1) with regard to On-Time-Performance of companies and levels of quality.

Apart from the master plan there was no way of tracking the construction progress or performance onsite. Measurements are needed to track, forecast and to create feedback that will lead to improvement. Feedback on construction work onsite did not occur on a regular basis and only in the event of quality issues being discovered at random. There were different perceptions on quality and no clear feedback process to improve it.

The concept of transparency is important to achieve this objective. Achieving clarity on problems and how these problems impact the overall process is necessary to generate useful feedback that can be used to achieve higher levels of improvements. Also, transparency is important to facilitate communication on improvements and to better track results. Important elements of the LCM model developed to improve transparency in performance measurement, such as the apartment clock, KPI,s and action plans are explained in Section 4.5.

4.4.7 Generate an interest in continuous improvement onsite

Finally, this objective addresses the lack of continuous improvement evident onsite, as companies focused on their own individual tasks and were not concerned with other aspects of the process (Section 4.3.9.1).

Ultimately, the new solution should generate an interest and support continuous improvement onsite. An element of "learning onsite" should evolve by making the process transparent through the use of visual tools and providing a physical point for discussing and resolving problems. The solution should be a platform for continuous improvement onsite**.** The principle of perfection is also an important construct as basis for continuous improvement.

The objectives described are a formal explanation of what the solution should do. Based on the objectives of the solution, visual tools were developed to be applied systematically as part of a Visual Management Model to achieve these objectives. Based on past experience and knowledge in the implementation of Lean and visual tools (Chapter 1, Section 1.4) and the problems described in Section 4.3 and summarised in Section 4.3.9.1, the researcher developed the first version of the Visual Management Model. This included a description of the various visual tools needed and the role each had in creating transparency and improving daily operations onsite.

4.5 Step 3: Develop solution

The following section presents the first steps carried out leading to the development of the visual elements of version 1 of the LCM model.

4.5.1 Visualise the overall construction process

The first objective of improving transparency in the overall process (Section 4.4.1) could be achieved by visualising the main process and its interdependencies. As discussed in (Chapter 2, Section 2.2), when applying the Lean principles to any process, an important first step is identifying value and understanding the Value Stream by creating a Value Stream Map (VSM). In order to create transparency in the value stream (Section 4.4.1) of the construction process, an important element of the LCM model is an Overall Process Map (OPM) (Figure 4.5) which is similar to a Value Stream Map. In Value Stream Mapping, the process, material and information flow with regard to a product family or service is visualised with the aim of improving that flow and eliminating waste. The aim of the Overall Process Map (OPM) is to visualise the overall construction process together with the key project participants at the different interfaces (client, planners, construction management etc.). The objective is to achieve a common understanding of the overall process, identify interdependencies between sub-processes, agree on the optimal flow and identify the first constraints in the process and identify measures to resolve them. Figure 4.5 shows the first Overall Process Map that was carried out during the development of version 1 of the LCM model. Each row represents a different sub process and the individual yellow cards represent a process step or activity as part of that sub process. The red and black arrows visualise important critical interdependencies between the individual sub processes. In practice today, creation of the Overall Process Map during the Overall Process Analysis phase is an important first step of every LCM instantiation (Chapter 5, Section 5.4.2).

Figure 4.5: Overall Process Map (OPM): Visualising the construction process at the case study side. The interdependencies between the apartments and other areas of the building highlighted in red and green.

4.5.2 Define the standard process

In order to implement flow and a pull system onsite i.e: to achieve the second objective of ensuring a logical order of leveled work and a holistic view of the process (Section 4.4.2), the first step was to identify a standard process. Standardisation is an important foundational element of the Toyota Production System (Chapter 2, Section 2.2). Identifying a standard process was considered important in the initial development of LCM to establish the most significant flow of work and basis for splitting work down into smaller sections (later on during future instantiations however, it became clear that is wasn't always possible to identify a standard process, which is one of the challenges of the nature of construction, (Chapter 2, Section 2.8.1; Appendix A.4). Future instantiations of the model showed that it could be applied to construction processes that were difficult to standardise. However, additional visual tools such as the Process Planning tool were needed to stabilise the process (Chapter 5, Section 5.4.2 and Chapter 7, Section 7.4.2).

In case study 1, the "standard" process was the process for one apartment, since this process would be repeated throughout the building. The researcher, together with the site manager defined the standard process for one apartment. This represented the optimal flow of work within a subsection on the construction project. While the apartments varied in size, the construction steps were identical in each apartment. The standard process can be seen in Figure 4.6 below. In each apartment, different subcontractors carried out different activities and in order to make this transparent on the standard process, the different companies were highlighted using different colours next to the activity.

	Activity	Firm
1	Assemble windows and balcony doors	A
2	Plaster and stone work	B
3	Guide bars and frames	B
4	Heating installation	C
5	Electric installation	D
6	Install Door frames	B
7	Install window ledge	A
8	Internal plaster	B
9	Close gaps	C
10	Close guide bars and frames	C
11	Install floor heating	C
12	Install floor	D
13	Dry	B
14	Finish electricial and ventilation work	B
15	Sand ceiling	A
16	Sand walls and frames	B
17	Install baths and showers	D
18	Tiling in bathroom and kitchen	C
19	Wallpapering and paint work	A
20	Final assembly electricial	B
21	Final assembly plumbing	C
22	Install wooden flooring	C
23	Install doors	B
24	Cleaning	A

Figure 4.6: The standard process for one apartment

4.5.3 Define daily work packages for this flow

The standard process was used as a basis for breaking work down to a daily level. Cards were used to visualise daily work packages, which in turn were visualised over a period of two weeks on a large planning board on the construction site (Section 4.6). This was a visual pull-system that controlled the amount of work entered into the execution phase. The idea to use cards and a board to visualise the construction process, was based on the researcher's previous experience of implementing visual production planning systems in manufacturing (2002-2007), where large boards were used to visualise and control production progress on an hourly basis.

The visualisation of daily work packages helped to focus on identifying problems in execution and resolving them. During these past projects in manufacturing, the researcher had observed how various forms of visualisation were used. Different colours were used to highlight deviations from plan, which were the focus point for discussion during daily meetings. During the daily meetings, problems in the process were discussed and solutions defined. The clarity on daily targets made it possible to measure and track if those targets were met. This was also an important point of discussion during the meetings; understanding “why” if targets had not been met and identifying improvement actions. The visual measurement of performance is an important objective of the LCM model. The experiences from the application of Visual Management for production planning and control in manufacturing gathered by the researcher influenced the development of the LCM model and the choice of visual tools that it is comprised of.

4.5.4 Develop the main elements of the Visual Management Model

Once transparency of the overall process was achieved and the process could be broken down into smaller sections (apartments), the next step was to develop the remaining elements of the model that would help to visually plan and control the process by achieving the objectives defined in Section 4.4. Section 4.6 presents the individual elements of version 1 of the LCM model and describes how they aim to achieve these objectives. The elements of the models are based on the concepts of transparency, value, value stream, flow, pull and perfection as discussed in Section 4.4.

4.6 Step 4: Demonstration of version 1

Based on the objectives outlined in section 4.4, the researcher set about creating a number of visual tools that could be used as part of a Visual Management Model to achieve these. Figure 4.7 illustrates the nine main visual elements of the original version of the LCM model (version 1). Section 4.6.1 describes each element in more detail and explains how the model as a whole was implemented onsite during instantiation 1A.

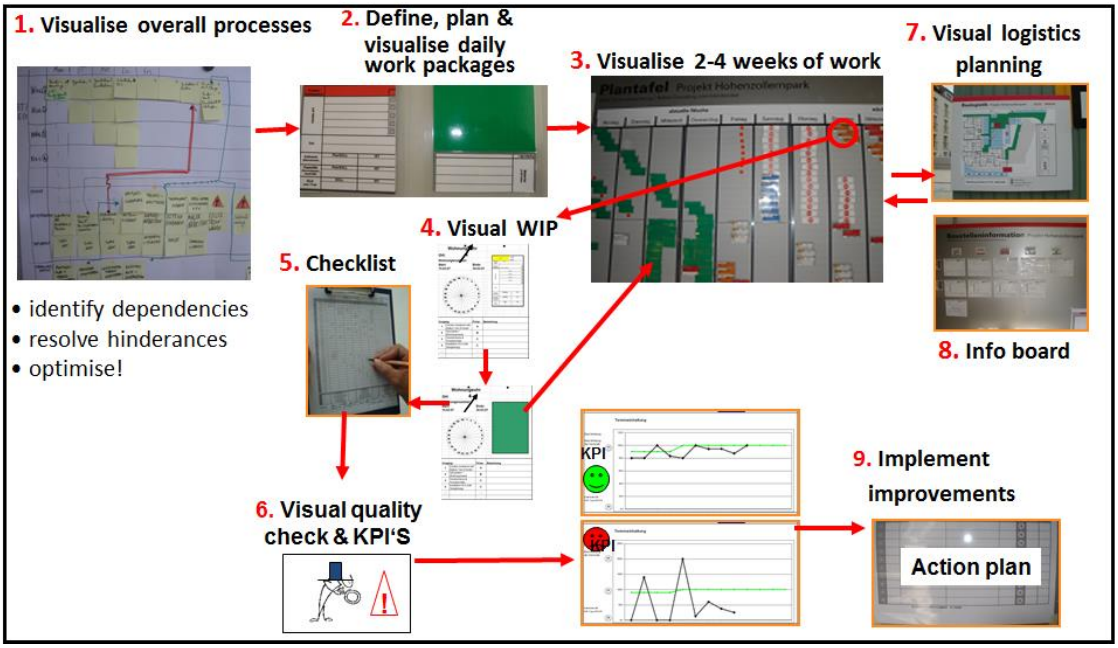


Figure 4.7: First version of the LCM model

4.6.1 Description and application of version 1 during instantiation 1A

The original version of the LCM model, consisted of 9 main visual elements; the Overall Process Map (no. 1, Figure 4.7), construction cards per company (no. 2, Figure 4.7), the daily planning board (no. 3, Figure 4.7), an apartment clock (no. 4, Figure 4.7), a construction checklist (no. 5, Figure 4.7), visual KPI's (no. 6, Figure 4.7), a logistics board (no. 7, Figure 4.7), an information board (no. 8, Figure 4.7) and an action plan (no. 9, Figure 4.7). The Overall Process Analysis had been carried out as a first step, before the development of the remaining visual tools (Section 4.4.1) and was used as basis for splitting down work and structuring the planning board. All other elements are applied together onsite and require input from construction management, company representatives and the participants at worker level. In this way they fulfil the objective described in Section 4.4.3, which is to ensure involvement of construction workers in the improvement process. The remaining visual elements of version 1 of the LCM model are as follows:

4.6.1.1 The construction card – "levelling the workload"

The objective of the construction card is to facilitate the process of splitting work down into daily packages so that the work could be evenly dispersed across the weeks visible on the planning board (Section 4.4.2). The construction card (no. 2, Figure 4.7) represented a unit of work, e.g. the installation of floor heating in apartment 1. An example of a construction card used during instantiation 1A of the LCM model can be seen in Figure 4.8. The cards were prepared by the foreman, together with the researcher and the subcontractors weekly, so that a detailed plan of work was available two weeks in advance. The cards also display the estimated worker capacity needed, the required building materials, the date, area and other relevant details. This information helped to control the amount of material building up on the site, as only material that was needed for the time period specified on the planning board was ordered.

Each day, the card for that day was collected by the worker in the morning from the planning board and taken to the area of work. At the area of work the card was placed on the "apartment clock" to indicate work in progress. When the construction worker finished his work, he turned the card around to indicate to the foreman that the work is completed. The foreman then checked the quality of the work and if everything is ok, the card was then replaced on the daily construction board, "green" side up, by the foreman. This process is illustrated in Figure 4.12.

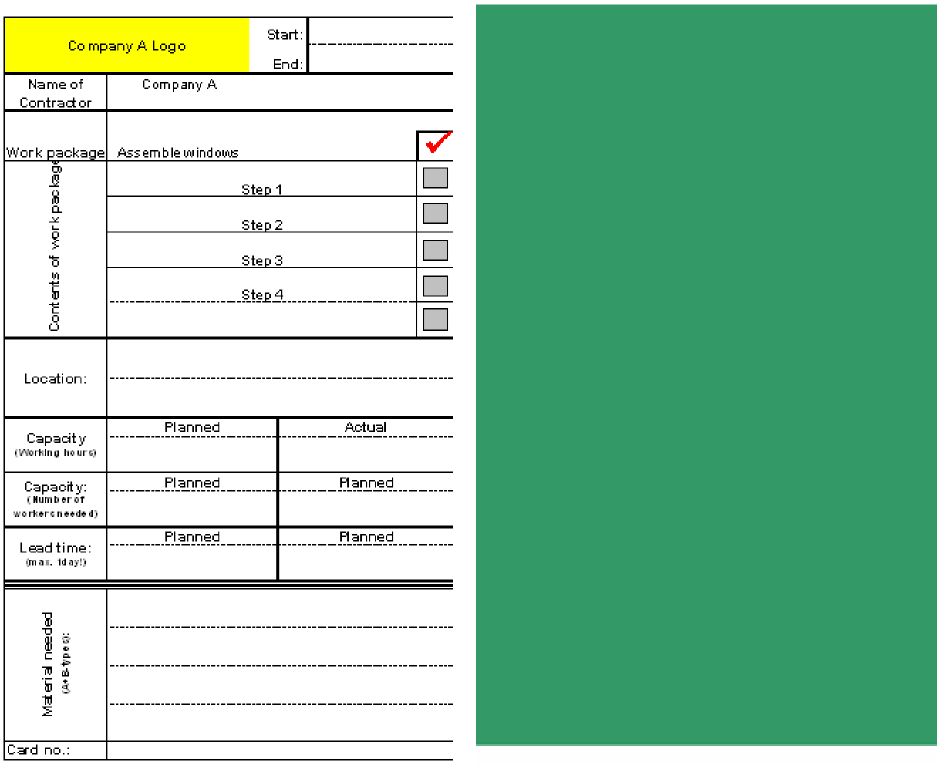


Figure 4.8: Construction card front (on the left) and turned around to face the green side (right)

4.6.1.2 The daily planning board – "visual pull system"

The objective of the daily planning board is to implement a visual pull system onsite, to facilitate the flow of leveled work (Section 4.4.2). The daily planning board (no. 3, Figure 4.7) is the "heart" of the LCM model. During the LCM instantiation on the construction site, the daily and weekly planned work packages were displayed on cards on this board, which was placed in a central area on the building site (Figure 4.9). These work packages were carefully defined and planned by the researcher, together with the foreman and subcontractors involved. They were based on work derived from the previously defined standard process, aiming to introduce flow in the work onsite.

In addition to implementing flow in the construction process, another effect of visualising these work packages was that once the cards were placed on the board it was clear to see in what areas of the site no work was being carried out (see nr. 1 and 2 on Figure 4.9). This enabled the foreman and contractors to “see” what work was carried out, where and to identify vacant areas where no work was being carried out. In addition, if a problem was perceived in the process, a problem card was placed in front of the construction card on the board. This was a signal that the work could not be carried out until the problem (described on the problem card) was resolved. It highlighted an opportunity to reduce the overall lead-time, since worker gangs could be dispersed in a more effective way so that work flowed through the building and subcontractors did not hindering each other’s progress. The visualisation of the daily activities in this way created transparency in the daily operations and a better understanding of the process in execution which could not be achieved by just using the master plan. The standard process as illustrated in Figure 4.6 was used as a source for the contents of the construction cards.

During instantiation 1A, the “standard process” included all process steps necessary to construct one apartment unit. Each apartment was visible on the planning board and just by taking one look (Figure 4.9) the status of work onsite at that particular time could be established. For example, it was clear what work was finished in what area (cards turned around to green side), which work had yet to be completed (coloured cards still positioned on board), which work was currently in operation (red spots indicating card has already been taken from the board) and where work could not be carried out for certain reasons like plaster drying (stop signs). Once the completed green cards were checked (nr. 5 and 6, Figure 4.7), data was gathered in terms of quality and On-Time-Performance (on this particular site, these were the factors considered most important by the foreman). The process of gathering, analysing and visualising performance measurement is described in Section 4.4.5-4.4.6. At the end of the working week the goal was to have a full green board indicating all work completed at an acceptable level of quality (see number 4 in Figure 4.10). The planning board was the central meeting point for the start of work each day and was the last stop for workers on leaving the site.

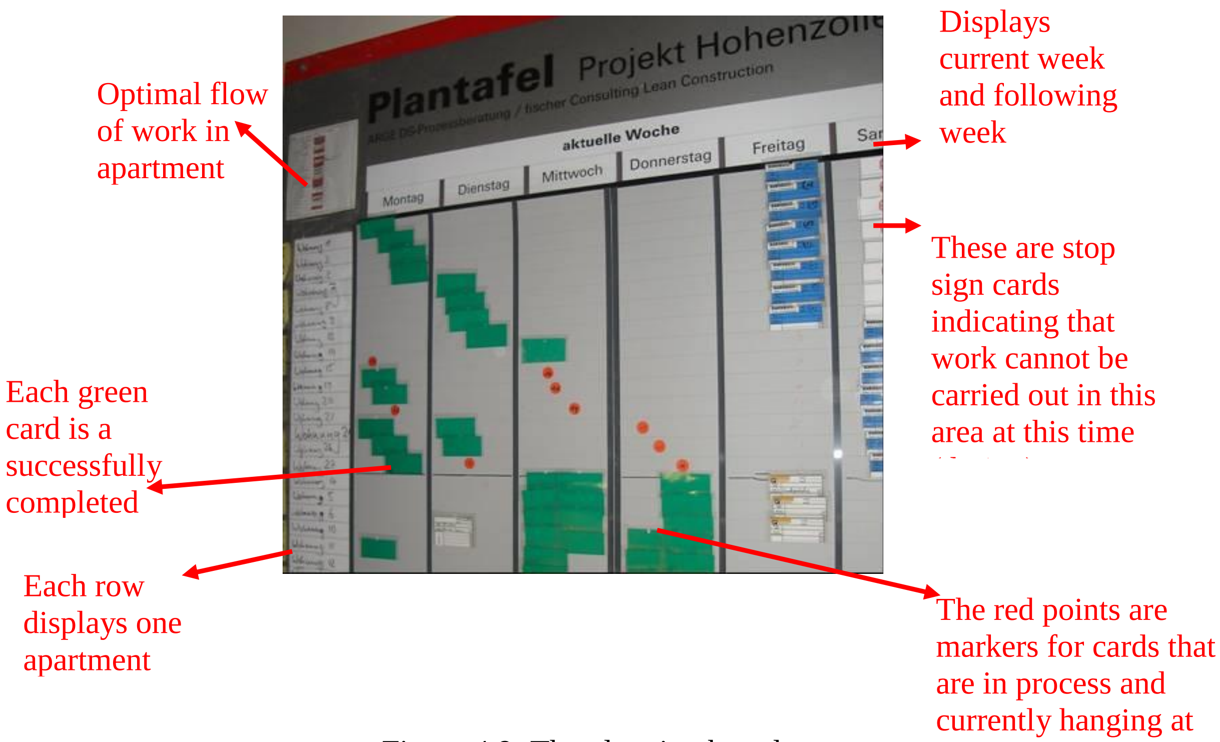
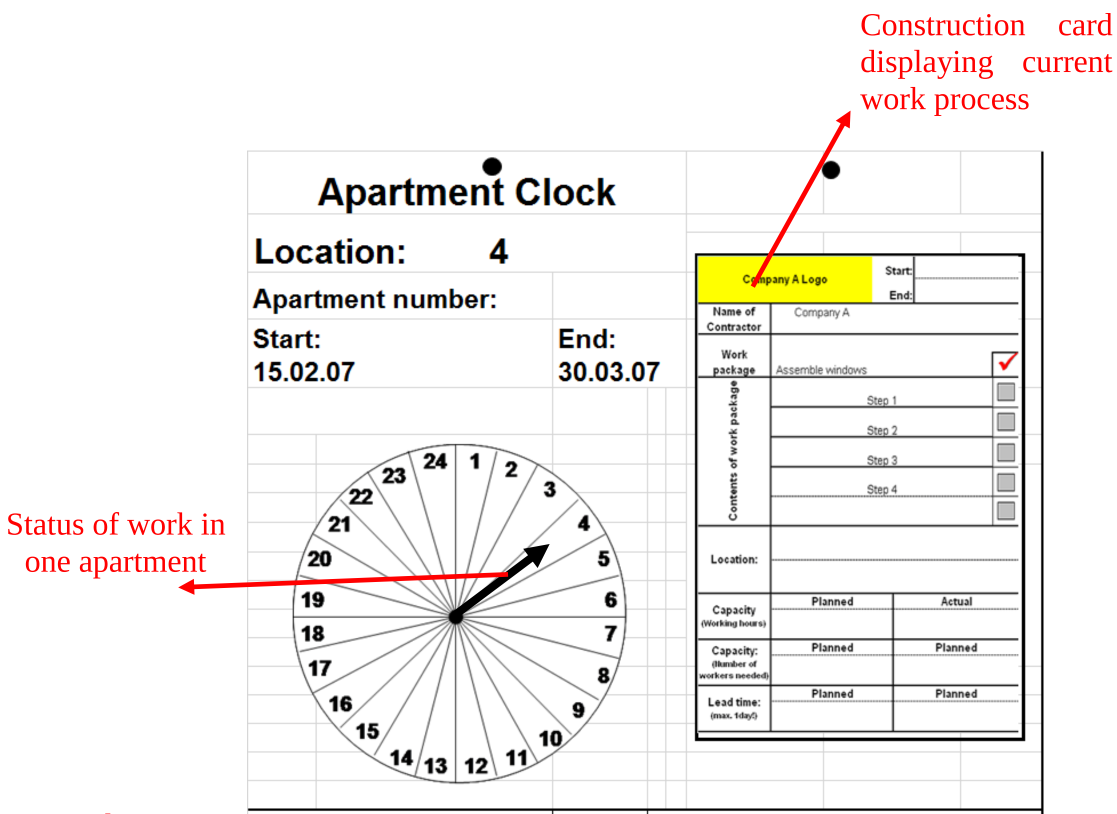


Figure 4.9: The planning board

Figure 4.10: The planning board process

4.6.1.3 The apartment clock – “facilitate regular quality checks”

The objective of the apartment clock is to visualise work in process at the area of work and to provide a mechanism for the regular quality check of that work (Section 4.4.5). The apartment clock (Figure 4.11 and Figure 4.13) was the only element of the LCM model that was visualised away from the planning board and instead displayed at the actual area of work (at the entrance to each apartment during instantiation 1A). The apartment clock visualised all steps to be taken to complete one apartment and what the current status of completion was. The process steps were written in text on the activity column and the status of the work in progress was indicated by the hand of the clock pointing to the activity that was currently in progress (Figure 4.11). The construction card was hung on the apartment clock by the construction worker to indicate which work was being carried out at the particular time. When the construction worker was finished his work, the card was turned around to the green side to indicate to the foreman that work was complete and should be checked. After reviewing the work, the foreman decided whether it met the correct quality standard or not. If not, further improvement actions were defined in discussion with the construction worker. If further measures were necessary, the foreman then turned the card back around (Figure 4.13), making a note of what had to be completed and updating the KPI’s. If the foreman was satisfied with the quality, he returned the card to the planning board, facing it the green side up. This process is illustrated in Figure 4.12.



Activity		Firm	Note
1	Assemble windows including balcony doors	A	
2	Drywall	B	
3	Plaster and foundation work	C	
4	Installation of heating and plumbing	C	
....	....	...	
....	....	....	

Figure 4.11: The apartment clock

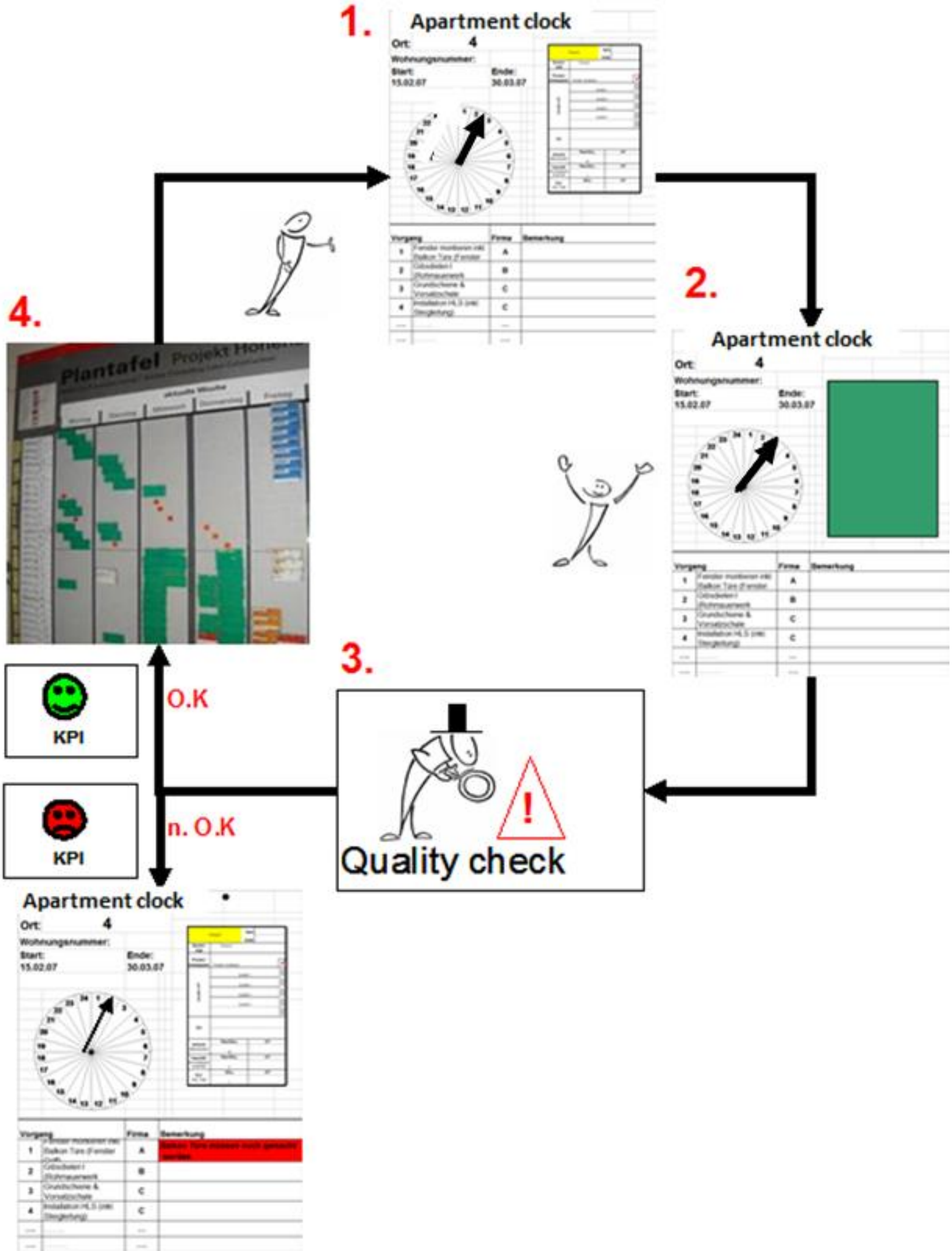
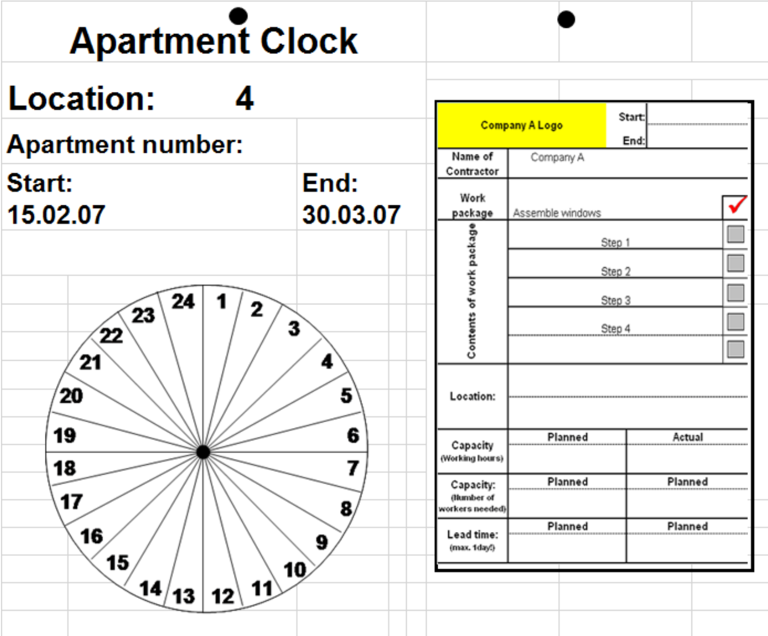


Figure 4.12: Process for use of apartment clock



Activity		Firm	Note
1	Assemble windows including balcony doors	A	Balcony doors are not fully completed
2	Drywall	B	
3	Plaster and foundation work	C	
4	Installation of heating and plumbing	C	
....	....	...	
....	....	....	

Figure 4.13: The apartment clock showing foreman requests

4.6.1.4 Construction checklist – "facilitate quality checks"

The objective of the construction checklist (Figure 4.14) was to facilitate the foreman when carrying out the daily quality check of work (Section 4.4.5). This aid was used for three main reasons:

- It was a paper copy of the "work packages" (construction cards) that had been agreed on, in the event of cards going missing from the daily construction board.

- It replaced the original protocol sent out by the foreman to the building contractors, so that everyone was aware of agreed work in the pipeline.
- It was used by the foreman as his guide to know where to expect completed work to check, on any given day.

		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Ground floor	Apt. 1						
	Apt. 2						
	Apt. 3						
First floor	Apt. 4						
	Apt. 5						
	Apt. 6						
Second floor	Apt. 7						
	Apt. 8						
	Apt. 9						
Third floor	Apt. 10						
	Apt. 11						
	Apt. 12						

	Activity	Firm
1	Assemble windows and balcony doors	A
2	Plaster and stone work	B
3	Guide bars and frames	B
4	Heating installation	C
5	Electric installation	D
6	Install Door frames	B
7	Install window ledge	A
8	Internal plaster	B
9	Close gaps	C
10	Close guide bars and frames	C
11	Install floor heating	C
12	Install floor	D
13	Dry	B
14	ventilation work	B
15	Sand ceiling	A
16	Sand walls and frames	B
17	Install baths and showers	D
18	kitchen	C
19	Wallpapering and paint work	A
20	Final assembly electricial	B
21	Final assembly plumbing	C
22	Install wooden flooring	C
23	Install doors	B
24	Cleaning	A

Figure 4.14: Checklist used by foreman

4.6.1.5 Visualised Performance Measurement – "transparency of performance"

The objective of the visualised performance measurement is to make performance of individual subcontractors and the quality of their work transparent (Section 4.4.6). Each afternoon, the daily construction cards were reviewed by the foreman (nr. 1 and 2 in Figure 4.16). Data for metrics such as quality and On-Time-Performance were gathered by the foreman, displayed and discussed at the weekly site meeting. The On-Time-Performance (OTP) metric is similar to the Percentage Plan Complete (PPC) in the Last Planner System (Ballard, 2000). Both metrics measure the extent to which commitments are realised and this measurement is expressed as a percentage. PPC is the number of planned activities completed divided by the number of planned activities expressed as a percentage. OTP is number of cards completed by the subcontractors (which are a pre-defined daily work package of activities for a specific area) divided by the total number of planned cards expressed as a percentage.

The quality and OTP metrics were calculated in a very simple way: the work on completed cards (green) was checked on a daily basis. If a company had planned to complete 6 cards and only completed 3, their On-Time-Performance was 50% (an example of the On-Time-Performance metric can be seen in Figure 4.15 (b)). From the number of completed green cards, a metric was calculated to reflect the level of quality (see Figure 4.15 (a)). The goal for quality was always 0 (Zero defects) so if 6 completed cards had just 1 quality mistake the metric would be 1/6 = 0,16. If there were 2 defects the metric was 0,33 and so on. The more defects, the further away from 0 and the lower the quality KPI would be. Corrective actions were noted and displayed on the action plan to be completed as soon as possible (number 4 in Figure 4.16). Progress of performance was monitored and displayed on the site information board (number 3, Figure 4.16). Positive results generated a positive atmosphere on the job while negative results encouraged participating companies to do better. It was observed by the researcher that the visualisation of the performance metrics helped to generate a positive element of competitiveness between the participating companies: the subcontractors generally did not want their company to represent a low performance level.

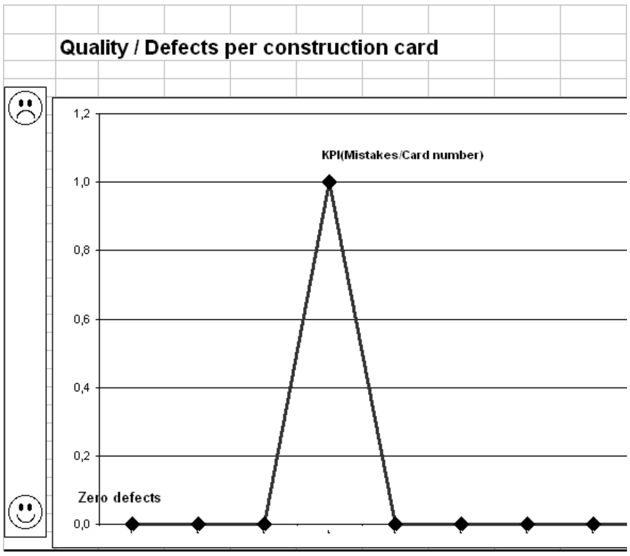


Figure 4.15 (a): Measuring quality as a KPI

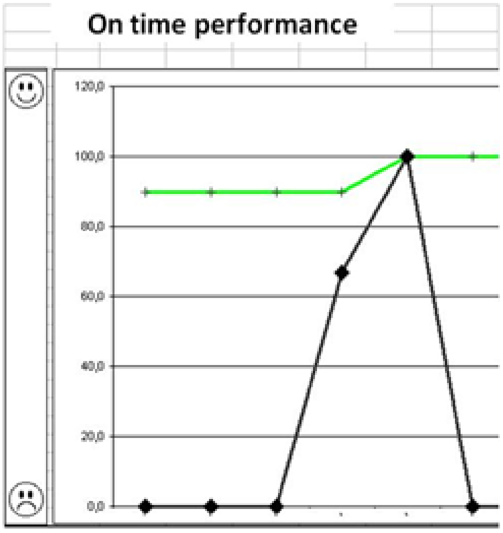


Figure 4.15 (b): Measuring On-Time-Performance as a KPI

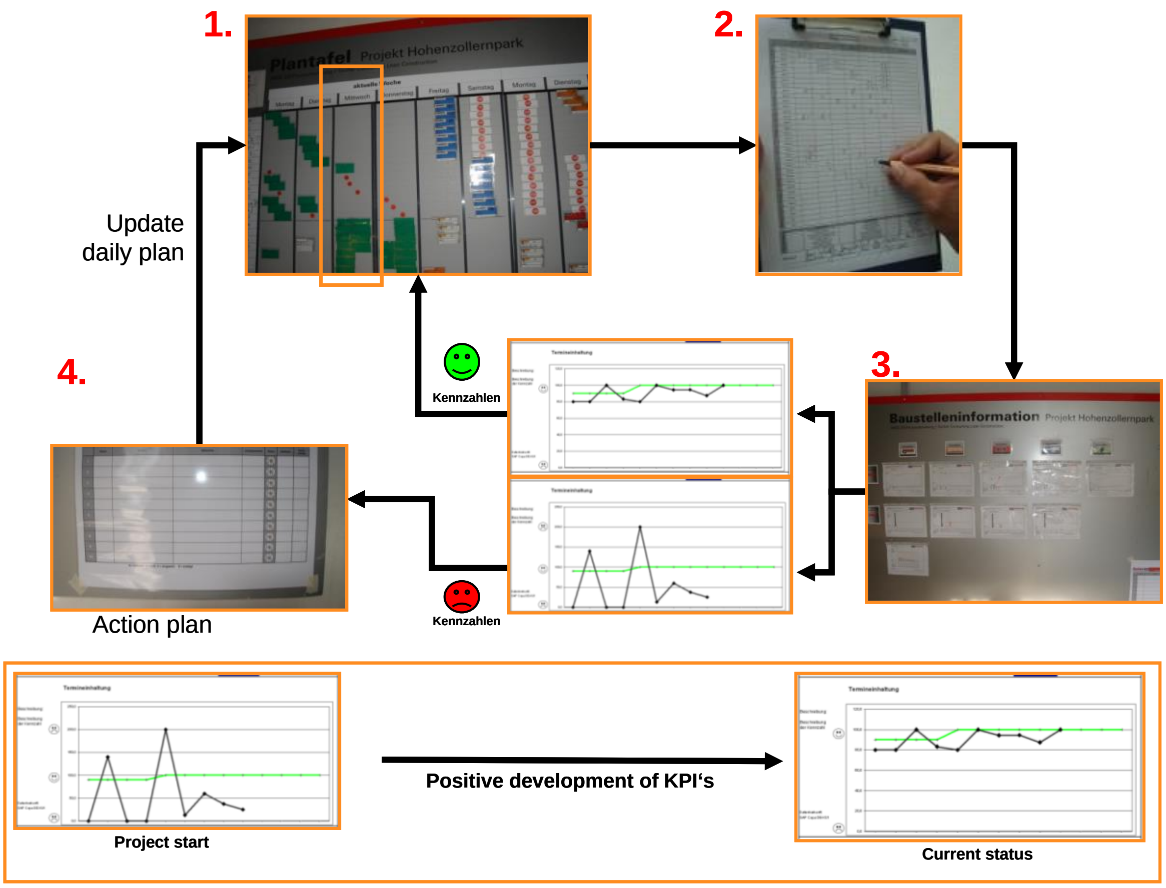


Figure 4.16: Process for gathering KPI's

4.6.1.6 The logistics board – "site management"

A further element of the LCM model was the logistics board (see Figure 4.17). The objective of the logistics board was to improve material organisation and storage onsite (Section 4.4.4). From the planning board, it was possible to more accurately estimate what material would be needed in the coming weeks. The logistics board visualised and controlled the designated areas for material storage. When suppliers arrived with material, they checked the board to see where to store the material they were delivering. This resulted in less walking, searching and less co-ordination of material needed onsite. This process is illustrated in Figure 4.18.

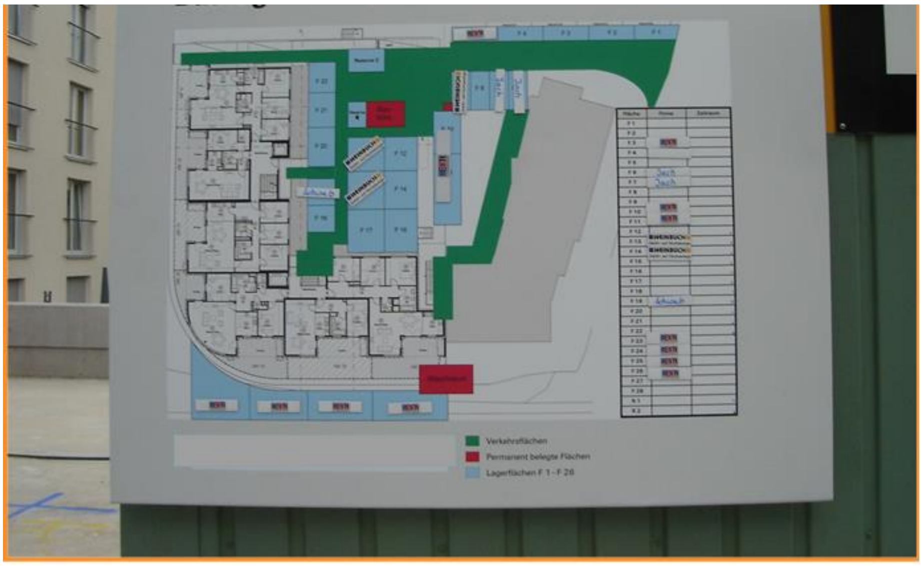


Figure 4.17: The logistics board

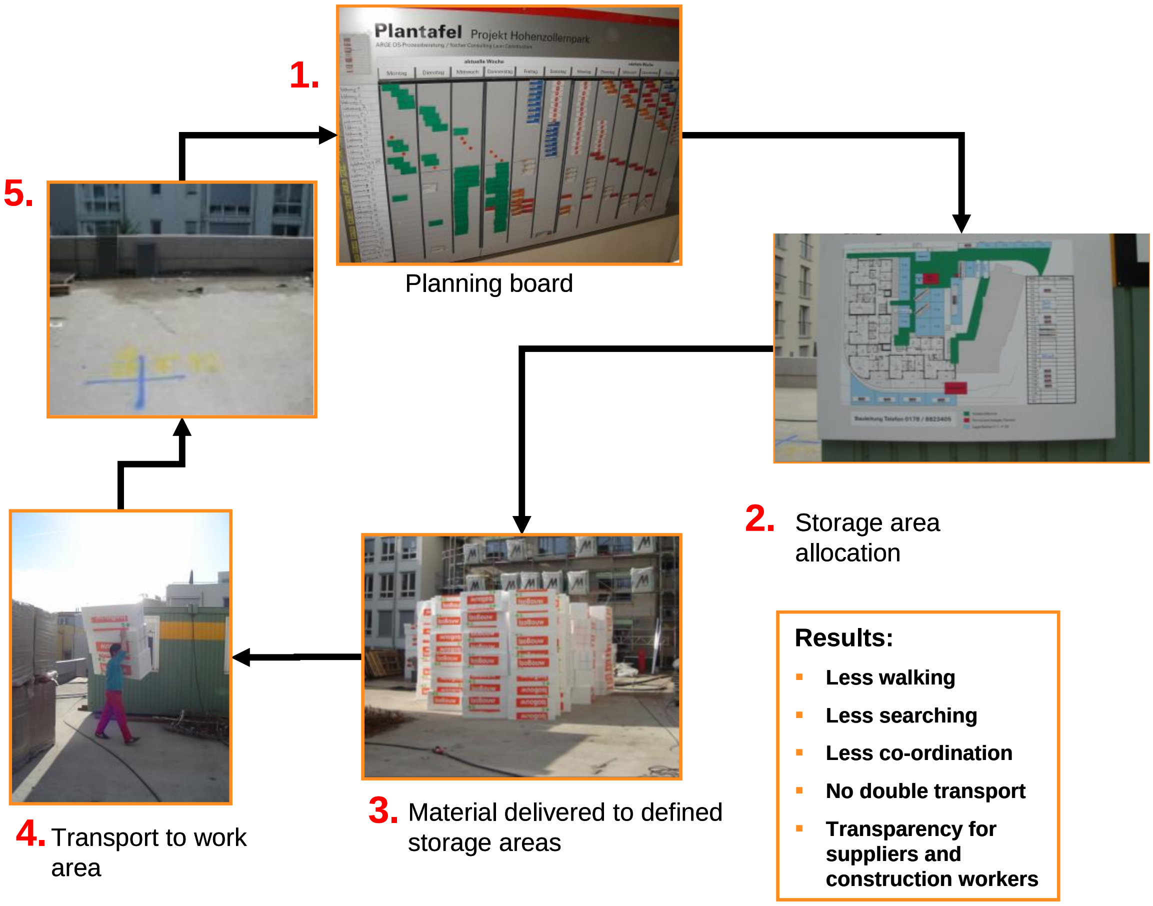


Figure 4.18: The logistics board process

4.6.1.6.1 The information board - "promote continuous improvement"

The objective of the information board (Figure 4.19) is to display all information relevant to the construction site: progress on KPI's, examples of quality issues, positive feedback. It enabled open communication on the building site and encouraged continuous improvement (Section 4.4.3 and 4.4.7). All workers at all levels from each company viewed this board to check general construction progress and news.

Figure 4.19: Information board at construction site

4.6.1.7 The action plan – "facilitating continuous improvement"

The objective of the action plan was to capture problems and their solutions identified in the construction process. Ideas from construction worker level were discussed (Section 4.4.3) and solutions defined, documented and visualised, thus facilitating continuous improvement onsite (Section 4.4.7).

Since completed work is checked on the evening it is completed, any minor issues that arose could have be taken care of immediately (since in most cases the construction worker was still present). Alternatively, problems were noted on the action plan (or the apartment clock) to be addressed the following day (Figure 4.20). The action plan was also displayed beside the planning board in the central communication area (LCM area). Since these issues were visualised, a greater awareness of the problems was created and also a greater interest in resolving them, as they remained on the action plan until they were implemented.

Action plan:
Identify and prevent problems on the construction site

	Date	Problem	Action	Responsible	Status	Target date	Date completed
1					P D A C		
2					P D A C		
3					P D A C		

Figure 4.20: The action plan

4.7 Step 5: Initial evaluation of the model

An initial reflection on the first instantiation of the model was carried out by the researcher to determine whether the first version of the LCM model was useful in improving transparency onsite and to establish what insights could be gathered regarding the future improvement of the model. The questions posed in the evaluation framework (Chapter 3, Section 3.8) were used as a guide for the researcher to reflect on the first LCM instantiation i.e.: did the visual tools of the LCM model help to improve the daily planning of activities? Could constraints be identified, removed and monitored using these visual tools? Could this be measured? Could waste be identified? Was overall transparency in the construction process improved? The main conclusions were drawn based on the feedback from the participants during the 8 weeks of implementation.

4.7.1 Limitations during the initial evaluation

There were some limitations regarding the data gathered and reviewed for the initial evaluation of the LCM model. Since the first version of the model was developed in 2007, two years before this research work began; the primary data was based on documentation and notes on discussions that had been gathered by the researcher in her role as a consultant during that time. It was not possible to formally interview any of the project participants during case study 1. In addition, KPI data gathered on On-Time-Performance and quality during the observation period was largely incomplete. The concept of measuring performance was a very new concept onsite and since the foreman was not present on site each day, the data was not gathered adequately. However, based on the discussions with the foreman on site and the impressions gathered from the observations the researcher carried out onsite, some positive effects could be noted.

4.7.2 An improvement in the transparency of work and performance

The feedback from the site foreman and the contracting companies indicated that the use of visual tools in this collective way had made the daily operations onsite more transparent. The preparation and visualisation of daily work packages strengthened the commitments and made it easier to monitor progress. The opinion of the foreman indicated that it helped him to identify and resolve problems in the construction process earlier, together with the sub-contractors. The logistics board enhanced the organisation of the site by reducing the overall amount of material stored throughout and in turn reduced the amount of walking, searching, transport needed.

> "LCM created transparency in the construction process, which helped the subcontractors to better plan resources. It requires a different way of thinking and all participants must play an active role in identifying problems and resolving them" (foreman).

The improved transparency of the construction process enabled the researcher to identify sub-processes for short Kaizen improvements onsite. The goal of these Kaizen workshops was to visualise and optimise a sub-process together with the construction worker. Two of these kaizen improvements were carried out during the LCM instantiation, which enabled the identification of various improvement actions that contributed to a reduction of waste in the process (excess movement, searching for material etc.). In the first example, a productivity improvement of 57% could be achieved. Worker movement needed to carry out the activity could be reduced by relocating the material and equipment needed. The overall lead time of the sub process could be reduced by at least 50%. In the second example, a productivity improvement of 25% could be achieved through a better organised and aligned process. These Kaizen improvements are described in more detail in Appendix C1 and C2.

4.7.3 Recommendations for future application and improvements to model

The experience gathered from the first development and instantiation of LCM, enabled the researcher to make recommendations for future application and improvements to the LCM model on future projects. These recommendations and improvements are summarised in Table 4.3 and described below.

4.7.3.1 Implementation in phases

As described in Section 4.4-4.6, the initial step in the application of the LCM model involved the visualisation of the overall process and definition of a standard process. The researcher recommended that an LCM instantiation should involve three main phases classified as the preparation, analysis and implementation phase. In each of the phases different tasks and roles were defined. The preparation phase for example, was concerned with carrying out the necessary preparations onsite eg: finding a suitable, central area to strategically place the visual tools, communicating to participants of the project about Visual Management, the model itself and their role in the process, forming a team at this stage that would work together to implement the model (the site manager, company representatives, planning specialists). An important part of the analysis phase was the teamwork in workshops to visualise the overall construction process, the interdependencies and critical issues. It was also important to gather all available information on the project: master plan, companies involved, information on site logistics. The implementation phase focused on adapting the individual elements of the LCM model to the specifics of the project in question, defining what roles were involved and how the individual elements of the model should be applied and how they are used. These recommendations have been implemented and further adapted in practice today and are more clearly described in Chapter 5, Section 5.4.2. A description of the associated method of the LCM model today is presented in Chapter 8, Section 8.4.3. Since the first instantiation (1A) described in this chapter, the main elements of the LCM model remain quite similar in practice today and the phases of implementation have become more formalised. The model has also been further developed (Version 2 & Version 3) through application to different construction scenarios than the one presented in this chapter (Chapter

5, Section 5.4.2; Chapter 7, Section 7.4.2). All of the improvements under the category of "process" in Table 4.2 have been adapted and are part of the method of application currently in practice.

4.7.3.2 Further improvements to the model

On further reflection, other improvements to the model were identified. These are clustered under the headings of improvements to "physical system" and "human element" in the Table 4.3. These improvement categories to the LCM model are mainly in a physical sense and considered to be of minor importance. It is not thought that the application of the model or its use will be greatly affected by these changes, perhaps slightly improved. These improvements were noted based on the experiences and feedback gathered during implementation. For example, a concern was expressed on a number of occasions by the foreman and subcontractors about the loss of cards from the planning board and how this could be avoided. Perhaps surprisingly, this never posed an issue but in later versions of the model (Chapter 7, Section 7.4.2), the electronic data base for card content meant that information on the cards could be reprinted in the event of loss of cards. Improvement ideas of adding an element of 5S to the LCM model and of combining the visual tools of the LCM model with ICT technologies are considered to be more significant improvements for future development. In practice today, further development work is currently going on regarding the combination of the LCM model with BIM technologies and the integration of the LCM model in the design phase. How these improvements will be implemented however is not within the scope of this research.

Table 4.3: Improvement points from first evaluation of version 1

Area	Improvement action
Physical system	Use of poke yoke preventing loss of cards
	Make 5S integral part of LCM
	Possibility to automate LCM using ICT technologies
	Development of handheld device to aid foreman
	Alternative, lighter material for construction board
	More concise and clear construction cards
	Improved visualisation and expression of KPI's
	Refine process for using action plan
	Develop reuseable construction checklist
	Improve link between action plan and apartment clock
	More user friendly display of information on information board for construction worker
	Rename logistics board to reflect functionality and ensure material suppliers are involved earlier in process
Process	Conduction of LCM instantiation in clearly defined phases: preparation, analysis and implementation
	Assign LCM team for instantiation consisting of a Lean specialist(s), construction management and representatives from contracting companies
	Create SOP's (Standard Operating Procedures) for each of these phases, which decribes how they should be conducted, what information and data should be gathered etc..
	Use visual tools such as process maps to create transparency in the construction processes and to help identify main processes and optimum flow which is the basis of the LCM model
	A clear and concise timeplan for implementation should be created and followed
Human element	Consider parameters such as age, nationality when preparing the LCM model
	Consider ways to improve motivation and reduce alienation of workers
	Improve cognitive ergonomics of LCM by standardising, exploiting stereotypes etc.

4.8 Chapter summary

This chapter presented the data collected and analysed for case study 1 as part of this research. The chapter was structured around the six steps of Peffers, et al. (2007) model for Design Science application: 1) problem identification, 2) definition of the objectives for a solution, 3) design and development, 4) demonstration and 5) evaluation. The process of development of the first version of the LCM model was presented, followed by an explanation of how the individual visual elements of the model were applied during instantiation 1A. In addition, findings from an initial evaluation of the model were presented.

The next chapter presents case study 2, in part 2 of this research, where the LCM model is further developed and applied to refurbishment construction.

5 Application of LCM to refurbishment construction: Case Study 2

5.1 Introduction

This chapter presents case study 2, carried out in part 2 of the research. Part 2 of the research focuses on the further development and application of the LCM model based on two instantiations to refurbishment construction (instantiations 2A & 2B). These two instantiations represent version 2 of the LCM model and are the focus of case study 2. Instantiation 2A was conducted by a third party and instantiation 2B was conducted by the researcher. Instantiation 2B presented a unique opportunity for the researcher to implement the improved model first hand (version 2) to a similar type of project as that in instantiation 2A. An important goal of case study 2 is to explain how the LCM model was further developed and applied to a different construction scenario than for which it was originally developed. Furthermore, an evaluation of the model is carried out based on instantiations 2A and 2B. Steps 3-5 of Design Science research, as per Peffers et al. (2007) model 3) design and (further) development 4) demonstration and 5) evaluation are the main research activities carried out to achieve this goal. As part of step 6) communication, an IGLC paper in 2013 and a CIB paper in 2014 on the work were published.

5.2 Data collection

Data was gathered on two LCM instantiations to refurbishment construction. For instantiation 2A, the data gathered (Table 5.1) was similar to that presented in Chapter 4, Table 4.1 in that it mainly consisted of different forms of documentation such as photos, descriptions of observations and of the application process, examples of visual tools used, templates for visual tools, presentations and reports on application (Table 5.1). This data was analysed to demonstrate and build an explanation of how the LCM model was adapted and applied to refurbishment construction. Explanation building is the analytic technique used to analyse the data from the case studies. Here, the goal is to analyse the case study data by building an explanation about the case; why and how the LCM model was developed and applied in the first instance (Chapter 4) and how it was further developed and applied to determine whether it was useful and applicable.

Table 5.1: Data gathered for instantiation 2A, refurbishment construction

DATA GATHERED FOR INSTANTIATION 2A				
Research focus	**Project description**	**Type of data**		**Date**
Case study 2: Instantiation 2A (refurbishment)	LCM instantiation to refurbishment project by 3rd party	Document analysis	1) Project proposal 2) Photos of implementation 3) Plans 4) Masterplan 5) LCM implementation plan 6) Copies of flipcharts from LCM workshops 7) Reports from LCM implementation workshops 8) Documentation of process planning 9) Action plans 10) Electronic construction cards used 11) Overview of areas for planning board 12) KPI data on companies (on time performance and quality) 13) Logistics documentation (overview of storage areas) 14) List of companies involved in implemenation 15) Dcoumentation describing DP meeting and how planning board is used	July 2011-July 2012
		Semi-structured interviews	1) 2 semi- structured interviews with LCM manager	14 th July 2013 & 6th August 2013

As part of the data collection for instantiation 2A, the researcher also carried out two semi-structured interviews (Table 5.3) with the third party who implemented the model to fully confirm the researchers understanding of how the model was applied and to evaluate its utility. Questions derived from an evaluation framework developed for this work (Chapter 3, Figure 3.4 and 3.5) were used as a guideline for the semi-structured interviews.

During instantiation 2B, where the researcher personally implemented the LCM model on a further refurbishment project (instantiation 2B), additional data was gathered from documentation and participant observation (Table 5.2). Data was gathered from observations of activities onsite, participation in and leading workshops, participation in meetings and observation of planning meetings. With regard to the participation in workshops and meetings on site during instantiation 2B, this could also be described as "action taking" in action research since the workshops and meetings were conducted to implement the model so that current practice was changed and improved (Baskerville, 1999). Action taking is part of action research where the researchers and practitioners collaboratively intervene into the client (practitioner's) organisation, causing certain changes to be made.

The researcher also conducted two semi-structured interviews with the foreman and the client involved in instantiation 2B (Table 5.3), which was an important source of data for the evaluation of the model (Appendix B.3). In addition, data on KPI's (On-Time-Performance and Quality) was gathered during instantiation 2B as part of the evaluation of the model. The KPI data was gathered each day by the foreman, who checked the completed work and the quality of that work. He would then note the daily performance and quality levels on the KPI's displayed in the LCM area. A list of the data gathered for instantiation 2B is presented in Table 5.2.

Table 5.2: Data gathered for instantiation 2B, refurbishment construction

DATA GATHERED FOR INSTANTIATION 2B				
Research focus	**Project description**	**Type of data**		**Date**
Case study 2: Instantiation 2B (refurbishment)	LCM instantiation to refurbishment project by researcher	Participant observation	1) 6 Workshops with client, planners and engineers to visualise the overall construciton process (15 participants). 2) 14 Meetings (monthly over 14 months) with client and construction management to prepare Process Planning meeting. 3) 14 process planning workshops (monthly over 14 months) to create and update visual Process Planning tool with client, planners, foreman and construction companies (30-35 participants) 4) 3 meetings with client for implementation status	1) April 2012 2) May 2012-July 2013 3) May 2012-July 2013 4) Aug 2012, Nov 2012, June 2013
			1) 15 planning board meetings onsite with construction companies, planners, forman (meeting took place weekly, researcher was present once a month) 2) Regular site visits to check the planning board / support foreman 3) Observation of storage areas, material delivery 4) Observation of quality issues	1) April 2012-July 2013 2) April 2012-July 2013
		Document analysis	1) Project proposal 2) Photos of implementation 3) Plans 4) Masterplan 5) LCM implementation plan 6) Documentation of process planning 7) Action plans 8) Construction card examples 9) Overall process analysis map 10) KPI's (On time performance / quality)	June 2012-July 2013
		Semi-structured interviews	1) 1 semi- structured interview with client 2) 1 semi-structured interview with foreman	15th August 2013

Table 5.3: Summary of interviews conducted

RESEARCH PART	NO. OF INTERVIEWS	FUNCTON OF INTERVIEWEE	DATE	SOURCES OF QUESTIONS
Part 2, Instantiation 2A	2 semi-structured interviews	LCM manager	14th July & 6th August	Evaluation framework, figures 3.4 & 3.5
Part 2, Instantiation 2B	1 semi-structured interview with client	Project manager	15th August 2013	Evaluation framework, figures 3.4 & 3.5 and interview questions appendix c, section 10.3.1
	1 semi-structured interview with foreman	Foreman	15th August 2013	

5.3 Further development (step 3: Design & Develop)

In chapter 4, the development of version 1 of the LCM model was explained and the elements of the model were presented. Recommendations for future implementation and improvements to the model were proposed (Chapter 4, Section 4.7.3). This chapter presents a further improved version of the LCM model (version 2) and demonstrates how this version was applied to refurbishment construction. Figure 5.1 presents version 2 of the LCM model. The most notable further development of the model compared to version 1 (Chapter 4, Section 4.6, Figure 4.7) is the addition of a visual tool for Process Planning (no. 2, Figure 5.1), a more detailed logistics board (no. 6, Figure 5.1) and the use of colour-coded plans to visualise work in process (no. 5, Figure 5.1), rather than the original use of an “apartment clock” at the area of work. Furthermore, in contrast to version 1, version 2 of the LCM model is applied in three clear phases to the refurbishment projects in instantiations 2A and 2B: the Overall Process Analysis phase, the Process Planning Phase and the Detailed Planning Phase. Section 5.4.3 discusses the new elements of version 2 of the LCM model in more detail.

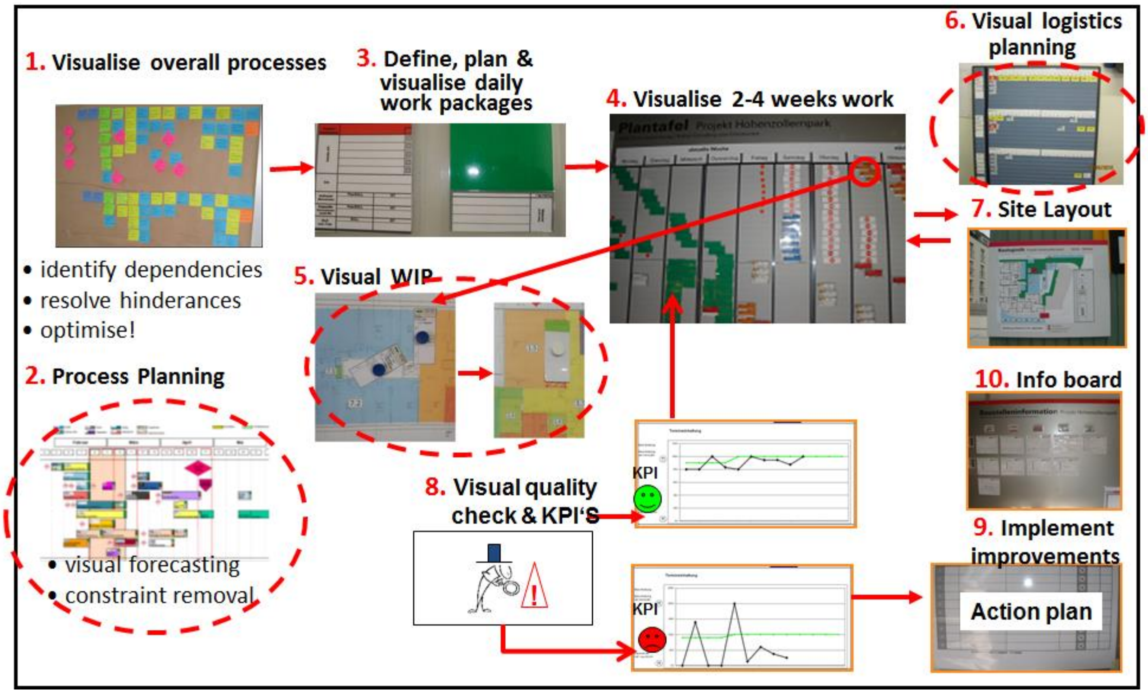


Figure 5.1: Version 2 of the LCM model – new elements highlighted in circles

The following section 5.4 presents the research carried out in case study 2. Section 5.4.1 presents the background of instantiation 2A and 2B. Section 5.4.2 presents a description of the more formal phases of implementation as part of version 2 of the model based on the two instantiations. An overview of the visual tools applied as part of the model in each phase is provided. Section 5.5 presents an evaluation of the model based on data collected on both instantiations, to establish the models usefulness and applicability.

5.4 Application of LCM to refurbishment (step 4: Demonstrate)

5.4.1 Case study 2

This section presents case study 2 which explains how version 2 of the LCM model was further developed and applied to refurbishment construction. Case study 2 is based on two instantiations of the model with the same client at the same geographic location (but two separate buildings). The background of the instantiations are presented separately in the case study, however the process of application of the model to the refurbishment projects is presented together as the process of application is identical. The researcher first of all, established how the model was applied to refurbishment construction by reviewing the data available on the application by third parties (instantiation 2A). The researcher then personally applied this further adapted model to an additional refurbishment project (instantiation 2B). KPI data on On-Time-Performance and quality of work during each instantiation was gathered and is presented in Section 5.5 as part of the evaluation of the model.

5.4.1.1 Background of instantiation 2A

Instantiation 2A involved the application of LCM model to a refurbishment project by a third party. The construction work involved the refurbishment of a 5-floor office building; 3 levels of offices and 2 technical levels due to be completed between March 2011 and February 2012. The office-building was part of the client's European company headquarters. Figure 5.2 shows the LCM area during instantiation 2A where the planning board and all visual tools of the LCM model were visualised.

Figure 5.2: LCM area during instantiation 2A of the model, case study 2

5.4.1.2 Background of instantiation 2B

Instantiation 2B of the LCM model to refurbishment construction was carried out by the researcher. The setting for this instantiation was the refurbishment of a 9-floor office building; 6 levels of offices and 3 technical levels, which was also part of the client's European company headquarters. The decision to apply the LCM model to this further refurbishment project at the same location, was based on the positive effects that the model had shown during instantiation 2A. The renovation of the second office building (instantiation 2B) was carried out between May 2012 and August 2013. This office building was similar to that of instantiation 2A, but it was a larger, more complicated refurbishment project due to the high number of unique room specifications. Figure 5.3 below shows the LCM area during instantiation 2B where the planning board and all visual tools of the LCM model were visualised.

Figure 5.3: LCM area during instantiation 2B of the model, case study 2

In contrast to case study 1, where the model was initially developed and applied during the construction phase, in case study 2, the process of the LCM instantiation began before execution. By applying LCM, it was hoped that the following effects would be achieved on both projects through the increased transparency:

- A more stable building process with better resource planning.
- A better understanding of the process flow.
- Identification of interdependencies and constraints earlier through increased transparency.
- Use of additional time buffer (identifiable through visualisation of the daily work).

5.4.2 Application of version 2 of the model in three phases

During the refurbishment instantiations, the LCM model was applied in three phases: 1) the Overall Process Analysis phase (OPA) 2) the Process Planning phase (PP) and 3) the Detailed Planning phase (DP). This section describes each phase and explains how the LCM model was adapted to this type of construction scenario.

5.4.2.1 Phase 1: Overall Process Analysis (OPA)

The first phase of implementing the LCM model which was carried out in both instantiations is known as the Overall Process Analysis phase (OPA). The goal of the Overall Process Analysis phase is to create an Overall Process Map (OPM) where the main construction processes and interfaces are visualised using different coloured post-it's on a large brown paper. The OPA took place once throughout the project, 2-3 months before the construction process began. The OPM was created in a workshop with participants from the different interfaces of the construction project. 3 workshops were needed to complete the OPM for instantiation 2A. Due to the higher complexity of the building in instantiation 2B, 6 workshops were needed to complete the OPM.

On both instantiations 2A and 2B, the participants included: an owner representative, construction management (site manager and supervisors), construction specialists (planners, engineers) and the LCM manager (in instantiation 2A this was a third party, in instantiation 2B, this was the researcher). In total, approximately 10 participants were present at the OPA workshops during instantiation 2A and approximately 15 participants during instantiation 2B.

During the OPA, the construction project was divided into suitable areas and processes that were later used as a structure for the Process Planning tool and the Planning Board.

Parallel to creating the Overall Process Map, any constraints known at this early stage of construction were noted and captured on an action plan. These constraints were discussed, the solutions developed and the persons responsible for implementation were defined along with the target date for completion. This action plan was tracked by the LCM manager and site manager to ensure completion. The site manager was responsible for co-ordinating and supporting the implementation of the action plan. The LCM manager would check the status of implementation on a weekly basis to ensure constraints were being removed and to identify any further support needed.

Figure 5.4 (a) shows a snapshot of the OPA for instantiation 2A. The main processes visualised on the OPM for instantiation 2A were: the process of each office floor, staircase, installation ducts, sanitation, facade, roof, air conditioning, IT and elevators. Figure 5.4 (b) shows a snapshot of the OPM for instantiation 2B. The main processes visualised on the OPM during instantiation 2B were: the process for each office floor, the process for the two steering committee levels, process for reception area, staircase, casino, elevator, garage, electrical engineering, break rooms, process for technical levels and roof. A more detailed snapshot of the result of the OPA (the OPM) from instantiation 2B can be found in Appendix D.

Figure 5.4 (a): Snapshot of Overall Process Map from instantiation 2A, case study 2

Figure 5.4 (b): Snapshot of Overall Process Map from instantiation 2B, case study 2

During the Overall Process Analysis, a common understanding among all participants of the process at an early stage was improved, so that communication on constraints, interdependencies and the flow of work was enhanced during the construction phase.

5.4.2.2 Phase 2: The Process Planning Phase (PP)

The main aim of this phase was to create the long-term forecast of work for the specified timeframe of 4 months, based on the OPA. During both instantiations 2A and 2B, a four-month forecast of activities per area was prepared and visualised using a tool called the Process Planning (PP) tool (Figure 5.5). The Process Planning tool is a further development by third parties (colleagues of the researcher) of the LCM model from version 1. It is a visualisation of the planned flow of work, the work areas, the sub-contractors for each activity, constraints, milestones and readiness of work (indicated using green for ready and red if a milestone has not been reached). During instantiations of the model following its initial development, the need for a better link between the Overall Process Map (Chapter 4, Section 4.5.1) and the planning board onsite was identified. Using Visio, a tool was created to focus on a four-month timeframe of the construction work. The processes defined in the OPA phase were added to the Visio template and activity blocks per subcontractor were added according to the specified flow of work. Information on timeframe and activities was also taken from the master plan. The Process Planning is similar to lookahead planning in the Last Planner System, which controls the flow of work (Ballard, 2000). A Process Planning workshop was carried out once a month during instantiation 2A, to update the information on the tool.

The participants of this workshop in both instantiations were the owner representative, construction management (site manager and supervisors), construction specialists (planners, engineers), the subcontractors and the LCM manager. In total, approximately 20 participants were present at the OPA workshops during instantiation 2A and approximately 30 participants during instantiation 2B. During instantiation 2B, an additional preparation meeting with the foreman and the client was carried out two weeks before each Process Planning workshop to ensure the complexity of the work was fully understood in time (the participants would receive a PP proposal two weeks in advance to have enough time to consider all constraints and possible solutions) and use the time effectively during the Process Planning workshop.

The Process Planning workshop was facilitated by both the LCM manager with the support of the site manager. In the workshop, the activities to be carried out in the four-month period were discussed. During the first Process Planning workshop, milestones were defined for the activities to help focus on the criteria important for the stability and reliability of work. During the monthly Process Planning workshops, the current status of planned activities were reviewed and updated and the activities for the new month were added. The status of constraint removal was checked and new constraints for the additional month were identified and captured in the Process Planning action plan (separate to the overall process planning action plan).

5.4.2.2.1 Use of visual tools to plan the process

The visual tools used in the PP phase are a combination of colour-coding and similar to the concept of Andon (Chapter 2, Section 2.2.1). Different colours were used to highlight the most significant elements of the construction project i.e: the work areas, the activities, the milestones, the constraints, the readiness of work, the flow of work and the parties responsible for carrying out that work. Figure 5.5 below shows a snapshot of the Process Planning tool from instantiation 2B.

Number 1 in Figure 5.5 shows the defined milestones – in instantiations 2A & 2B. Examples of milestones were that all approvals should be available 6 weeks in advance of construction and material should be available 2 weeks in advance of construction. Number 2 in Figure 5.5 shows the readiness of work: green meaning ready, red meaning not ready (this is similar to the concept of Andon. Andon systems use lights to indicate there is a problem in a process (Liker, 2004). In this case, a small red circle is displayed beside an activity to indicate that this work is not ready for execution). Number 3 in Figure 5.5 shows a constraint in the process identified by a number in front of the activity. This number corresponds to the number on the action plan visualised in the LCM area. Number 4 in Figure 5.5 shows the activities and the subcontractors responsible for the activities. A specific colour is allocated to the individual subcontractors and activities, which corresponds to the colours used on the cards for the planning board later on. Number 5 in Figure 5.5 shows the different areas identified in the project which corresponds to the structure of the planning board later on. Finally, the Process Planning tool itself visualises the planned flow of work for the four-month time period.

On completion, the Process Planning forecast was then printed out in A0 and displayed in the LCM area. The Process Planning workshop provided an important link for two way communication between the construction management, planning and the execution teams. Planned worked was discussed, the constraints were identified and the outcome of these two-way discussions was visualised on the PP tool.

A KPI metric to measure the stability of the Process Planning was developed by the LCM manager during instantiation 2A. After each PP workshop, the number of activities altered from the previous months PP were noted. KPI data regarding the stability of the Process Planning was only gathered during instantiation 2B of the model and is presented in the evaluation Section 5.5.

The KPI for stability was calculated as follows:

$$\frac{\textbf{Total promised activities from PP} - \textbf{Number of activities not feasible}}{\textbf{Total promised activities from PP} + \textbf{Postponing factor}}$$

The "postponing" factor was determined by how many weeks the activity was postponed e.g. for 1-2 weeks, add on 1 point, for 3-4 weeks, add on 2 points and for 5 weeks or more add on 3 points. By comparing any alterations in planned activities from month to month, the stability of the promises made in the Process Planning phase could be measured.

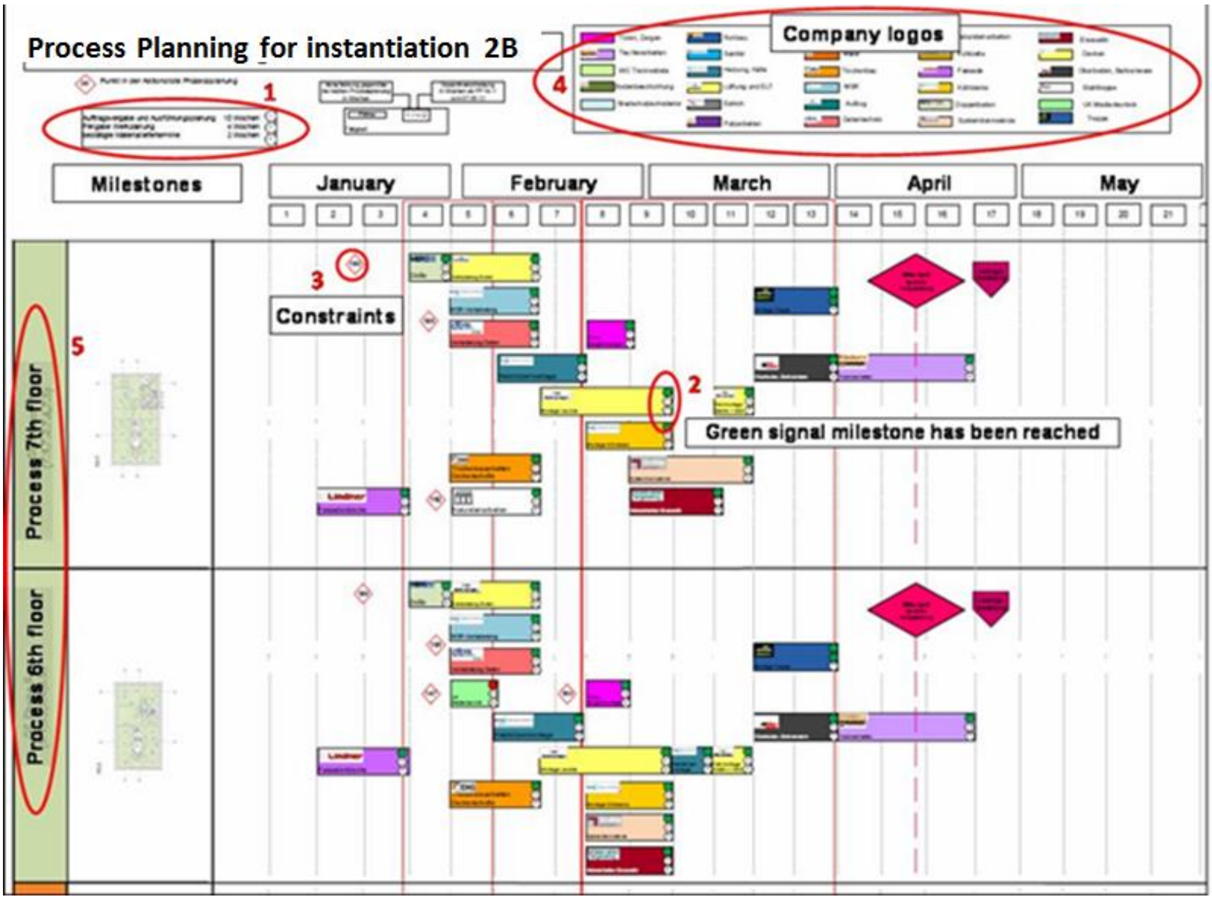


Figure 5.5: Snapshot of the Process Planning tool from instantiation 2B, case study 2

5.4.2.3 Phase 3: The Detailed Planning phase (DP)

The four-month forecast from the Process Planning was an important guide for the Detailed Planning process and provided a link between the long term planning (over 4 months) and short-term planning of construction work. A three week subsection from the Process Planning was focused on for the Detailed Planning, where daily work packages were visualised on the planning board (Figure 5.6) in the LCM area. This is similar to the process described in case study 1 (Chapter 4, Section 4.6). The LCM area, was the designated central area onsite where all of the visual tools of the LCM model were displayed together. It was the place where all levels of the project came together to retrieve and display information and communicate on current construction issues (Figures 5.2 and 5.3).

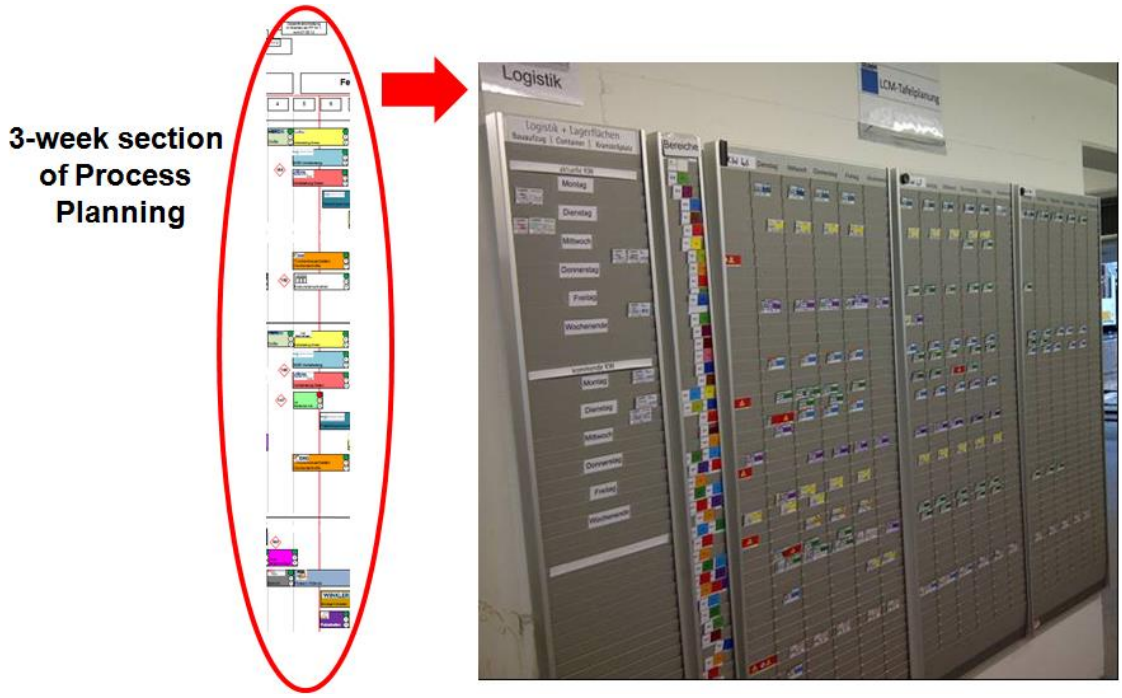


Figure 5.6: Planning board, instantiation 2B, case study 2

As part of this phase, a weekly planning meeting (Figure 5.7) took place at the planning board to discuss, complete and "place" cards on the board at the area of work and to resolve any constraints that were in the way of this work. Participants of the meeting were: the site manager, site planer, supervisors, sub-contractors and the LCM manager.

Figure 5.7: Weekly meeting at the planning board

The actions defined (Figure 5.8) were tracked and visualised (Figure 5.9) on the information board (Figure 5.10), along with other important details which were displayed such as the action plans from the OPA and PP, the KPI's, a description of roles, the most current version of the PP, a section of the OPA, and a status of implementation (how many actions have been implemented in the OPA, PP and DP phases expressed as a percentage) (Figure 5.11).

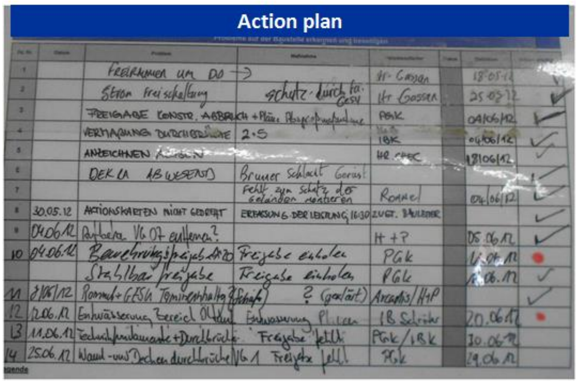


Figure 5.8: Action plan (DP)

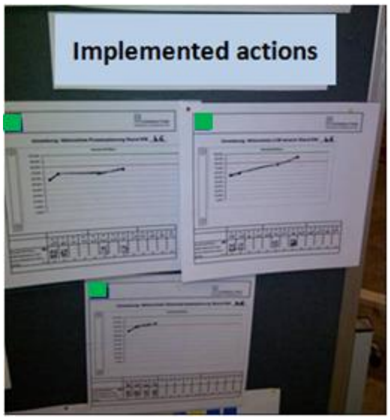


Figure 5.9: Tracking implementation

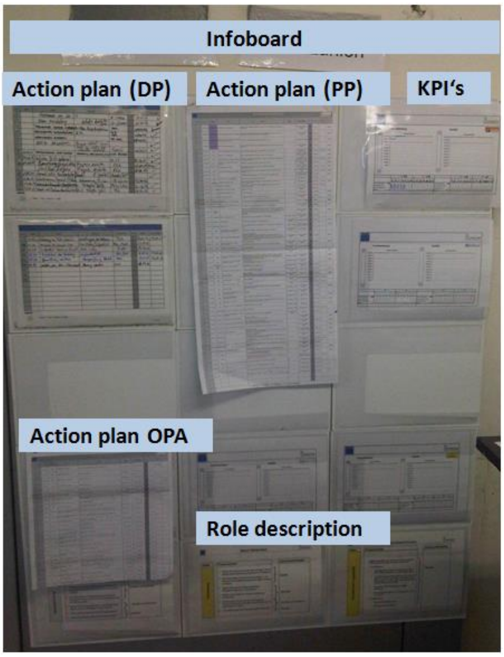


Figure 5.10: Infoboard displaying action plan from OPA, PP and DP, KPI's, role description for the LCM instantiation

Figure 5.11: Infoboard displaying current PP, master plan, section of OPM and status of implemented actions

The purpose of the planning board and how the process was carried out was similar to that described in case study 1 (Chapter 4, Section 4.6). The main difference was each morning the construction worker would remove his card from the planning board and place it on the plans in the LCM area (Figure 5.12 and 5.13 (a) & (b)) rather than placing it on an "apartment" clock at the area of work as described in case study 1. The apartment clock was not used during the LCM instantiations to refurbishment since it was considered more practical to view the status of work throughout the entire site in one central area (i.e. on the coloured plans in the LCM area). The visualisation of the work in process on the colour-coded plans in the LCM area, meant that it was possible to see at a glance what work was been carried out where each day, without having to first of all walk to the areas of work where the apartment clocks would have been displayed. This meant that the foreman could gather up the completed cards from the colour-coded plans each day to check the work without needing an overview of what work to check on a construction checklist (Chapter 4, Section 4.6).

Figure 5.12: Worker hanging card on colour-coded plan before work

b)

a)

Figure 5.13 (a) and (b): Visualisation of work in process on colour-coded plans (a) and site layout (b), case study 3

Once the daily work packages for the following three weeks were agreed upon, it was then possible to use this information for better logistics planning onsite. A logistics board (Figure 5.14) was used in addition to the planning board to plan resources such as lifts, containers and crane parking area. During instantiation 2B, the logistics board was divided into three columns representing lifts, containers and crane parking area. Below these headings, the board was further divided into two rows representing the current and the following week. Logistic cards were placed in the columns for either lifts, containers and parking areas in the row for the current week or the following week depending what was needed when.

Figure 5.14: Logistics board

5.4.3 Formative evaluation of version 2

While many of the visual elements of version 2 of the LCM model remain the same as those applied in version 1, some additional visual elements (Figure 5.1) have been added to improve the link between planning and construction and to better suit the nature of refurbishment construction. There are six main further developments of the model from version 1, which can be described as follows:

5.4.3.1 The addition of a further visual tool (Process Planning tool)

Once the high level processes and the flow of work had been defined in the Overall Process Analysis, there was a need for a further visual tool to facilitate the long term planning and preparation of work for a defined part of the high level process. This Process Planning tool was important to provide a better link between the long and short term planning. It also provided a more realistic basis for the daily planning of work in the Detailed Planning phase.

5.4.3.2 The addition of a further KPI to measure stability of the PP

This metric was important to measure the stability of promises made in the monthly PP meetings (Section 5.4.2.2). It reflected how frequently activities planned in the PP were rescheduled in the following month.

5.4.3.3 Use of colour-coded plans to visualise work in process.

In contrast to version 1 of the LCM model in case study 1, the apartment clock was no longer used in version 2. Instead of visualising the work in progress on the apartment clock at the area of work (as was the case in version 1), the construction cards were visualised on coloured plans in the LCM area. The decision was made to keep all relevant information regarding the planning and control of the site in one central area. The foreman could gather the completed cards from the colour-coded plans each day to carry out the quality check without needing a summary of the work to be checked in the form of a construction checklist.

However, future applications of the LCM model could consider how additional visual tools could be used throughout the site to create transparency at the areas of work in addition to the transparency that is created in the planning and control of the process;

5.4.3.4 A more detailed logistics board.

This allowed for the daily planning of site resources such as cranes, crane parking areas, containers, lifts, storage areas. In version 1 of the model, the logistics board was mainly used to control the amount of material entering the site and to visualise where this material can be stored. In version two, the logistics board also included the management and control of the available site resources.

5.4.3.5 Implementation in three clear phases

In case study 1, the LCM model was first developed during execution. It was established however, that the process of an LCM instantiation should follow clear phases, beginning before the start of construction. During the refurbishment instantiations, the LCM model was applied in three clear phases: 1) the Overall Process Analysis phase (OPA) 2) the Process Planning phase (PP) and 3) the Detailed Planning phase (DP) (Section 5.4.2). In contrast to version 1, the Overall Process Analysis was carried out (once) before execution began. This was important to define the optimal flow of the process at an early stage and to identify constraints and interdependencies early that would be significant for execution later on. The addition of the Process Planning tool, led to the definition of an additional phase (the Process Planning phase) which began just before execution and continued monthly throughout execution. The Detailed Planning phase took place during execution (as was the same in case study 1) and was conducted on a daily and weekly basis throughout the project. This phase focused on the execution process and the stability of work on a daily basis onsite.

Important steps for the method of application of the model became clearer during this part of the research. These steps provide a basis for the method description in Chapter 8, Section 8.4.3, which is also an important output of this work. The steps include:

- **Define and inform** participants of OPA workshops.
- **Conduct OPA phase** to create the OPM before execution commences. Output of OPA is an Overall Process Map. Process steps and flow are agreed. Structure of planning board and content of construction cards are established.
- **Define and inform participants of PP workshops**. First workshop takes place just before execution commences and continues monthly through the course of the project.
- **Prepare Process Planning tool** as basis for PP workshop.
- **Detailed Planning phase commences** at the same time as execution. All elements of the LCM model must be in place in a central area: planning board, construction

cards, logistic board, info board with KPI's, process information, section of OPA, the most current PP and visualisation of work areas on plans.

Table 5.4 presents a summary of the new elements of versions 1 and 2 of the LCM model, highlighting the main differences between the implementation process and the visual elements applied.

Table 5.4: Summary of new elements in version 1 and 2

Case study	Goal of case study	Visual elements of the LCM model	New elements	Implementation process	Measureable results
1	Development of the LCM model	1) the overall process analysis, 2) the daily planning board, 3) construction cards per company,4) visual KPI's, 5)action plans, 6) construction checklist, 7) an apartment clock, 8) an information board and 9) a logistics board	all	Parallel to execution phase	Some data showing improved On-Time-Performance and quality
2	Further improvement and application of the LCM model to refurbishment construction	1) the overall process analysis, 2) process planning tool 3) the daily planning board, 4) construction cards per company,5) visual KPI's, 6) action plans, 7) plans visualising work in process, 8) an info board and 9) a logistics board	1) Process planning tool & stability KPI 2) Detailed logistics board 3) Coloured plans to visualise work in process	1) Implementation carried out in 3 clear phases. Phase 1 is carried out before execution. Phases 2 begins just before execution and is carried out parallel to execution (monthly meeting). Phase 3 is carried out parallel to execution (daily and weekly meeting). 2) Work in process no longer displayed at area of work (apartment clock), but on visualised plans in LCM area. 3) More detailled logistics planning	1) KPI data on On-Time-Performance, quality and stability of PP (instantiation 2B) 2) Data on lead time 3) Data on constraint removal

The following section presents an evaluation of the utility and applicability of version 2 of the LCM model.

5.5 Evaluation of utility and applicability (step 5)

An important focus of this section is the summative evaluation of the LCM model to determine whether it was useful based on five lower level criteria: 1) improvement in daily planning, 2) constraint identification and removal, 3) waste identification and removal, 4) improved transparency and 5) measurability of performance. Data from both instantiations is presented below as basis for the evaluation. The questions from the evaluation framework

(Chapter 3, Figure 3.4 and 3.5) and those presented in Appendix B.3, were used as a guideline when interviewing the participants involved in case study 2.

5.5.1 Limitations of the data

Quantitative data on On-Time Performance and quality was gathered during the observation periods on both instantiations. Before the LCM instantiation, no data was gathered on On-Time Performance or quality which meant no basis existed for comparison after the LCM instantiation. While the data in most cases show positive developments at times in on-time performance and quality during the observation period, the data itself is not conclusive. However, this data forms a basis for possible future comparisons.

5.5.2 Usefulness of the LCM instantiations

The data gathered from the interviews with the LCM manager, foreman and client (Table 5.3) and the KPI data gathered during the observation period was used to establish the usefulness of the LCM instantiations in improving 1) daily planning, 2) constraint removal and 3) waste through increased transparency during both instantiations.

5.5.2.1 Improvement in daily planning through increased transparency

The usefulness of the LCM instantiation in stabilising daily planning through the increased transparency, could be noted from the KPI data gathered on On-Time-Performance of the sub-contractors and the level of quality of their work during both instantiations. In addition, data on the stability of commitments made (Figure 5.19) was gathered during instantiation 2B. This data is presented in Figures 5.15-5.18). Based on the KPI data and the information gathered from the interviews with the LCM manager (instantiation 2A) and the foreman and client (instantiation 2B), it appears that the model helped improve daily planning onsite as a result of the increased transparency in the process:

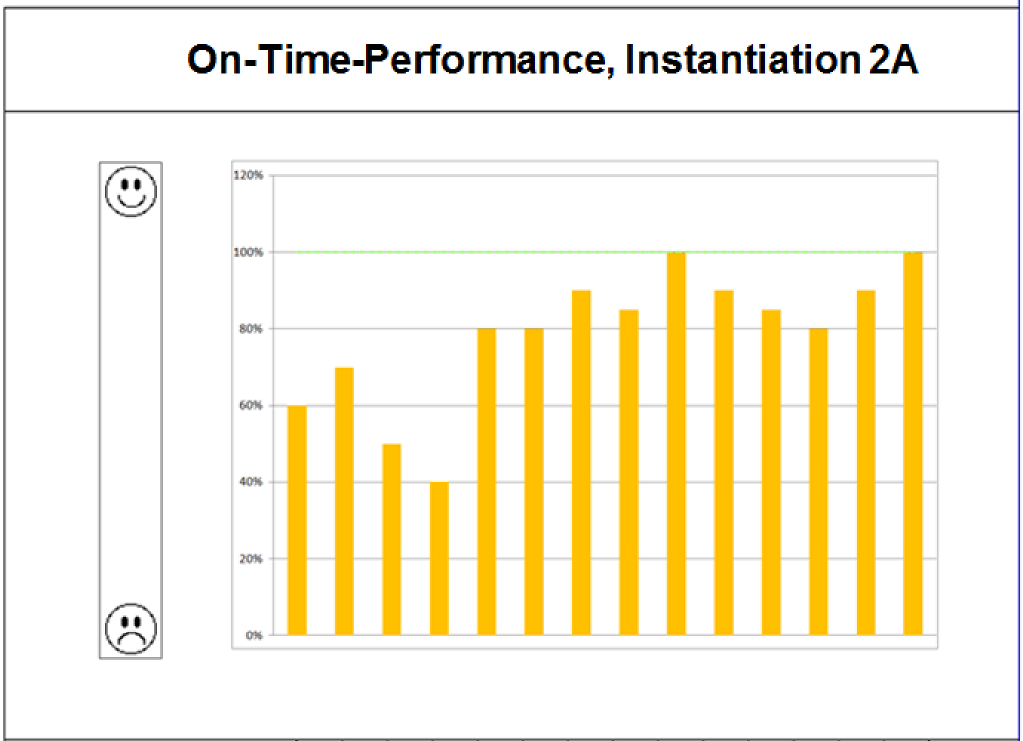
> “By applying LCM, the construction process becomes more transparent. Constraints are identified and resolved earlier with the monthly Process Planning. By using the Planning Board onsite, one can anticipate problems in the execution process before they occur”, (client: foreman, Instantiation 2B, Table 5.3).

In general, the client was convinced that the additional communication supported by the visual tools in the Process Planning and Detailed Planning phases, led to more stable commitments and better quality levels:

> “The guiding principle behind LCM requires you to think in advance, meaning you need a little more time in the startup phase of our construction projects. But by clearly defined interfaces and a clear channel of communication, downtime and delays in execution are reduced” (client: project manager, Instantiation 2B, Table 5.3).

On-Time-Performance was tracked for a period of 14 weeks (Figure 5.15) and quality of the planned activities was tracked (Figure 5.16) for a period of 24 weeks during instantiation 2A. A constant stability in the On-Time-Performance of the companies could be noted from the KPI data (from week 21-30) during the 14 week period (Figure 5.15). The discussions on the feasibility of work began 4 months in advance at the Process Planning phase, which meant that constraints were being identified early. In addition, the construction cards representing daily packages of work by the subcontractors were prepared by the companies themselves and placed on the Planning board, 3 weeks before execution. This also helped to achieve stability in OTP, since any further problems in execution could also be noted at this stage allowing some time to resolve issues before the work should be carried out. It was noted by the LCM manager that:

> “By using the LCM planning board (4 weeks lookahead) and the LCM Process Planning (4 month lookahead), problems could be detected earlier, so that a stable and smooth construction process could be achieved“ (LCM manager, Instantiation 2A, Table 5.3)



Week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Average
Weekly average	60%	70%	50%	40%	80%	80%	90%	85%	100%	90%	85%	80%	90%	100%	79%
Target	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	

Figure 5.15: On-time-performance data, instantiation 2A, case study 2

Similarly, a positive development in the quality of work could be noted at times from the KPI data (Figure 5.16). KPI data on quality was noted over a time period of 24 weeks. During this time, on average 71% of the work completed each week was up to the expected level of quality. The regular quality check meant that any issues were discovered soon after they occurred, preventing them from „spreading“ to other areas. Quality issues were discussed with the subcontractors as they occurred, which increased awareness of the importance of quality. From the 24 weeks, there were only 5 weeks where the quality reached levels of 50% or below. There was no data available on the reasons why the quality levels reached 50% or below.

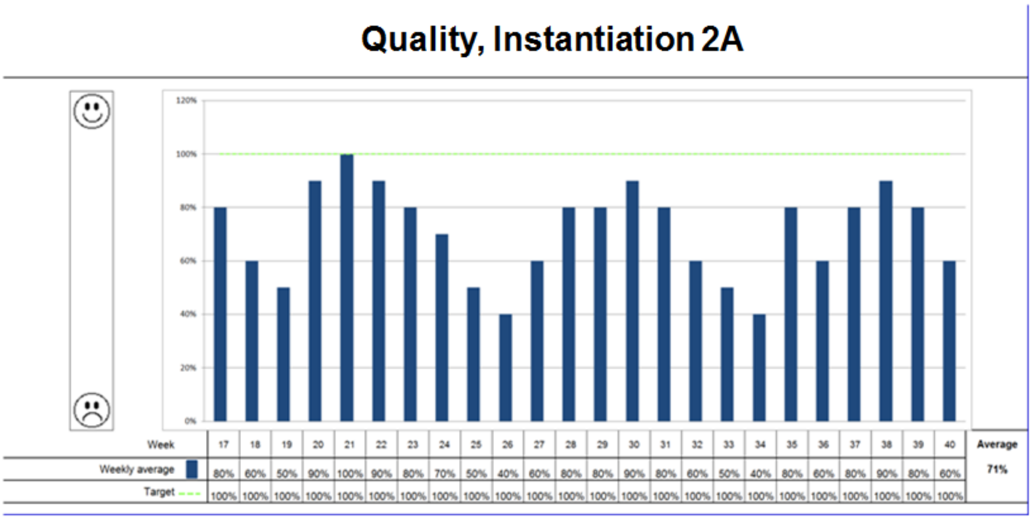


Figure 5.16: Quality data, instantiation 2A, case study 2

During instantiation 2B, On-Time-Performance and quality of the planned activities were tracked for a period of 24 weeks (Figure 5.17 and 5.18). Stability in the On-Time-Performance of the companies could also be noted from the KPI’s data (Figure 5.17). The data showed that during this time period, promised commitments were fulfilled on average 84% of the time. Similar to instantiation 2A, this was largely to do with the earlier discussions that were taking place at the Process Planning and Detailed Planning Phase that led to more sound commitments that could be delivered as promised.

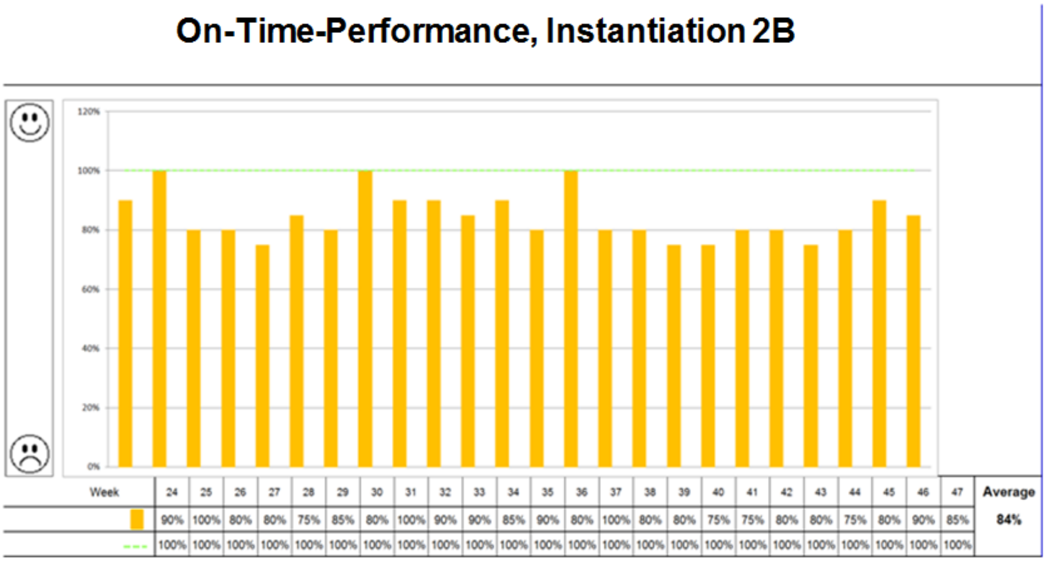
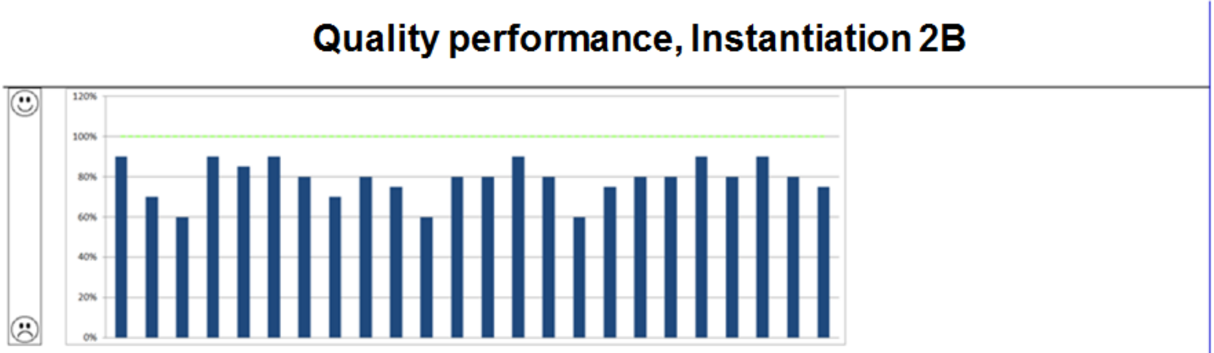


Figure 5.17: On-Time-Performance data, instantiation 2B, case study 2

A positive development in the quality of work could also be noted from the KPI data gathered during instantiation 2B (Figure 5.18). KPI data on quality was gathered for the same time period of 24 weeks. During this time, on average 79% of the work completed each week was up to an expected level of quality.



Week	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	28	28	28	28	Average
Weekly average	90%	70%	60%	90%	85%	90%	80%	70%	80%	75%	60%	80%	80%	90%	80%	60%	75%	80%	80%	90%	80%	90%	80%	75%	79%
Target	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	

Figure 5.18: Quality data, instantiation 2B, case study 2

In addition to the data gathered on On-Time-Performance and quality, during instantiation 2B the stability of the Process Planning was measured using data gathered on the stability KPI (Section 5.4.2, Process Planning Phase). From months 4-6 a positive development in the stability of commitments during the Process Planning Phase was noted (Figure 5.19). However, from the 6th and 7th month on, the stability decreased due to difficulties with an external supplier who was responsible for providing the metal for the roof. This supplier could not confirm a delivery date for the metal for weeks and this was a key activity which affected most other activities. The instability in the Process Planning decreased as a result in the remaining months. It is important to note that this decrease was not reflected in the On-Time-Performance and quality data, since this data only focused on the work packages, where feasibility had already been determined. A further point to note is that while the LCM model can improve daily planning through increased transparency, it cannot remove obstacles caused a result of non-compliance (if companies choose not to participate adequately).

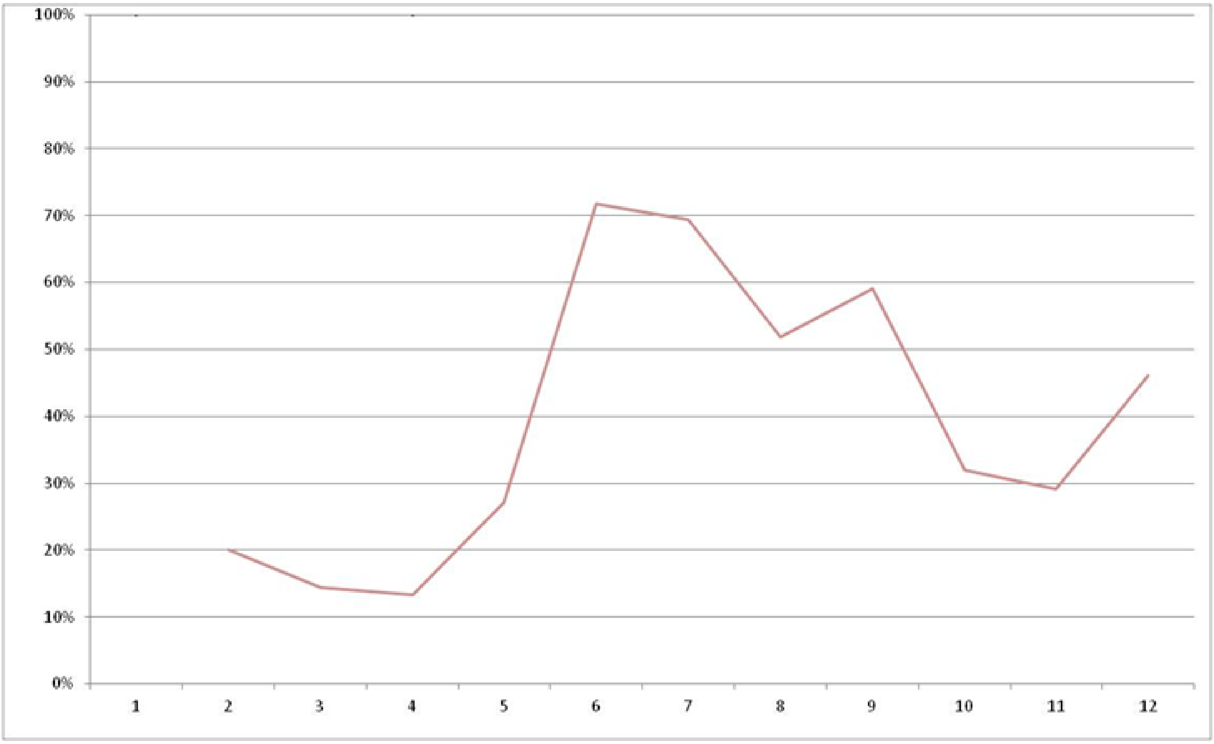
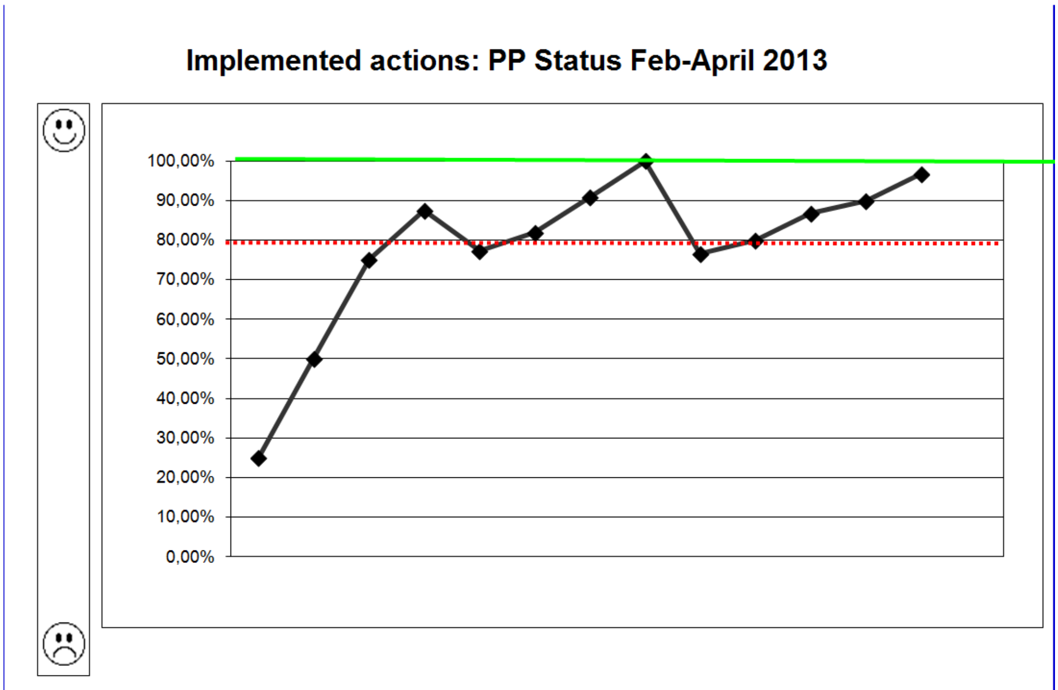


Figure 5.19: Stability of process planning, instantiation 2B, case study 2

5.5.2.2 Improvement in constraint removal through increased transparency

The usefulness of LCM in identifying and removing constraints could also be measured. During instantiation 2A, a total of 400 constraints were identified and removed throughout the three phases of implementation (50 at the OPA phase, 200 at the Process Planning Phase and 150 at the Detailed Planning phase). At each phase of implementation, action plans were created (Figure 5.8). The actions were noted by the LCM manager during the Overall Process Analysis, Process Planning and Detailed Planning meetings during the discussions on constraints. The types of constraints varied; typically the constraints in the OPA and PP were more to do with unclarities in the planning processes and attainment of approvals. In the DP phases, the constraints identified were more concerned with the execution process such as the availability of material or quality of material and also to do with issues with LCM implementation (i.e. if cards were inadequately filled out or placed on the board).

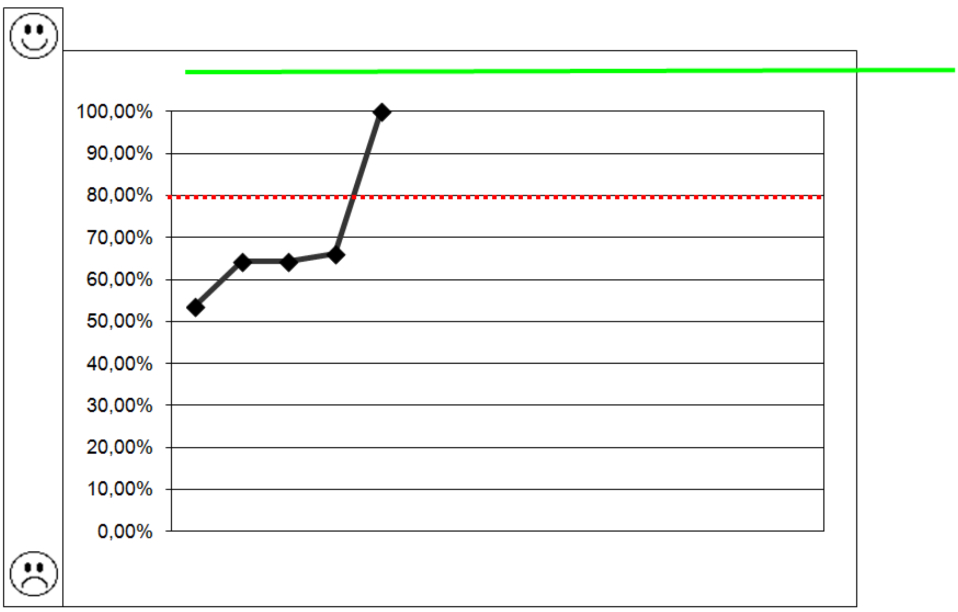
During instantiation 2B, a total of 600 constraints were identified and removed (150 at the OPA phase, 250 at the Process Planning Phase and 200 at the Detailed Planning phase). The implementation of improvement actions to resolve these constraints were tracked weekly which showed a constant positive development of implemented actions. Figure 5.20 (a), (b) and (c) show a snapshot of how the implemented actions from the OPA, PP an DP phase were tracked and visualised during instantiation 2B. The completed actions are expressed as a percentage of the total actions. The LCM manager checked the status of the open actions with the foreman and updated the figure. This shows that improvement actions were not only identified but also consequently implemented.



	Feb				March				April				
	KW 06	KW 07	KW 08	KW 09	KW 10	KW 11	KW 12	KW 13	KW 14	KW 15	KW 16	KW 17	KW 18
KPI (Actual/Target)	0,3	0,5	0,8	0,9	0,8	0,8	0,9	1,0	0,8	0,8	0,9	0,9	1,0
implemented actions (actual)	20	40	60	70	85	90	100	110	115	120	130	135	145
total actions (target)	80	80	80	80	110	110	110	110	150	150	150	150	150
Goal	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0

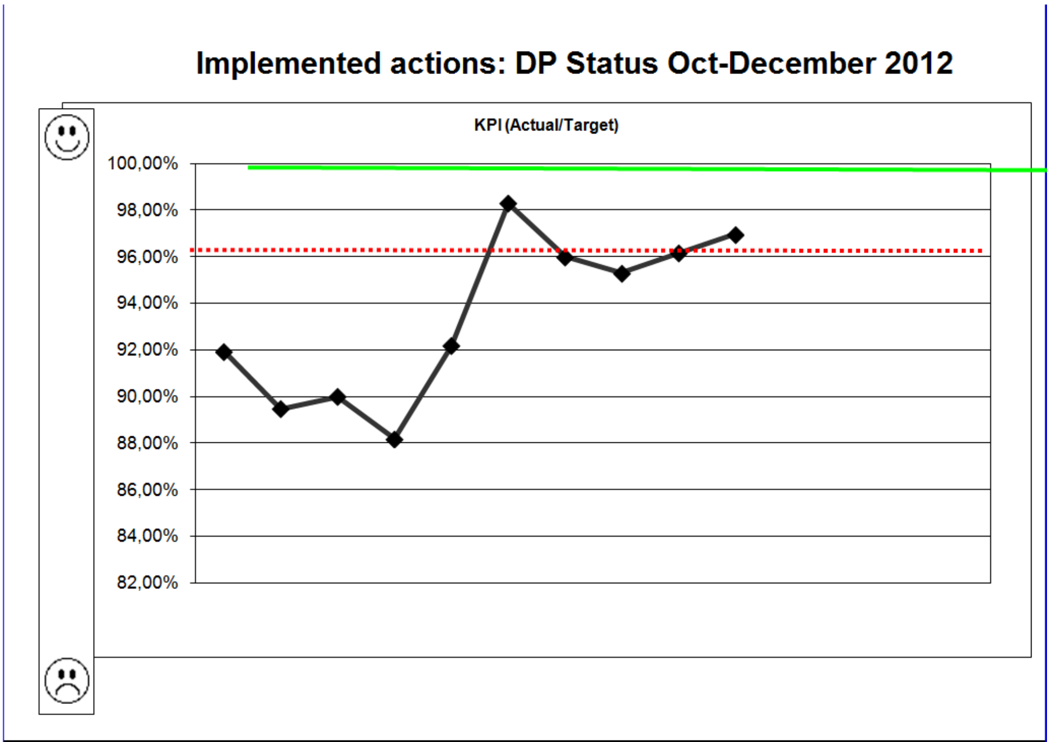
Figure 5.20 (a): Status of implemented actions from the OPA, instantiation 2B, case study 2

Implemented actions: OPA Status June-July 2012



	June				July						
	KW 23	KW 24	KW 25	KW 26	KW 27	KW 28	KW 29	KW 30	KW 31	KW 36	KW 37
KPI (Actual/Target)	0,5	0,6	0,6	0,7	1,0						
implemented actions (actual)	30	36	36	37	56						
total actions (target)	56	56	56	56	56						
Goal	1,0	1,0	1,0	1,0	1,0						

Figure 5.20 (b): Status of implemented actions from the PP, instantiation 2B, case study 2



	October				November				December			
	KW 41	KW 42	KW 43	KW 44	KW 45	KW 46	KW 47	KW 48	KW 49	KW 50	KW 51	KW 52
KPI (Actual/Target)	0,9	0,9	0,9	0,9	0,9	1,0	1,0	1,0	1,0	1,0		
implemented actions (actual)	80	85	90	97	106	115	120	122	125	128		
total actions (target)	87	95	100	110	115	117	125	128	130	132		
Goal	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0		

Figure 5.20 (c): Status of implemented actions from the DP, instantiation 2B, case study 2

5.5.2.3 Improvement in the reduction in waste

While it was difficult to measure waste reduction in general during the instantiations in case study 2, based on the feedback received during the semi-structured interviews with the LCM manager (instantiation 2A), the foreman and client (instantiation 2B), the opinion was that waste such as waiting (to begin work and for material), inventory (material and buffer time between tasks), space, worker utilisation and making-do was improved through the increased transparency of the planning process for execution.

> “By applying LCM, the increased transparency helped to identify and remove problems which meant that work could begin on time. The refurbishment of the office building was finished two-months ahead of time“ (LCM manager, Table 5.3)

During the instantiation 2A, the effect of a reduction in buffer time between tasks could be measured since the project was completed 2 months earlier than anticipated. This however was partly due to the reduced buffer between activities and partly due to the earlier identification and removal of constraints. During instantiation 2B, due the problems with the metal supplier, the project was completed 4 weeks later than anticipated. The increased transparency and early identification of the need for the metal by a certain date, could not have resolved the problem with the metal supplier. However, during the execution phase of instantiation 2B, it became apparent that the brick work would need 6 weeks longer than had been originally anticipated. The transparency achieved by the visual tools, helped to better utilise buffer between the construction activities by integrating further work. In this way, a further extension of the completion date by 6 weeks was prevented.

5.5.3 Applicability of the LCM model based on instantiations 2A and 2B

With regard to applicability, both instantiations are evidence that it was possible to apply the LCM model to a different type of construction project than instantiation 1A (case study 1). While the majority of the elements that make up the LCM model remained the same, additional visual elements were added that further supported the creation of sound commitments, the measurement of performance and control of logistic resources (Process Planning tool, stability KPI (instantiation 2B), logistics planning board (Section 5.4.3). Figure 5.21 below illustrates the process of application during the LCM instantiation to refurbishment construction.

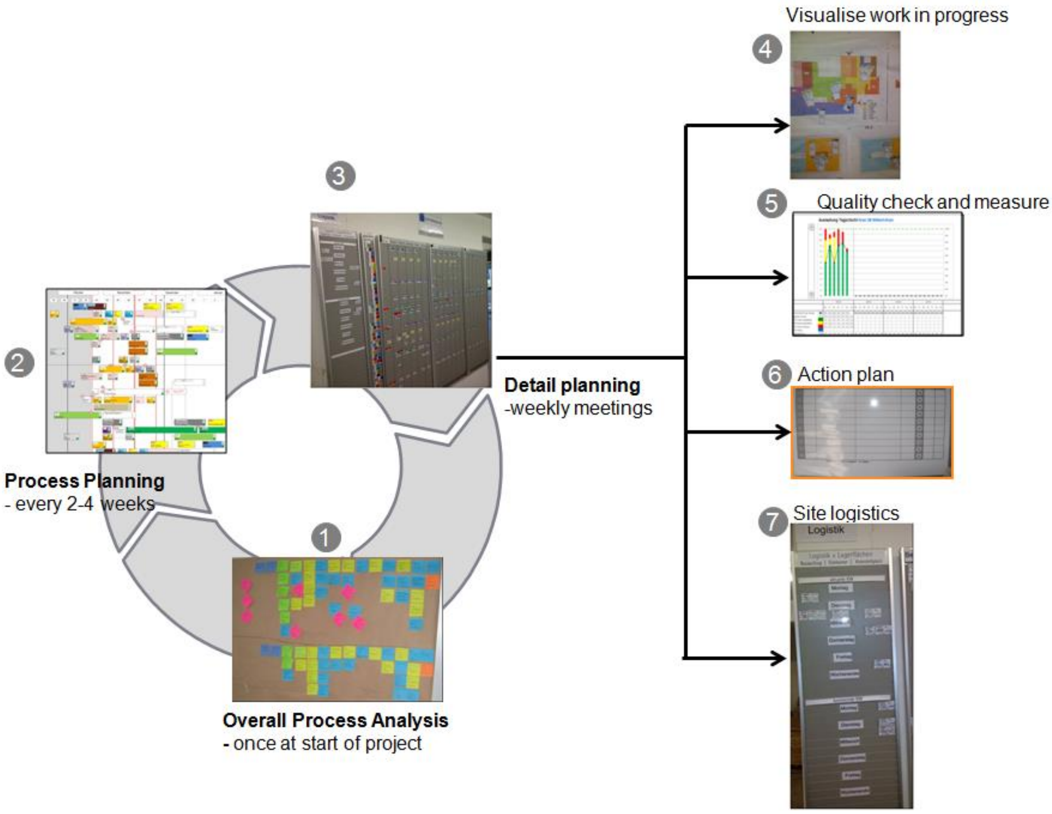


Figure 5.21: Overview of LCM instantiation to refurbishment construction

5.6 Chapter summary

This chapter presented the data collected and analysed for case study 2 as part of this research. The chapter was structured around steps 3-5 of Peffers, et al. (2007) model for Design Science application: 3) design & (further) development, 4) demonstration and 5) evaluation. Case study 2 presented version 2 of the LCM model which is a further development of version 1. This chapter explained the main new developments of the model from version 1 and described the process of application to refurbishment construction based on two instantiations of the model (2A and 2B). The chapter concluded with an evaluation of the model to establish its usefulness and applicability.

The next chapter presents findings from an observational study in Brazil, which was also carried out in part 2 of the research.

6 Observational study, Brazil

6.1 Introduction

This chapter presents findings from an observational study carried out in Brazil in part 2 of the research. The main goal of the observational study was to compare Visual Management practices observed on sites in Brazil, to the LCM model. This comparison would help to determine if similar models of Visual Management application were evident on the sites there and if the LCM model could contribute to existing practices observed. Another purpose of the observational study was to verify findings from the literature review that indicated that Visual Management application tended to focus on the application of individual tools rather than the use of systematic models of application (Arbulu et al., 2005; Picchi et al, 2004; Kemmer et al., 2006; Jang & Kim, 2007; Tommelein, 2008; Saurin et al., 2008); Tezel, 2011).

This chapter presents an overview of the Visual Management practices observed on three construction sites and explains the function of each tool. An analysis of the different functions of Visual Management observed is presented and discussed. The chapter concludes with a discussion on how the observed VM tools and their functions compare to the LCM model.

6.2 Data collection

Data was gathered from site visits of companies that were research collaborators with the Federal University of Rio Grande du Sul, based in Porto Alegre, RS (Table 6.1). Four site engineers and two foremen were interviewed onsite (Table 6.2). The questions used as basis for these interviews can be found in Appendix B.1. In addition to the site visits, three separate focus groups were carried out, involving academics and company managers where the researcher presented her work and had a chance to discuss and compare the LCM model to visual tools used by the companies. A list of focus topics and questions used as basis for these focus groups can be found in Appendix B.2. The data gathered is listed in Table 6.1.

Table 6.1: Data gathered during field trip, Brazil

OBSERVATIONAL STUDY BRAZIL				
Research focus	**Description**	**Type of data**		**Date**
Observational study on construction sites in Brazil	Field trip to Brazil: site visits, focus groups and presentations	Direct observation	1) 3 sites visits 2) 2 company visits	March 2013
		Semi-structured interviews	1) 3 Semi-structured interviews with engineers and formen	19th, 20th, 21st March 2013
		Document analysis	1) Photographs 2) Presentations	March 2013
		Focus groups	1) 1 focus group with academics 2) 2 focus groups with companies	25th, 26th, 27th March 2013

Table 6.2: Summary of interviews conducted

RESEARCH PART	NO. OF INTERVIEWS	FUNCTION OF INTERVIEWEE	DATE	SOURCES OF QUESTIONS
Part 2, observational study	1 semi-structured interview at site 1	Site engineer	19th March, 2013	Appendix B.1
	2 semi-structured interview at site 2	Site engineer & foreman	20th March, 2013	
	3 semi-structured interview at site 3	Site engineer & foreman	21st March, 2013	

6.2.1 Visual Management practices at site 1

The first construction site visit took place in March 2013. The site visited was the construction of a distribution centre for a large retailer in Brazil (Figure 6.1). Visual tools were not widely used on this construction site, but those observed are presented below. According to the project manager, who was interviewed by the researcher, first attempts at applying Lean and visual tools had failed since the site engineer onsite was not fully committed to implementation.

Figure 6.1: Site visit 1, construction of distribution centre

Only 4 examples of visual tools were observed on this site and are described below.

6.2.1.1 Visual forecast of rainfall

Due to the type of soil where the distribution centre was being built, it was important to foresee heavy rainfall that could affect the construction process. A visualised rainfall forecast (Figure 6.2) was displayed in the trailer to indicate when heavy rainfall should be expected.

Figure 6.2: Visualisation of rain fall forecast

6.2.1.2 Visualisation of work completion

Also visualised and displayed on the wall of the site office, was an illustration showing the construction areas that were complete and those to be completed in the future (Figure 6.3). Completed areas were indicated by the grey shaded areas on the plan.

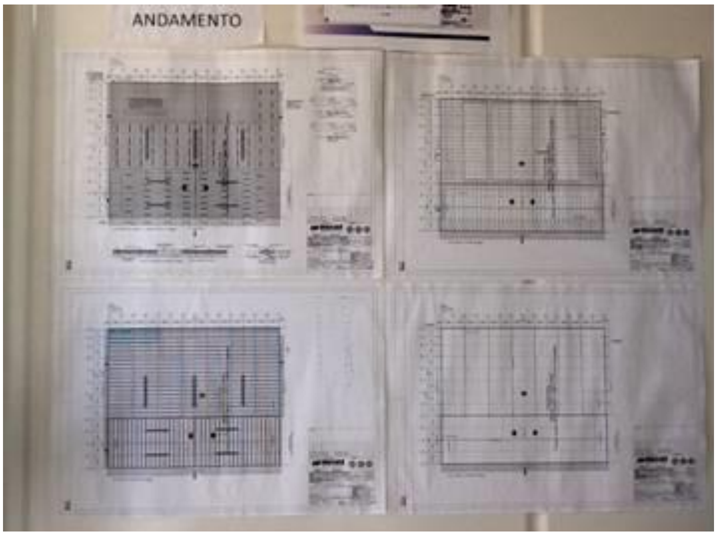


Figure 6.3: Visualisation of work completion

6.2.1.3 Visualisation of "flow" of activities

The flow of activities per section and timeframe was visualised on a plan that resembled a master schedule (Figure 6.4). The site manager used this as basis for work planning and scheduling onsite.

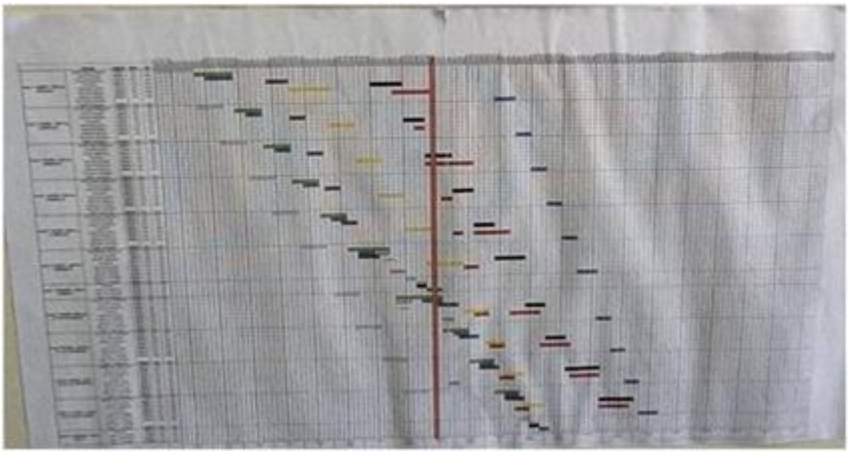


Figure 6.4: Visualisation of flow of activities

6.2.1.4 Manual numbering of material

No visual tools were evident on the actual site. However, written descriptions (numbers) were noted on the components for prefabrication onsite, indicating the type and length of the components (Figure 6.5).

Figure 6.5: No. of frame size written on material

6.2.2 Visual Management practices at site 2 and 3

The two remaining sites (Figure 6.6) that the researcher visited were from the same company. A wider use of visual tools was evident on these sites. There appeared to be a company standard with regard to the type of visual tools applied, since for the most part, the visual tools observed on each site were similar. It was estimated by the engineers that 2 days (1 person) was spent per week updating and visualising the information. A further 17 examples of visual tools were observed on sites 2 and 3 and are described below.

Figure 6.6: Site visit 2 and 3, construction of residential buildings

6.2.2.1 Overview of project plan

A high level overview of the project plan was displayed on the wall of the trailer onsite (Figure 6.7). It is a long-term plan showing the activities to be carried out over the total timeframe of construction. It was updated weekly by the site engineer.

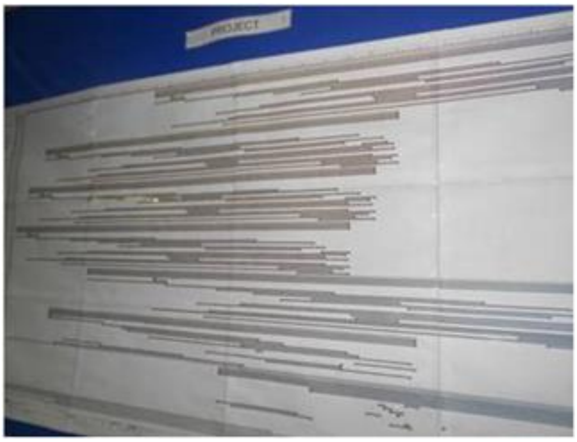


Figure 6.7: Visual overview of project plan

6.2.2.2 Detailed project plan

A detailed project plan was displayed beside the main project plan. It was updated weekly by the engineer. This information was used to update the project plan overview in Figure 6.7. Once a month a meeting took place with the engineers and the management of the company and the detailed plan was discussed.

Figure 6.8: Detailed project plan

6.2.2.3 Short term plan and quality overview

The short term plan (Figure 6.9) and quality overview was used as a weekly plan for the site. This sheet shows the subcontractors (on the left), the activity to be carried out and also states what quality check has to be carried out. The engineer filled this out, monitored it and delegates the quality checks to a trainee from the company. Only the current week is displayed – and not what has happened the previous week, regarding PPC.

Figure 6.9: Short term plan and quality overview

6.2.2.4 Sequence of activities "little stairs"

The "little stairs" (Figure 6.10) showed the sequence of activities for one tower of the building (there were 5 in total). The different colours represented different activities that were completed. It was possible to see the planned completion date and the actual completion date. The diagram resembled a stairs as much as possible to ensure that the optimal flow of work was visible. In Figure 6.10, the activity highlighted in red ran faster than was planned and could be clearly noted. This indicated overproduction and focused attention on work that may have caused issues depending on the activities and interdependencies.

Figure 6.10: “Little stairs”

6.2.2.5 Visual plan for facade

The two visual tools below are used to plan and organise the two crews who were responsible for the facade (blue and pink in Figure 6.11 (a)). The first visual tool showed which crew was responsible for which work. The visual tool displayed in Figure 6.11 (b) shows the completion of the work. The coloured areas represent the completed work and different colours indicate the actual week during which the work was completed. What could not be seen on this visual tool were the interdependencies between the facade and other areas of construction.

Figure 6.11 (a): Visual plan for facade

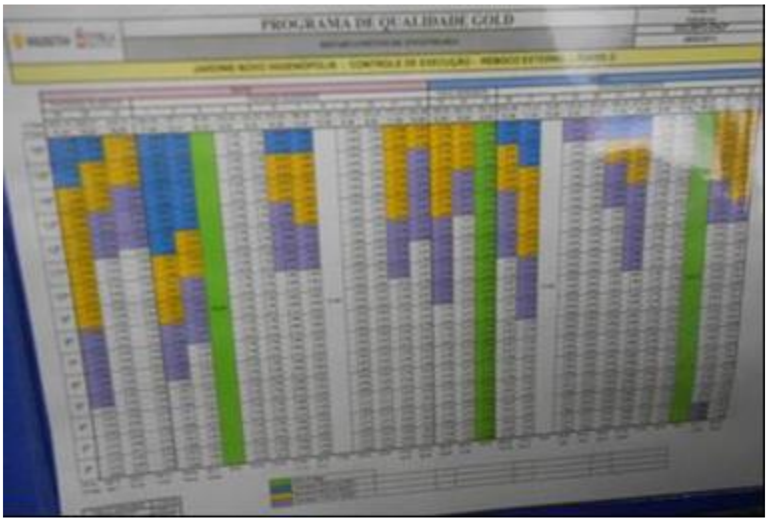


Figure 6.11 (b): Visual plan for facade

6.2.2.6 Management of concrete delivery

On the visual tool below (Figure 6.12), areas were marked out showing where the concrete should be delivered so that the quality of the concrete samples could be checked and sent to the lab for testing. A plan was sent to the supplier two weeks in advance with the concrete requirements. The same visualisation was used for the metal.

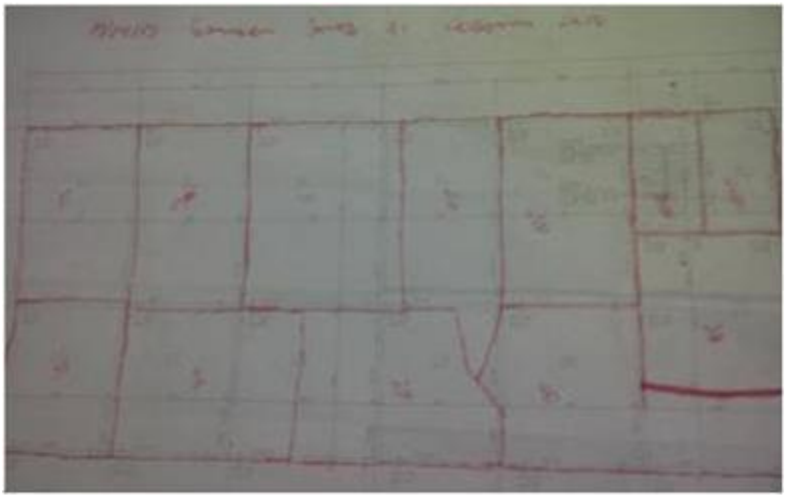


Figure 6.12: Management of concrete

6.2.2.7 Crew control for services

This visual tool displays the service crews (Figure 6.13) that were used (both from the company and the sub-contractors). Services such as cleaning, scaffolding, foreman etc were included. The capacity needed was also displayed.

Figure 6.13: Crew control for services

6.2.2.8 Lookahead plan for constraints

The constraints regarding the purchase of material and other resources were monitored using the visual tool shown in Figure 6.14. At the time of the observational study, there were 47 constraints identified in total. The visual monitoring of constraints other than those to do with purchasing were not apparent on this site.

Figure 6.14: Lookahead plan for constraints

6.2.2.9 Quality control sheets

The sheet shown in Figure 6.15 was referred to as a quality control tool but actually it is more a productivity control or completion control tool. There was one sheet for each main activity for each tower. Each row represents a floor, the first columns show the area of brick lines to be filled (in this case). The second group of columns shows how many workers were needed to carry out the work in that area (so productivity in man-hours/m² could be calculated). The third group of columns was used to monitor the amount of material that was used. In addition, the sheet also displayed the total lead time (start and end date) of the activity.

Figure 6.15: Quality control sheets

6.2.2.10 Worker capacity overview

This visual tool (Figure 6.16) was similar to the one shown in Figure 6.16 above, except it just shows information on the moulds of concrete. As they have less variables to control, they use a graph to see if the productivity was as good as planned.

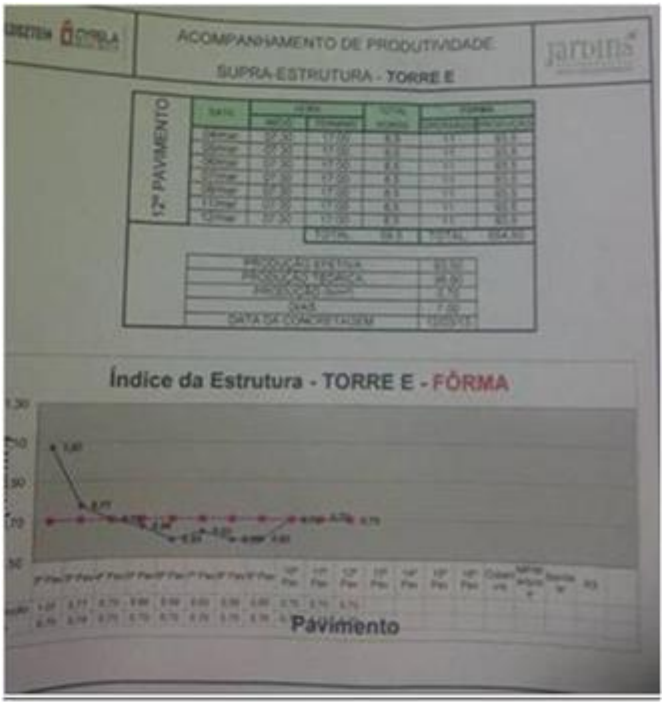


Figure 6.16: Worker capacity overview

6.2.2.11 Quality control

The quality control sheet shown in Figure 6.17 measured the „strain“ of the slab, sometime after the concrete work was completed. Here, a code was displayed highlighting where measurements should be carried out and how long each measurement should take.

Figure 6.17: Quality control

6.2.2.12 Visualisation of cost control and completion

The visual tool shown in Figure 6.18, is an overview of the planned costs compared to actual costs on completed work on the project.

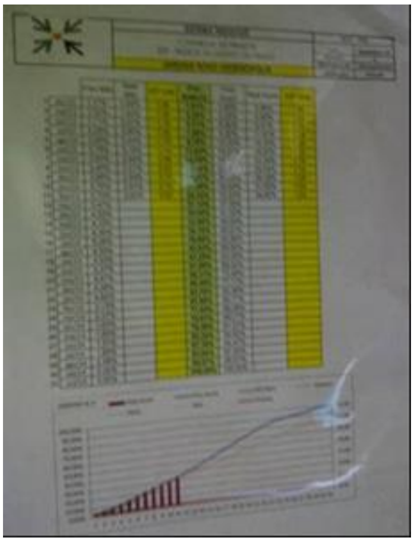


Figure 6.18: Cost control and completion

6.2.2.13 Visualisation of site layout

The visualised layout shown in Figure 6.19 was used for general site organisation; designated location for material, iron work, worker containers.

Figure 6.19: Visualisation of site layout

6.2.2.14 Performance of subs onsite

Onsite the performance level of sub-contractors was visualised (Figure 6.20). The categories evaluated were: a) meeting schedule / task completion b) safety (using correct equipment) c) quality d) co-operation. The performance for each category was indicated using different colours: 1. green: ok 2. yellow: improving 3. red: problem. A weekly meeting was held to address any issues.

Figure 6.20: Performance of subcontractors

6.2.2.15 SOP's: Standard Operating Procedures

Standard procedures for wood, iron, concrete, brick and facade work (Figure 6.21) were visualised onsite.

Figure 6.21: Standard Operating Procedures (SOP's)

6.2.2.16 Visualisation of safety statistics

Safety statistics indicating the number of days since an accident occurred (Figure 6.22) were visualised onsite.

Figure 6.22: Safety statistics

6.2.2.17 Visualisation of quality performance

The performance of the subs with regard to quality was visualised onsite (Figure 6.23). This was a newly introduced visual tool in use on the site at the time of the observational study. Green indicated that the quality was ok, yellow meant there were some minor issues and red meant more critical issues were apparent.

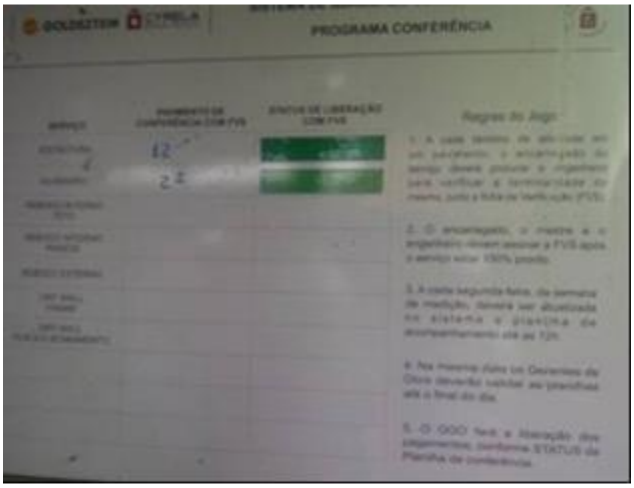


Figure 6.23: Quality performance

6.2.2.18 Visualisation of material type

Visualisation of the material type onsite was noted during the observational study (Figure 6.24). Workers could easily see the size of brick that was needed.

Figure 6.24: Visualisation of material type

6.2.2.19 Visualisation of the brick laying process and JIT material delivery

Four visual tools were used to facilitate the brick laying process onsite. Numbered plans were visualised at the area of work (Figure 6.25 (a)) to show where the bricks should be delivered to. Bricks were delivered to the place of work when they were needed, just-in-time (Figure 6.25 (b)). The bricklaying process was documented and visualised at the area of work (Figure 6.25 (c)), to ensure consistent quality. One day of inventory was kept onsite and inventory levels for each type of brick was clearly defined (Figure 6.25 (d)). A type of Kanban system was in place where by the warehouse manager sent a „signal" to the engineer when inventory levels reached a specified minimum.

Figure 6.25 (a)-(d): Visualisation of brick laying process and JIT material delivery

6.2.3 Data analysis

In this section the analysis of the data collected is presented. The main focus of the data analysis is to identify the main functions of the Visual Management practices observed and to establish how these elements and functions compare to the LCM model. 23 different visual tools were observed in total on the construction sites visited in Brazil. The majority of the visual tools (16 out of 23 in total) were in paper form (A4 or A3) and displayed on the walls of the site office. While the information was very useful for the site engineer in managing and controlling the site, the information appeared to be quite hidden and not easily accessible for all project participants. 7 of the visual tools observed, were displayed on the construction site at the area of work. Here, the information was clear for all to see and encouraged discussion and communication between site management, sub-contractors and worker level. While only four examples of Visual Management application were evident on site 1, a wider application of Visual Management was evident on sites 2 and 3.

Overall the feedback was positive from both the engineers and the site manager interviewed regarding the use of visual tools on sites 2 and 3. The site manager reported that even if the company did not insist on using these visual tools he would willingly want to use them to help plan and organise the day to day activities onsite. The visual tools helped to create transparency on project performance and no downside to the visual controls was identified. According to the engineers, the subcontractors also responded well to the visual tools put in place onsite and the feedback was positive regarding the sub-contractors use of the visual tools and participation.

6.2.3.1 Functions of Visual Management observed

Tezel (2011) identified nine functions of Visual Management in his work (Appendix A.3): 1) transparency, 2) discipline, 3) continuous improvement, 4) job facilitation, 5) On-the-job training, 6) Creating shared ownership, 7) Managing by facts, 8) simplification and 9) unification (Appendix A, Section A.3). Table 6.3 presents the functions of VM that were identified on the three construction sites visited. The function of the majority of visual tools observed on the sites was to create transparency, promote discipline and for job facilitation (Table 6.3).

Table 6.3: Functions of visual tools observed on sites 1-3

		Visual tools observed	Transparency	Discipline	Continuous improvement	Job facilitation	On-the-job training	Creating shared ownership	Managing by facts	Simplification	Unification
Site visit 1	**1**	Visual forecast of rainfall	x			x					
	2	Visualisation of work completion	x								
	3	Visualisation of "flow" of activities	x			x					
	4	Manuel numbering of material	x			x					
Site visit 2 and 3	**5**	Overview of project plan	x			x					
	6	Detailled project plan	x			x					
	7	Short term quality overview	x	x	x	x					
	8	Sequence of activities "little stairs"	x	x		x					
	9	Visual plan for facade	x			x					
	10	Management of concrete delivery	x	x	x	x					
	11	Crew control for services	x							x	x
	12	Lookahead plan for constraints	x		x	x					
	13	Quality control sheets	x			x					
	14	Worker capacity overview	x	x							
	15	Quality control	x	x							
	16	Visualisation of cost control and completion	x	x					x		
	17	Visualisation of site layout	x			x					
	18	Performance of subs onsite	x	x	x				x		
	19	SOP's: Standard Operating Procedures	x	x	x	x	x				x
	20	Visualisation of safety statistics	x	x				x	x		x
	21	Visualisation of quality performance	x	x	x						
	22	Visualisation of material type	x			x					
	23	Visualisation of the brick laying process and JIT material delivery	x	x		x					

6.2.3.1.1 Create transparency

Transparency is a core function of Visual Management and on the sites visited various visual tools were used to create transparency: 1) in the progress of work (Table 6.3: site 1, no. 2; site 2 and 3, no.13), 2) in the overall construction process for the purpose of planning and scheduling (Table 6.3: site 1, no. 3), 3) to easily find and locate material needed (Table 6.3: site 1, no. 4; site 2 and 3, no. 17 & no. 22), 4) to visualise the flow of work and identify bottlenecks or over production (Table 6.3: site 2, no. 5, 6 and 8), 5) of information on system wide services such as cleaning, scaffolding etc. (Table 6.3: site 2, no. 11) and 6) in the best practice for construction activities (Table 6.3: site 1 and 2, no. 19 and 23).

6.2.3.1.2 Discipline

A further function of VM according to Tezel (2011) is to promote discipline of the construction worker while carrying out their tasks. Using Visual Management to promote discipline among the project participants was apparent on some sites. Some examples are: the visual tools that imposed specific quality checks to be monitored by the site engineer (Table 6.3: site 2 and 3, no. 7) and checks to approve the strain of concrete slabs (Table 6.3: site 1 and 2, no. 15). Other visual tools (site 2 and 3, no. 8) were used to monitor the flow and of work so that adjustments could be made if overproduction occurred or bottlenecks identified. Visual tools were also observed on sites 2 and 3 that monitored the amount of worker and material resources used for the job (Table 6.3: site 2 and 3 no.13 and no. 14) to ensure that the levels were according to plan. Safety statistics were also displayed (site 2 and 3, no. 20) to remind construction workers of the significance of safety onsite. Furthermore the SOP's displayed encouraged construction workers to carry out work in an approved way (Table 6.3: site 2 and 3, no. 19 and no. 23).

6.2.3.1.3 Continuous improvement

There was some evidence on the sites of using visual tools for continuous improvement. For example, some visual tools used for weekly planning also included integrated quality checks to identify and improve quality issues (Table 6.3: site 2 and 3, no. 7). The performance of subcontractors was visualised with regard to task completion, safety, quality and co-operation (site 2 and 3, no. 18 and no. 21). During regular meetings onsite, these elements were discussed, feedback was given and improvement actions where necessary were defined. In addition, standards were defined and visualised for carrying out specified work processes which promoted continuous improvement (Table 6.3: site 2 and 3, no. 19).

6.2.3.1.4 Job facilitation

Job facilitation is realised by providing physical aids to support the workers in their daily tasks. There were many examples of visual tools used to facilitate work in planning and scheduling (Table 6.3: site 1, no.1; site 2 and 3, no 5, 6 and 7), organisation of material (site 1-3, no. 4 and no.22) and in conducting work based on standard operation procedures (SOP's) (site 2 and 3, no. 19 and 23).

6.2.3.1.5 On-the-job training

On-the-job training is a further function of Visual Management. Apart from the SOP's that were displayed to inform workers how to carry out a task in the best way, no further forms of on-the-job training with the help of Visual Management were evident.

6.2.3.1.6 Creating shared ownership

Creating shared ownership was evident through the display of large boards indicating safety statistics (Table 6.3: site 1 and 2, no. 20). This was clearly an area where internal marketing efforts were carried out to promote safety on the construction sites.

6.2.3.1.7 Managing by facts

Some examples of Visual Management being used for management by facts was observed on the sites 1 & 2. Performance figures on cost and completion (Table 6.3: site 1 and 2, no 16), resources used (Table 6.3: site 1 & 2, no. 13) and safety statistics (Table 6.3: site 1 and 2, no. 20) were displayed. In addition, information on performance of subcontractors with regard to task completion, safety, quality and co-operation were displayed and discussed (Table 6.3: site 1 and 2, no. 18).

6.2.3.1.8 Simplification

The simplification of system wide information was achieved in some cases by displaying and monitoring the activities of other services on site such as cleaning, scaffolding etc. that are not directly to do with the construction work (Table 6.3: site 2, no. 11).

6.2.3.1.9 Unification

Finally, some examples of attempts to unify the construction process and the different work groups were made by sharing visual information on the construction process (Table 6.1: site 2 and 3, no.19), quality, safety (Table 6.3: site 2 and 3, no. 20) and performance.

6.2.4 Comparison to the LCM model

Table 6.4 presents a summary of the visual tools observed and describes how these compare to the LCM model. The following conclusions can be drawn:

6.2.4.1 Use of Visual tools

First, the reason for the application of the Visual tools on the sites visited, appeared to be to support the site engineer in his function of managing and controlling the site, rather than in providing a framework for two-way communication by increasing transparency, as is the case in the LCM model. The 7 visual tools observed onsite however, did encourage communication between the different levels (Table 6.4: no 4, 18, 19, 20, 21, 22, 23).

6.2.4.2 Application of Visual tools

There did not appear to be any logic behind which tools were used and how they were displayed; some visual tools showed information at a very high level with little detail, whereas other visual tools nearby displayed detailed information on costs and individual processes of the building. The conclusion from the literature review that lean tools tend to be applied in isolation on construction sites, rather than holistically, was reflected on these sites. There was no evidence to suggest that these tools formed part of an overall holistic application of a Visual Management Model. In the LCM model, visual tools are applied throughout 3 phases of implementation, allowing the information to be broken down in a sequential way from the high level processes to daily activities onsite.

6.2.4.3 Functionality

Finally, it could be established that the functions of 13 of the visual tools, were similar to the functions of some of the visual tools of the LCM model. The purpose of many of the visual tools observed (15 from 22) was to assist the site engineer in production planning and control, which is also an important goal of the LCM model. Table 6.4 summarises the visual tools observed on the site visits and indicates which visual tools had a similar function to some of the visual tools of the LCM model.

In conclusion, while many of the functions of the visual tools observed were similar to that of the individual elements of the LCM model, the tools observed were not systematic in nature. Information was displayed on certain individual aspects of the process, but there were no structures in place to promote the use of and communication of that information as in characteristic of the LCM model.

Table 6.4: Summary of observed Visual Management practices compared to LCM

		Visual tools observed	Function	Visualised where?	Comparison with LCM
Site visit 1	1	Visual forecast of rainfall	***Job facilitation:*** this helped to schedule work on days where the soil would not be too wet due to excessive rail fall.	Inside site office	None
	2	Visualisation of work completion	***Transparency:*** high level overview of execution progress (areas that are complete and not complete)	Inside site office	The visual tools of the LCM model (Overall Process Map, Process Planning, planning board, card, visualisation of cards on plans) visualualise the overall flow of work, planned work over four months, the status of competion of daily work packages per company and the work in progress.
	3	Visualisation of "flow" of activities	***Transparency & iob facilitation:*** High level planning	Inside site office	This visual tool is comparable to the process planning tool in the LCM model. However, it was created by project management (top-down) and visualised in the container out of view.
	4	Manuel numbering of material	***Transparency & iob facilitation:*** Material organisation	Outside	None
Site visit 2 and 3	5	Overview of project plan	***Transparency & iob facilitation:*** High level planning	Inside site office	In the LCM model, the OPM visualises the processes on a high level and is created through collaboration workshops with the client, planners and construction management.
	6	Detailled project plan	***Transparency & iob facilitation:*** Detail planning	Inside site office	The detailled planning is carried out in the LCM model on site at the planning board, using more visualisation and communication with the companies involved.
	7	Short term quality overview	***Transparency, discipline & iob facilitation:*** Detail planning	Inside site office	This visual tool was a type of weekly plan of activites and quality check which is the function of the visual tools used in the Detailed Planning Phase of LCM implementation.
	8	Sequence of activities "little stairs"	***Transparency, discipline, continuous improvement & iob facilitation:*** Visualises flow of work for section of building	Inside site office	The flow of work is visualised and broken down at three different levels in the LCM model. The first level (OPA) visualises the overall flow of the main processes. The Process Planning is a more detailled visualisation of flow per area of the building over a 4 month time frame. Finally, the planning board visualises the flow of work at a daily level.
	9	Visual plan for facade	***Transparency & iob facilitation:*** Visualises crew planning and work completion of facade	Inside site office	Daily crew scheduling and completion of work is visualised by the planning board in the LCM model.
	10	Management of concrete delivery	***Transparency, discipline, continuous improvement & iob facilitation:*** Indicates where concrete should be delivered so that the quality of concrete samples could be checked an sent to lab for testing.	Inside site office	The logistics board in the LCM model is used to plan and organise the site resources including determining where material should be stored and delivered.
	11	Crew control for services	***Transparency, simplification & unification:*** Planning of service resources onsite ie: waste removal	Inside site office	none
	12	Lookahead plan for constraints	***Transparency, continuous improvement & job facilitation: visualising an m***onitoring constraints with regard to resources	Inside site office	In the LCM model, constraints are visualised and removed at three different levels: OPA, PP and Detailled planning an are not specific to only site resources
	13	Quality control sheets	***Transparency & job facilitation:*** Overview of productivity	Inside site office	Quality control has a different meaning in the LCM model. This tools monitors the productivity levels, whereas in the LCM method, a daily quality check is carried out as part of the process. Improvements if any are visualised an implemented.
	14	Worker capacity overview	***Transparency & discipline:*** Overview of productivity for concrete	Inside site office	none
	15	Quality control	***Transparency & discipline:*** Measures strain of slab	Inside site office	none
	16	Visualisation of cost control and completion	***Transparency, discipline & management by facts:*** overview of project cost an completion target	Inside site office	none
	17	Visualisation of site layout	***Transparency & job facilitation:*** site organisation	Inside site office	Similar to the site layout plan in the LCM model
	18	Performance of subs onsite	***Transparency, discipline, continuous improvement & management by facts:*** Measurement of sub perfomance with regard to task completion, safety, quality and co-operation	Onsite	KPI's (quality an on-time performance) for each sub-constractor are gathered an visualised in the LCM model.

Table 6.4 (continued): Summary of observed Visual Management practices compared to LCM

		Visual tools observed	Function	Visualised where?	Comparison with LCM
Site visit 2 and 3	19	SOP's: Standard Operating Procedures	***Transparency, discipline, continuous improvement, job facilitation, on-the-job training & unification:*** Visualisation of best practice on-site	Onsite	none
	20	Visualisation of safety statistics	***Transparency, discipline, creating shared ownership, management by facts & unification:*** safety awareness	Onsite	none
	21	Visualisation of quality performance	***Transparency, discipline & continuous improvement:*** focus on quality	Onsite	In the LCM model, quality is tracked and visualised using the KPI's combined with daily checks and feedback.
	22	Visualisation of material type	***Transparency & job facilitation:*** material organisation	Onsite	none
	23	Visualisation of the brick laying process and JIT material delivery	Clear understanding of brick laying process	Onsite	none

6.3 Chapter summary

This chapter presented the data collected on the construction sites visited during the observational study carried out in Brazil. It presented examples and a description of the Visual Management practices observed. The chapter concluded by defining the different functions of the VM tools observed and highlighting how these visual tools and functions compare to the visual elements of the LCM model.

The next chapter presents the research work carried out in part 3 of the research. It focuses on case study 3, which involves a further development of the LCM model and application to power plant construction. A further evaluation of the model is also carried out to establish the models usefulness and applicability based on 5 instantiations to power plant construction.

7 Application of LCM to power plant construction: Case Study 3

7.1 Introduction

This chapter presents the research work carried out in part 3 (Chapter 3, Figure 3.1). An important goal of this chapter is to explain how the LCM model was further developed and applied to another different type of construction scenario, representing version 3 of the model. Similar to chapter 5, this chapter focuses on steps 3-5 of Peffers et al., (2007) process model: 3) design & (further) development 4) demonstration 5) evaluation. As part of step 6) communication, the findings of the research work are communicated in this PhD thesis.

Case study 3 is the main focus of part 3 of the research. It focuses on five instantiations (instantiations 3A-3E) of the LCM model to power plant construction, none of which involve the researcher directly. The five power plant sites are referred to as power plants A-E and are presented in Table 7.1. Table 7.1 also shows the period of time the LCM manager was present onsite during the instantiations and during which time the KPI data used for the evaluation was gathered.

Table 7.1: Power plant LCM implementations

Power plant	Location	LCM implementation period
A	location 1, Germany	April-December 2009
B	Czech republic	June- December 2010
C	location 2, Germany	August-December 2010
D	the Netherlands	January - June 2011
E	location 3, Germany	July-December 2011

7.2 Data collection

The LCM model was applied to 9 power plants in total, with the same client at different locations. Data was available on five of these instantiations (instantiations 3A-3E). Each instantiation represents an application of the model to an individual power plant site. The majority of the data gathered was in the form of documentation and is presented in Table 7.2 and 7.3 Data gathered on the instantiation 3A (Table 7.2) was analysed to form an explanation of how the LCM model was further developed during instantiation 3A and adapted to suit power plant construction, representing version 3.

Table 7.2: Data gathered for instantiation 3A, power plant construction

DATA GATHERED FOR INSTANTIATION 3A				
Research focus	**Project description**	**Type of data**		**Date**
Case study 3: Instantiation 3A (power plant construction)	LCM instantiation to first power plant site	Semi-structured interviews	1) 1 Semi- structured interview with LCM manager 2) 1 Semi-structured interview with client	14 th July & september 4th, 2013
		Document analysis	1) Project proposal 2) Photos of implementation 3) Plans 4) Masterplan 5) LCM implementation plan 6) Copies of flipcharts from LCM workshops 7) Reports from LCM implementation workshops 8) Documentation of process planning 9) Action plans 10) Electronic cards	June 2012-July 2013

This further developed version of the model was then rolled out on 8 power plant sites. As mentioned, only 4 of these 8 projects were chosen for analysis based on the data available on these instantiations. In case study 3, data from these four instantiations (3B-3E) is used mainly for evaluation purposes. KPI data was gathered on crane utility and On-Time-Performance of the subcontractors, including reasons for low performance (Table 7.3).

The data for the KPI's was gathered during the evening meetings together with the site manager, site planner, supervisors and assembly companies, which occurred daily. As part of this daily evening meeting, the status of planned work was checked for that day to determine if it was complete (as was the case during case study 2). If so, the card was placed green side up on the board to indicate completion and a note was made per subcontractor of how many completed cards there were compared to how many there should be. This information was then updated on the information board which was displayed in the LCM area. The logistics board (Chapter 7, Figure 7.20) was also checked to see if the planned slots were utilised for the cranes and the operators were given a sheet to fill out, in order to document the downtime of the crane and the reasons for this. The KPI data gathered was in the form of bar charts (Chapter 7; Appendix E). The data gathered on reasons for non-performance were analysed and the results presented in the form of a pie chart (Appendix E).

Table 7.3: Data gathered for instantiation 3B-3E, power plant

DATA GATHERED FOR INSTANTIATION 3B-3E				
Research focus	**Project description**	**Type of data**		**Date**
Case study 3: Instantiation 3B-3E	Roll out of adapted version of model (version 3) for power plant construction	Semi-structured interviews	1) 1 Semi- structured interview with LCM manager 2) 1 Semi-structured interview with client	14 th July 2013 & september 4th, 2013
		Document analysis	1) Project proposal 2) Photos of implementation 3) Plans 4) KPI data on crane utility and ontime performance 5) Documentation on implementation process 6) Actions plans with reasons for low crane utility and low ontime performance	June 2012-July 2013

In addition, three semi-structured interviews were carried out with the LCM managers and the client (Table 7.4) to gain a deeper understanding of the application and to evaluate the models utility and applicability by applying the evaluation framework. A summary of the interviews conducted is presented in Table 7.4.

Table 7.4: Summary of interviews conducted

RESEARCH PART	NO. OF INTERVIEWS	FUNCTON OF INTERVIEWEE	DATE	SOURCES OF QUESTIONS
Part 3, Instantiation 3A-3E	2 semi-structured interviews	LCM manager	14th July 2013	Evaluation framework, Figures 3.4 & 3.5
	1 semi-structured interview with client	Project manager	4th September	Evaluation framework, Figures 3.4 & 3.5 and interview questions Appendix C, Section 10.3.1

7.3 Further development (step 3: Design & Develop)

Figure 7.1 presents version 3 of the LCM model. The most notable further developments from version 1 and 2 (Chapter 4, Section 4.6, Figure 4.7 and Chapter 5, Section 5.3, Figure 5.1) are: 1) the absence of the Overall Process Planning, 2) the creation of an erection concept (with the addition of a parts list for the defining of individual components needed – no. 1, Figure 7.1) and 3) the addition of extra pre-planning activities (such as completion of a detailed planning form – no. 3, Figure 7.1).

In contrast to case studies 1 and 2, a first step of the LCM instantiation to power plant construction involves an additional preparation step to create an erection concept for the power plant which is needed later on for the Process Planning and Detailed Planning phase.

The structure is broken down into smaller sections which are later visualised and planned in more detail during the Process Planning phase. During the power plant instantiations, a different program (Primavera – no. 2, Figure 7.1) was also used to visualise the Process Planning tool and it was feasible to prepare the construction cards electronically in advance of the weekly Detailed Planning meeting (no.4, Figure 7.1).

Section 7.4.2 explains the process of application of the LCM model to power plant construction based on instantiation 3A at power plant A and gives an overview of the visual tools used. Section 7.4.3 discusses the new elements of version 3 in more detail and section 7.5 presents an evaluation of the model to determine its utility and applicability, based on the 5 instantiations.

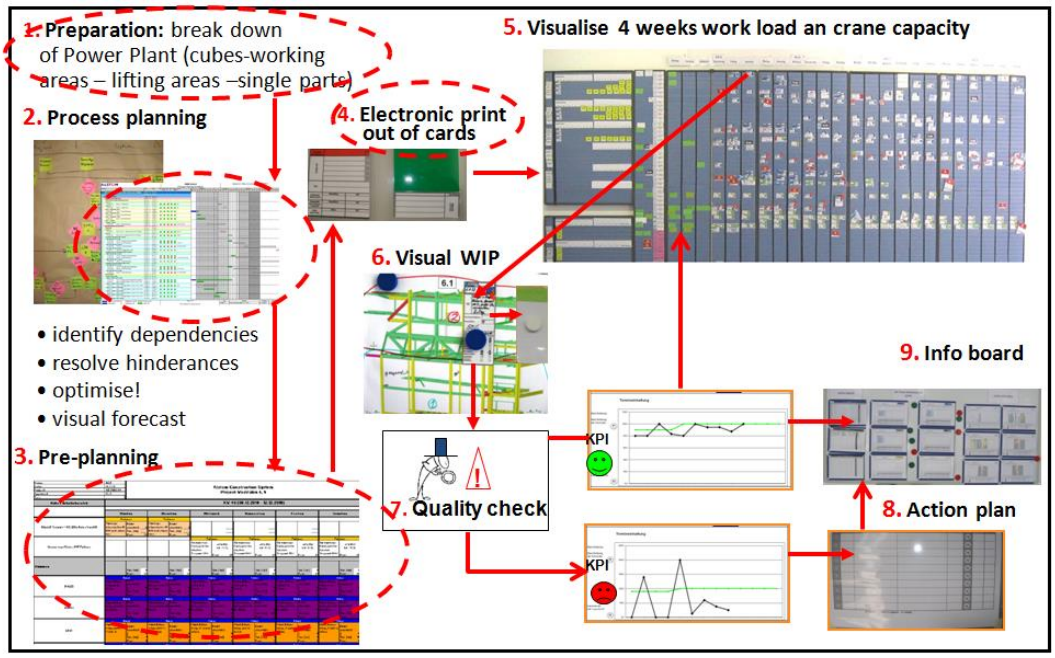


Figure 7.1: Version 3 of the LCM model – new elements highlighted in circles

7.4 Application of LCM to power plant construction (Step 4: Demonstrate)

7.4.1 Case study 3

Case study 3 explains how the LCM model (Figure 7.1) was further developed and applied to power plant construction, representing version 3 of the model. The common goal for the LCM instantiations on all of the power plants was to improve daily planning, optimise buffer times, crane utility and to reduce overall lead time for execution. According to the project manager from the client side, there was a general lack of transparency on all client power plant sites and a missing standard approach to plan, control and compare the site operations.

The purpose of instantiation 3A is to show how the LCM model was further adapted to suit power plant construction (version 3). The purpose of the further instantiations of the model for this research is to gather data from interviews and KPI data on crane utility and On-Time-Performance which are an important source of data for the evaluation (Appendix E).

7.4.1.1 Background of instantiation 3A

Power plant A was the pilot project and represents instantiation 3A where the LCM model was adapted to suit power plant construction. Once a suitable version of the model for power plant construction was adapted, the aim was to use this version as a company standard for the client to apply to its power plant sites worldwide. Each of the power plants were made up of smaller sections called cubes and initially, the scope of instantiation 3A on power plant A was to apply an adapted version of the LCM model to one of these cubes (Figure 7.2 (a) and if some positive effects were determined after a 6 week period, the model would be rolled out on all cubes on the project. Figure 7.2 a shows a sub section of power plant and the individual cubes. The decision was made to implement the model on all of the cubes after 6 weeks, which is evidence of initial positive effects that were noted in application. At this early stage however, it was not possible to actually measure improvements and the only evidence of these positive effects lies in the company's decision to continue implementation on all other cubes and ultimately, on other sites.

The hierarchical structure on the project during instantiation 3A to power plant A, consisted of a site manager, a site planner (who was responsible for scheduling and reported to site manager) and three supervisors who were each responsible for the steel, canal and compression element subcontractors. The role of the three site supervisors focused on coordinating and managing the work to be carried out by the subcontractors in their area and to liaise between the subcontractors and the site manager. They were the direct contact persons for the subcontractors. The LCM project manager worked very closely with this team when adapting the LCM model to the first power plant A.

Before instantiation 3A of the model, weekly construction meetings took place to plan and execute work. Difficulties in communication were experienced since a notable characteristic on the site (and on the remaining sites later on) was that the engineering phase of the project (during which the definition of component requirements for the power plant was an important focus) and the construction phase were very much separate processes – no communication took place between the engineering and construction teams. They were viewed as separate functions that were conducted independently of each other. This resulted in major problems, especially when often the engineering phase was carried out parallel to construction. The result was that approximately 80%-90% of the time (estimated by the LCM manager), material would arrive at the site that was not appropriate for assembly. This material would have to be reworked, or sent back depending on the situation. An important aim of LCM instantiation was to establish a better link between engineering and site management. In addition to the issues of communication and co-operation, other problems were apparent onsite before the LCM instantiation and are summarised below.

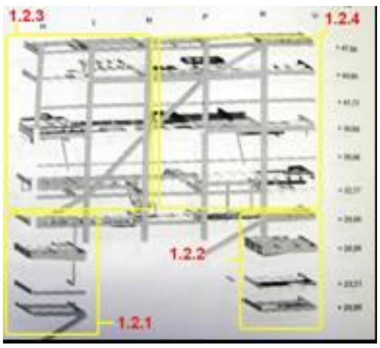


Figure 7.2 (a): Power plant A (sub-section)

7.4.1.2 Problems evident onsite

- **Leadership issues:** according to the LCM manager, site management found it difficult to ensure that the sub-contractors would carry out planned work at the scheduled time.

- **Missing documentation:** often the sub-contractors failed to provide important documentation needed to carry out the work. This was a critical issue due to the abundance of documentation required of which the timely submission of which was critical.

- **Insufficient planning of work and crane usage:** there was no transparency of crane utilisation and fulfilment of commitments.

- **Communication issues:** communication between the interfaces (engineering, site manager, site planners, supervisors and sub-contractors) was not effective.

- **Quality control:** quality checks and job releases of the individual sections were often missing or incomplete.

- **Component supply**: deliveries of components to the site were very often late and incomplete.

7.4.1.3 Background of instantiations 3B-3E

Once a suitable version of the LCM model for power plant construction had been adapted during instantiation 3A, it was then applied to 8 further power plant sites worldwide for the same client. 4 of these instantiations were selected for study in this case study (power plants B-E), as the most complete data was available on these. Figures 2 (b)-2 (e) shows the power plants B-E (either whole or in part), which were the setting for the instantiations 3B-3E. Two of these power plants were located in Germany, one in the Czech Republic and one in the Netherlands.

The hierarchical structure on instantiations 3B-3E was similar to instantiation 3A, consisting of a site manager, a site planer and three supervisors who were each responsible for the steel, canal and compression element subcontractors. The role of the three site supervisors, as in the instantiation 3A, focused on coordinating and managing the work to be carried out by the subcontractors in their area and to liaise between the subcontractors and the site manager. They were the direct contact persons for the subcontractors. The LCM project manager worked very closely with this team when applying version 3 of the model, which was adapted during instantiation 3A, to these sites.

The problems experienced before the LCM instantiations on power plants B-E, were similar to those noted during instantiation 3A. Communication issues were evident as a result of the separation of engineering and construction. Problems relating to missing documentation needed for sub-contractors to carry out work and inefficient usage of cranes were evident.

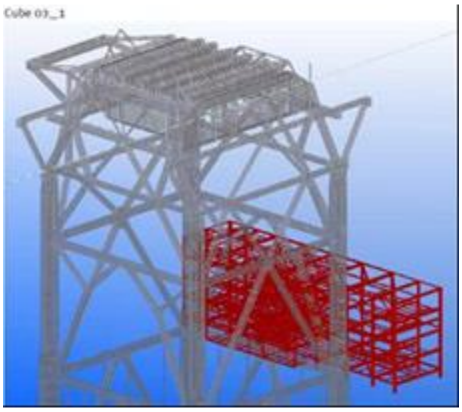


Figure 7.2 (b): Power plant B

Figure 7.2 (c): Power plant C

Figure 7.2 (d): Power plant D

Figure 7.2 (e): Power plant E (sub-section)

7.4.1.4 Objectives of LCM instantiations on all sites

Based on the initial problems observed during instantiation 3A and the problems evident during the following instantiations, the following objectives of the LCM instantiations were defined by client project manager together with the LCM manager. These objectives can be summarised as follows:

- to improve transparency and provide a standard to manage and control site operations, at all power plant sites.
- to improve the link between engineering and site management.
- to better link the crane capacity and the planned process so that capacity can be effectively used (especially in the event of any changes or adjustments at short notice).
- to optimise the overall process by implementing a process-orientated flow using visual tools.

- to identify buffer times in which no value-added activity is being carried out and to optimise the process so that value is increased (in this case to reduce lead time).
- to increase flexibility in response to any changes at short notice (delays in previous work, quality issues etc.).
- to enable close collaboration between subcontractors when planning daily work, to improve reliability.

The following section describes version 3 of the LCM model and the process of application to power plant construction.

7.4.2 Application of version 3 of the model in three phases (instantiation 3A)

7.4.2.1 Phase 1: Overall Process Analysis (OPA)

The first phase of an LCM instantiation typically involves the creation of an Overall Process Map (Figure 7.3) in the Overall Process Analysis phase (Chapter 4, Section 4.5.1; Chapter 5, Section 5.4.2). In this phase, the main construction processes are visualised optimised and the interdependencies between them are identified. However, in power plant construction, the typical Overall Process Analysis played a less significant role. During the instantiation 3A at power plant A, an Overall Process Map was created in a workshop with the site manager, site planer, engineering, supervisors and the LCM manager. It was found however that since the overall process in the each of the power plants was the same and the main players and important sections of the process were known, it was unnecessary to create an Overall Process Map each time. The Overall Process Analysis at power plant A, served the purpose of gathering all necessary information with regard to the important process steps, content and logistic channels specific to power plant construction.

What turned out to be more difficult to determine and required more detail at an early stage at the power plant sites, was the detail needed for the daily operational activities on-site. This is typically a focus of phase 2 of the LCM instantiations - the Process Planning phase in practice (Chapter 5, Section 5.4.2) and later on phase 3, the Detailed Planning phase. However this deeper analysis of the process and activities, turned out to be phase 1 when applying LCM to the power plant sites. During the instantiation 3A of the LCM model, the Overall Process Analysis phase focused on gaining an understanding of power plant construction and determining how the LCM model could be adapted to this type of project. Some of the differences noted during instantiation 3A were:

- The engineering phase was carried out mainly parallel to construction which created issues in the suitability and availability of components.
- The components needed for assembly, usually came from abroad and were not sourced locally.
- According to the LCM manager, almost all of the components needed were unique in nature. There were no standard component types.
- The construction timeframe for a power plant tended to be longer that traditional construction projects.
- More storage area was needed onsite due to size of the components and the need for added space for pre-assembly onsite.
- On the power plant sites, there was a large amount of rework of material. The LCM manager estimated this to be at approximately 80-90% and this was largely to do with the engineering work being carried out parallel and correct components requirements being defined too late.
- Daily work was more complex, according to the LCM managers and more detail was needed for the daily planning of work for power plant projects as opposed to traditional projects.

While this phase of instantiation 3A, focused mainly on the gathering of information and understanding power plant construction, it was also possible to identify some known constraints parallel and to develop solutions for these. This characteristic is typical of phase 1 of LCM application (Chapter 5, Section 5.4.2), where constraints are gathered during the creation of the Overall Process Map. Approximately 100 constraints were identified at this point on the site. These constraints were consequently tracked and removed as soon as possible (using similar actions plans and in the same way as described in Chapter 5, Section 5.4.2.).

The experience gathered during instantiation 3A of LCM at power plant A, determined the first notable difference between LCM application to power plant construction and traditional construction: the first step of the LCM instantiation to power plant construction is not the Overall Process Analysis but it is to focus as soon as possible on the Process Planning Phase. In preparation this involved the splitting down of areas, identification of parts, structuring of the planning boards and pre-planning (discussed in more detail below).

In summary, the adapted version of the LCM model for power plant construction is equivalent to starting at the Process Planning phase (phase 2) in practice (and approaching it in a different way) instead of at phase 1.

Figure 7.3: First (and only) Overall Process Map for power plant A

7.4.2.2 Phase 2: The Process Planning Phase (PP)

As demonstrated in Chapter 5, Section 5.4.2, the Process Planning phase typically begins after the Overall Process Planning phase. In power plant construction however, the LCM instantiation began with the Process Planning phase. Similar to case study 2, the ultimate goal of the Process Planning phase was to create a four month forecast of stable work by defining and visualising milestones and removing constraints. The Process Planning was carried out in a workshop with the site manager, site planer, engineering, supervisors and the LCM manager. At this point, in contrast to case study 2, the subcontractors were not involved. It was considered more important to involve the engineering and the construction management teams to resolve the issues around the component availability and suitability (a critical problem in the process) than to involve the subcontractors. However, the subcontractors were involved in some preparatory steps which were carried out in advance of the Process Planning. In preparation for the first Process Planning meeting, the site manager, supervisors and subcontractors worked together to create an erection concept for the plant. The aim was to split down the plant into smaller sub sections and to define the individual parts needed to assemble each section. The sub sections were called cubes and can be seen in Figure 7.4 below

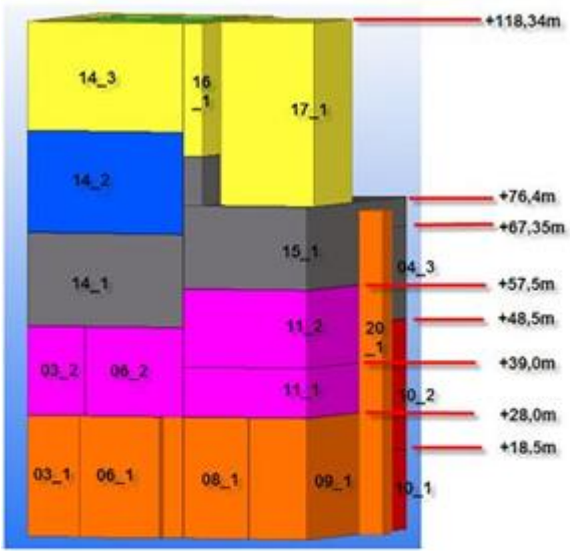


Figure 7.4: Power plant divided into sub-sections called cubes

Each cube was then split down further into what were called working-areas (Figure 7.5 and 7.6) and then lifting units (Figure 7.7). The splitting down of the power plant in this way was the same for all sites. This breaking down of areas was a necessary step to clearly define activities later on and to provide a structure for visualising these activities on the planning board. Each working area functioned independently of each other, so that parallel work could be carried out which was important for improving lead time. The working areas and lifting units were assigned a number as shown in Figure 7.5 and 7.6.

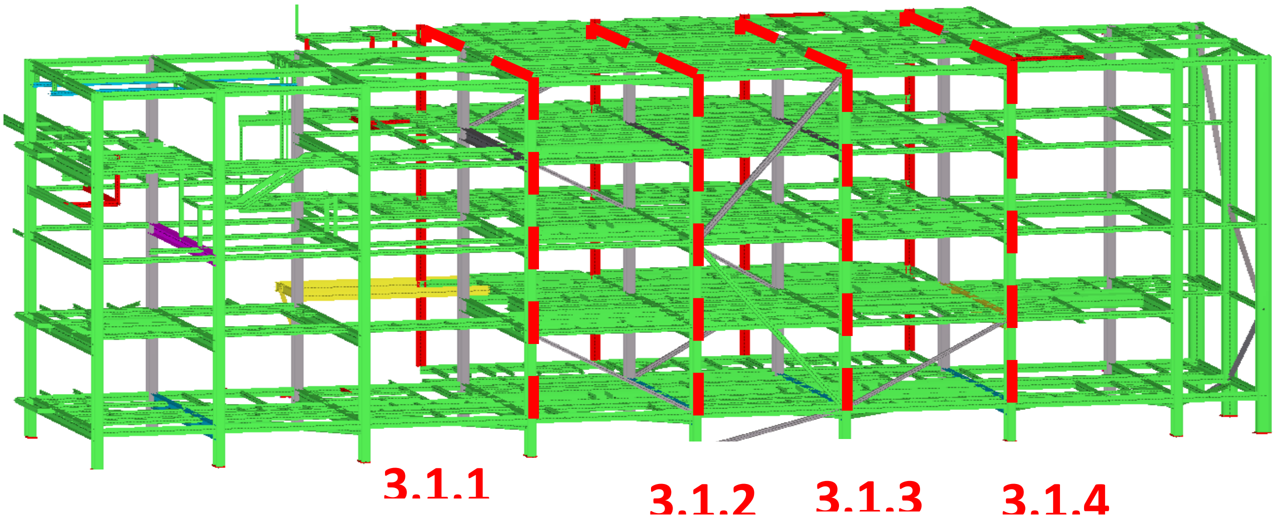


Figure 7.5: Division of cube 3.1 into four working areas

Figure 7.6 shows how a working area was divided into different lifting units. A lifting unit was either a single part or a complete preassembled unit. Each lifting unit was assigned its own number. Figure 7.6 shows how the working area 3.1.1 was divided into seven lifting units: 3.1.1.1 – 3.1.1.7.

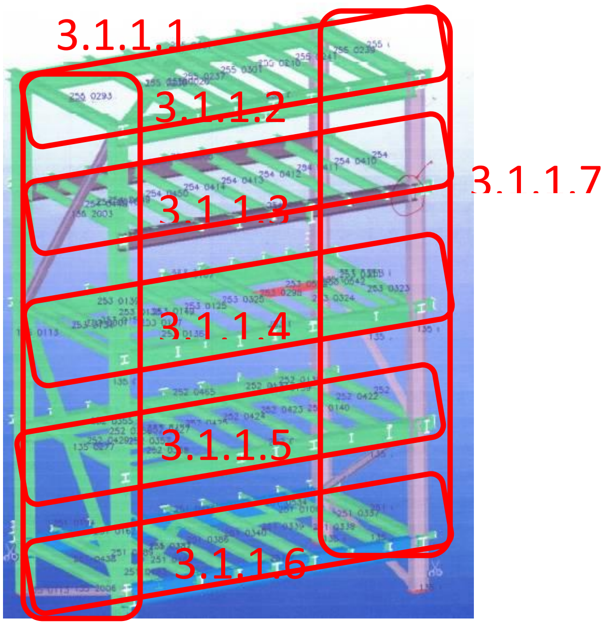


Figure 7.6: Working area 3.1.1

The supervisor then defined the single parts for each lifting unit. Figure 7.7 shows the eight single parts of lifting unit 3.1.1.1 that were identified.

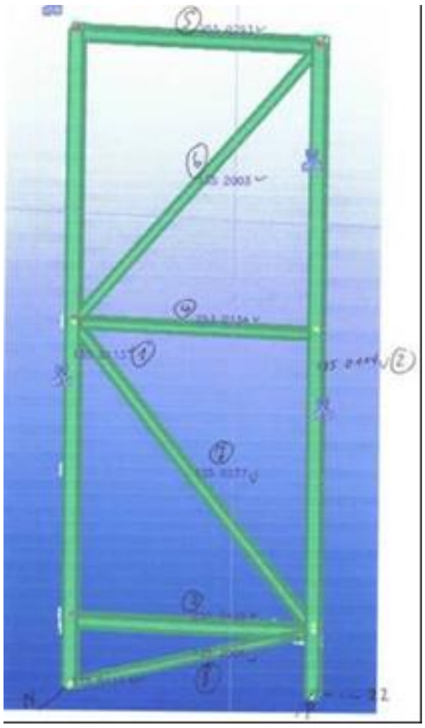


Figure 7.7: Lifting unit 3.1.1.1

During the Process Planning workshop which took place monthly, discussions revolved mainly around what work should be carried out in what area in the specified timeframe of 4 months: i.e. what were the construction activities to be carried out, what resources were needed: components, area, crane, documentation and approvals etc. were identified and planned. Constraints relating to these were identified and documented. As in case study 2, the function of the four month lookahead plan created in the Process Planning phase was to prepare and stabilise the optimised flow of work so that it was possible to implement a pull system using the planning board onsite at a later stage. The Process Planning was an intermediate step, which linked the planning, preparation of work to the operational work onsite. It was a guide and basis for the weekly and daily planning of activities onsite.

On the Process Planning tool for the power plant sites, single activities were merged to one activity (eg: only one bar for one cube) and the forecast was restricted to one or two pages to retain clarity. The Process Planning tool was also further adapted during the additional instantiations on the power plant sites. Figure 7.8 shows an example of the earlier version of the tool and Figure 7.9 shows the Process Planning tool that became the standard. The new standard for the process planning tool was created in the program “Primavera”. This was a centralised planning tool used by the company, in which the participants didn’t need any further training and where all processes merged together. Previously, the Process Planning tool had been created in Visio, with which the company employees were not familiar with. The company could prepare and update the Process Planning tool without the help of the LCM manager when he was absent from the site. The result of the Process Planning workshop was visualised as seen below in Figures 7.8 and 7.9.

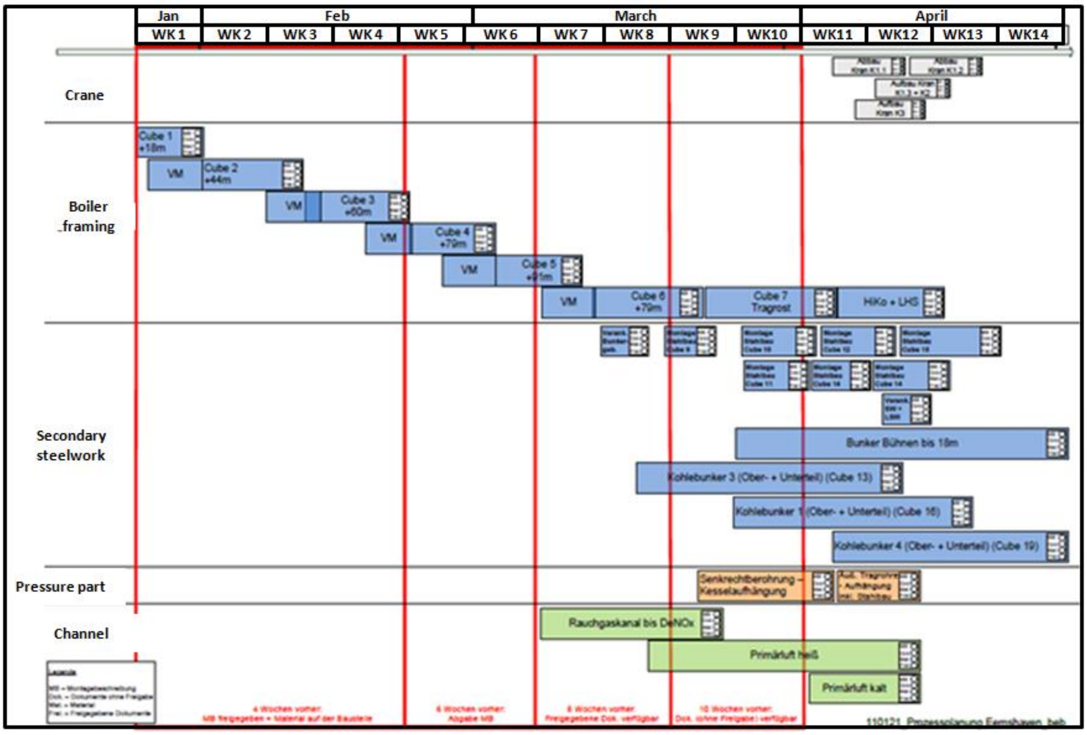


Figure 7.8: Example of original Process Planning tool

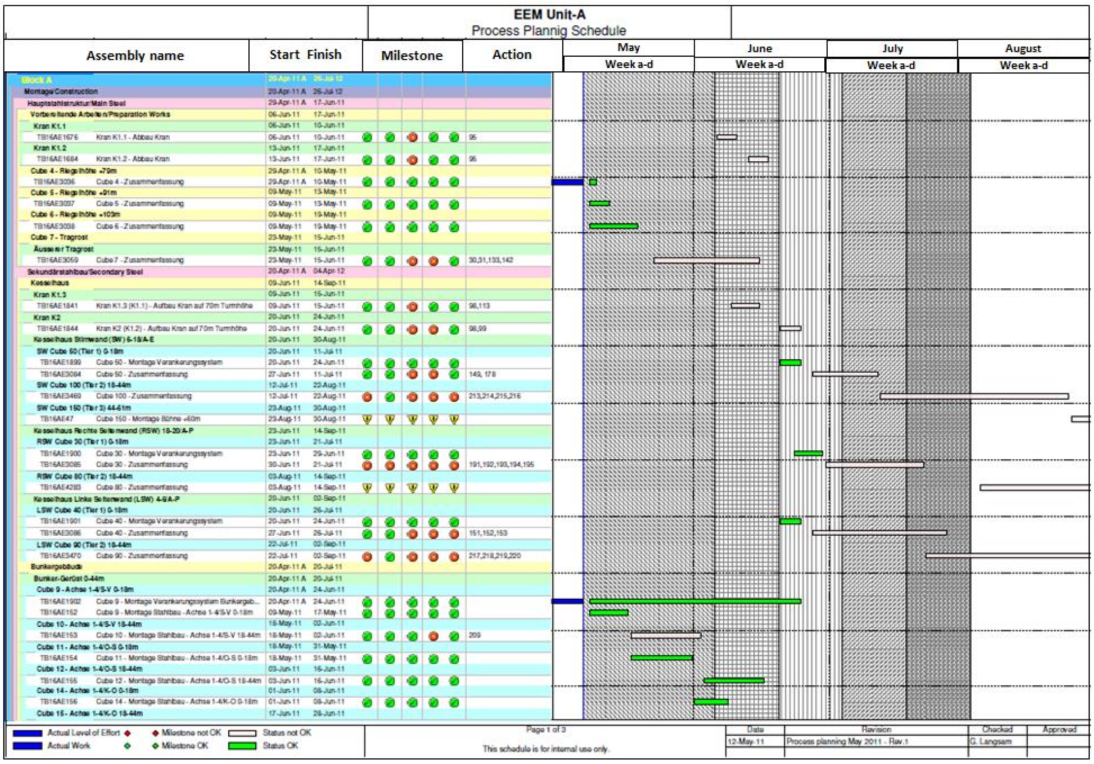


Figure 7.9: Process Planning tool adapted for power plant sites

7.4.2.3 Definition of milestones

Five milestones were defined and visualised so that they could be applied to each activity displayed on the Process Planning tool (see Figures 7.10-7.14 below). These five milestones were the same for each of the power plants A-E. Using these milestones as a guide, the readiness of the activities in the proceeding four months was determined and visualised by using different colored circles beside the activity. On the Process Planning tool, if there was a problem in achieving the milestones, this was highlighted using a red circle displayed beside the activity, if not, a green circle was shown beside the activity (Figure 7.9). All reasons for red signals were documented in the action plan and tracked**.** The five milestones identified were: 1) Documentation submission – has all of the necessary documentation been handed in at least 10 weeks before beginning of erection? 2) Release documents – have the documents been released by engineering 8 weeks before start of erection? 3) Detailed erection concept – has the detailed erection concept been handed over 6 weeks before start of erection? 4) Manufactoring static - has this been handed over four weeks before start of erection? This was important since a structural analysis calculation was needed for each sub stage 5) Are all the components available onsite 4 weeks before start of erection?

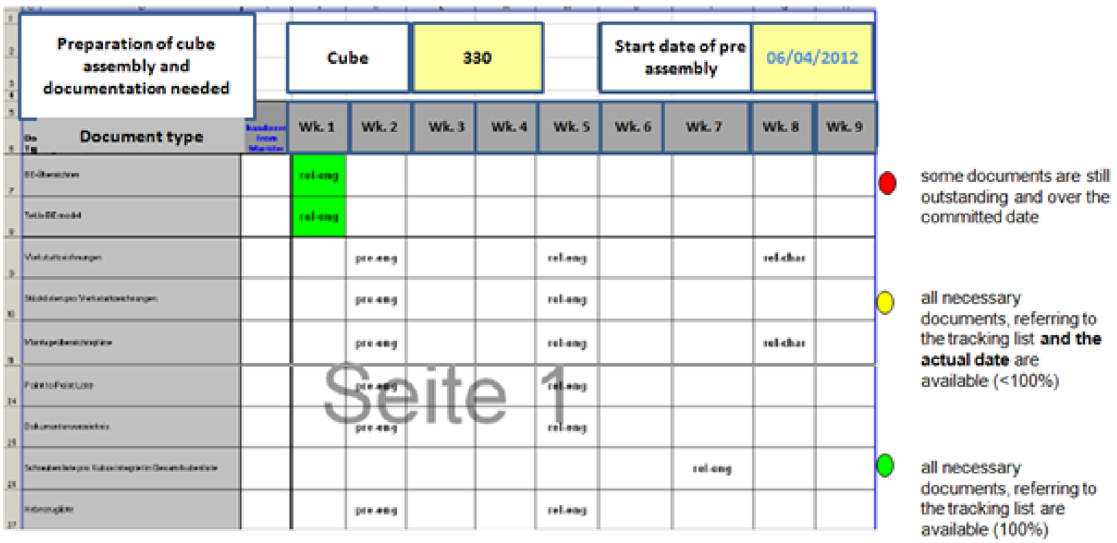


Figure 7.10: Milestone 1: The tracking list for documentation must be completed by the responsible supervisor for each system or cube

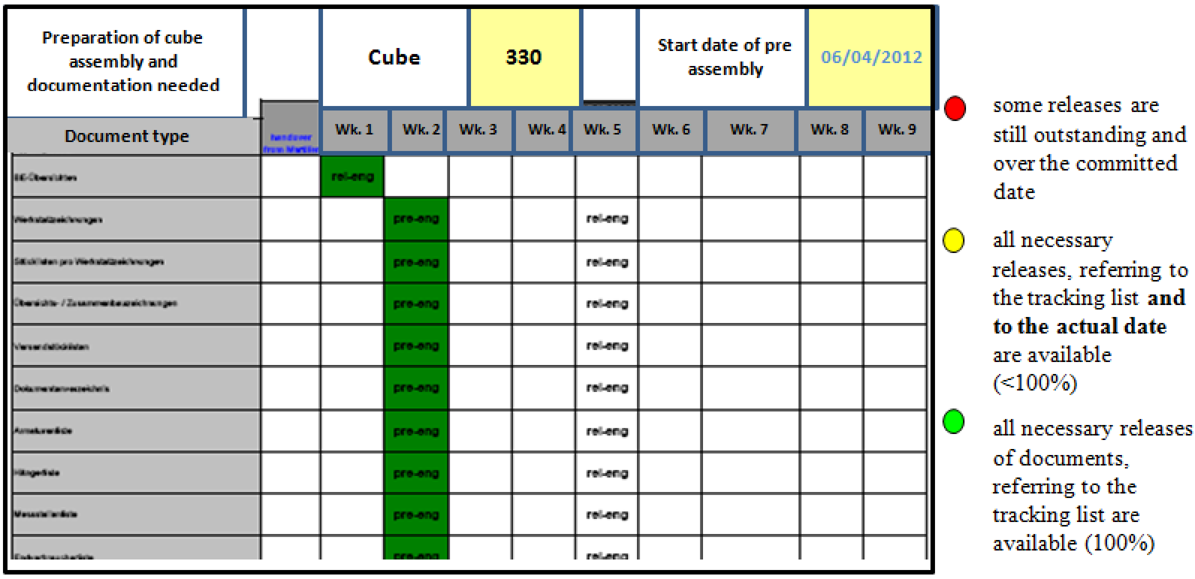


Figure 7.11: Milestone 2: Tracking the release of documentation 8 weeks before start of erection

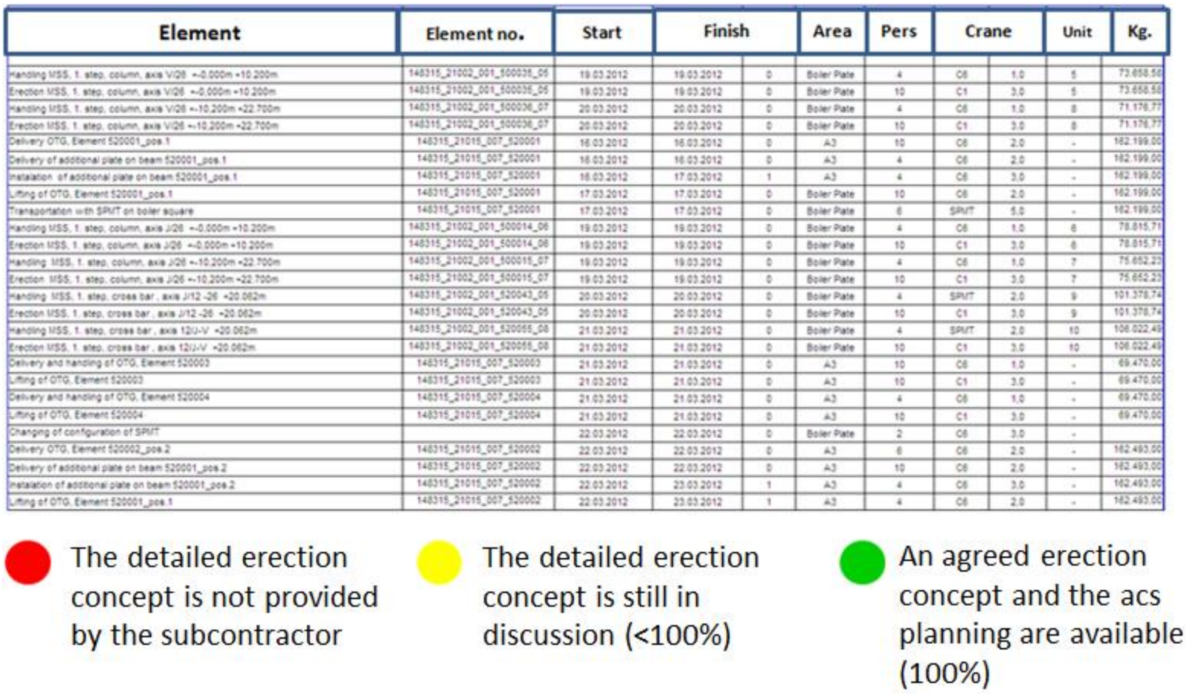


Figure 7.12: Milestone 3: Detailed erection concept

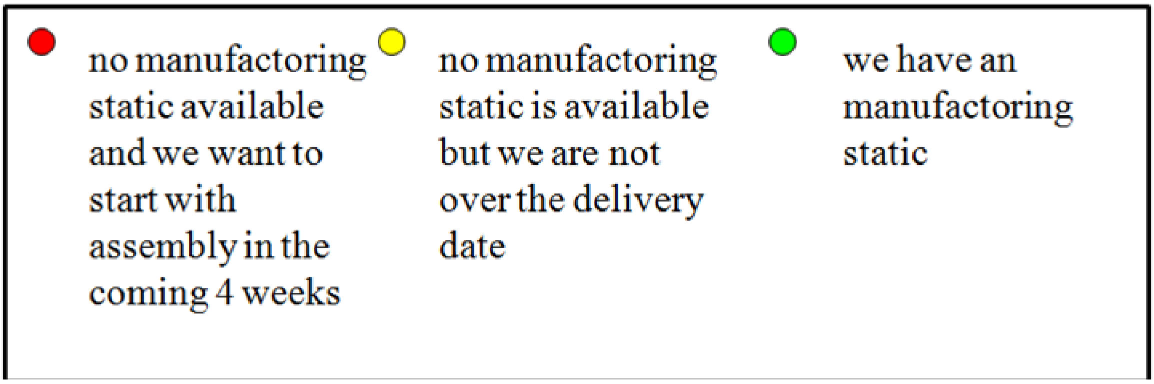


Figure 7.13: Milestone 4: Manufactoring static

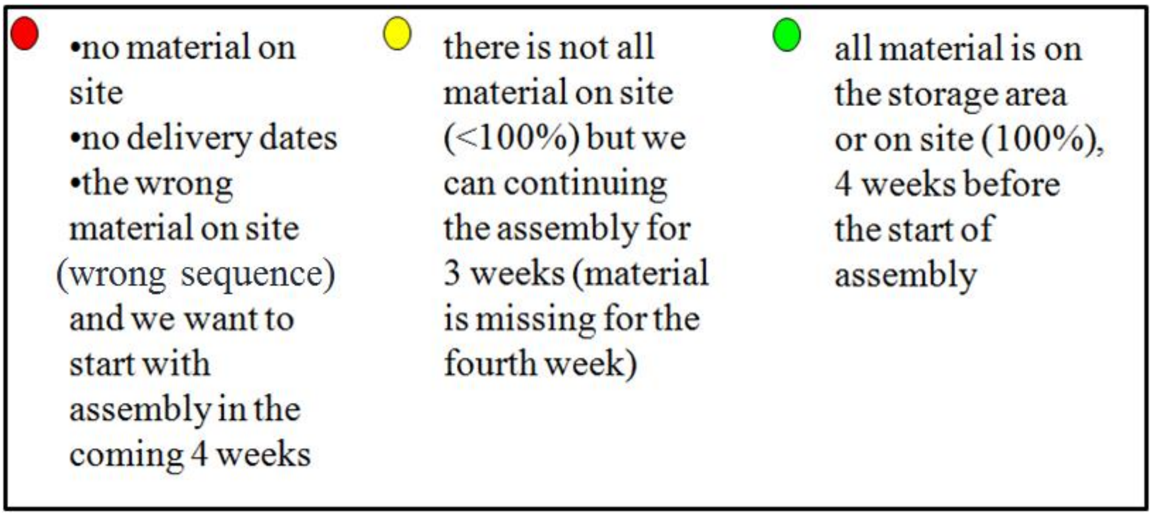


Figure 7.14: Milestone 5 – Availability of components (material)

7.4.2.4 Phase 3: The Detailed Planning phase

In contrast to case study 2, a more detailled planning was required on the power plant cases to ensure that the work could be split down adequately for the cards and used in the Daily Planning later on. The single parts identified when developing the erection concept, were all allocated to the corresponding lifting unit in the ”Excel-part-list” as shown below in Figure 7.15 (the excel list was prepared by the supervisors together with the subcontractors): three columns were added behind each part: cube/category, sub-cube/working area and lifting unit. The supervisor inserted the number of the cube, working area and lifting unit in these columns. Figure 7.15 below shows the result of filtering for lifting unit 3.1.1.1 which is the basis of the component release order.

PARTS IDENTIFICATION - ENGINEERING DATA				Dispatch		DELIVERY to SITE				ener	Assembly			
Ass.bly Group	Pos.	Drawing No.	DE Rev. No.	Qty	DE Weight [kg]	Target Date	Diff. [d]	Actual Date	Current Location	Change	Target Date (finish)	Cube/ Category	Sub-Cube/ Working Area	Lifting Unit
8	8	8	8	8	8836,49	8		0	0	0	0	8	8	8
1	2	3	4	20	21	30	31	32	33	4	60	64	65	66
135	0113	148280_21135_1016	0	1	3.016		0					03_1	1	1
135	0114	148280_21135_1137	1	1	2.874		0					03_1	1	1
135	0277	148280_21135_1158	0	1	238		0					03_1	1	1
135	2003	148280_21135_1159	1	1	223		0					03_1	1	1
135	2006	148280_21135_1167	0	1	284		0					03_1	1	1
251	0438	148280_21251_1348	1	1	576		0					03_1	1	1
253	0134	148280_21253_1152	0	1	399		0					03_1	1	1
255	0293	148280_21255_1253	1	1	1.226		0					03_1	1	1

Figure 7.15: Parts list in Excel

As part of the pre-planning, six weeks before the planned erection, the sub-contractors submitted the following “detailed planning form” which was structured like the planning board to the supervisor (Figure 7.16 and Figure 7.17). On this form the content for the work packages, the erection dates and the erection sequence of a complete week were defined for a four week period. The supervisor checked and signed this form. An updated form was submitted weekly to the supervisor for approval and was used as a guide to write the cards during the weekly meeting (discussed later on). On some of the later instantiations, this information was entered into a database and the cards were printed out in advance of the meeting.

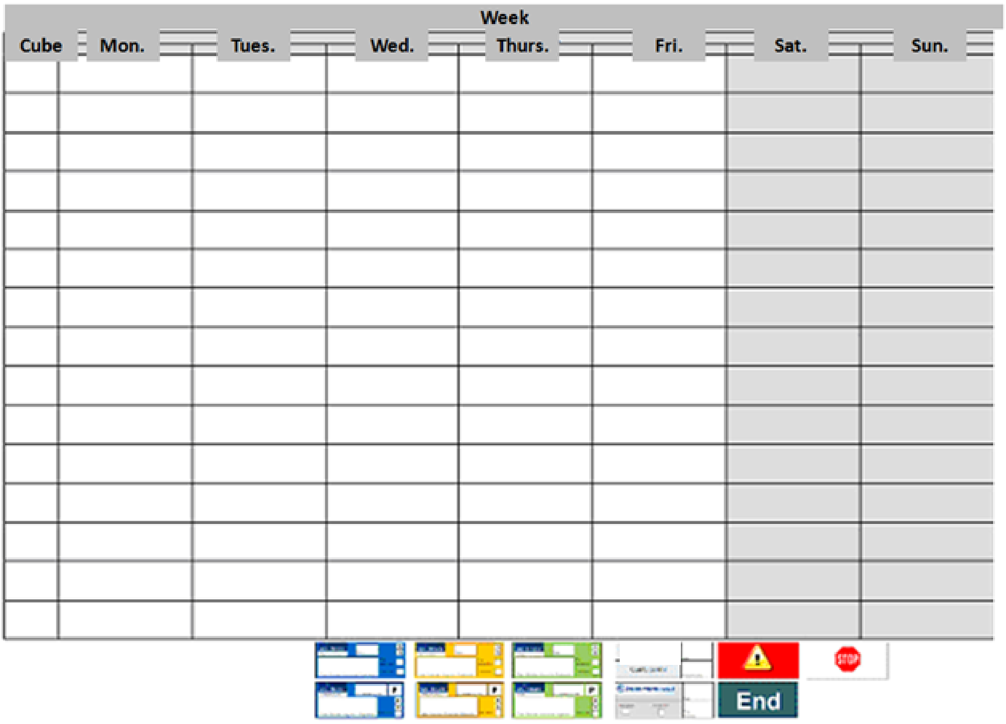


Figure 7.16: Detailed planning form

Cube / Area	Monday	Tuesday	Wednesday
	3.1.1	3.1.1.1 – 3.1.1.7	
	3.1.2	(Crane C3: 10 h)	
	3.1.3		
	3.1.4		
	3.1.5		
Pre-assembly area 1	3.1.1.1, 3.1.1.2, 3.1.1.3, 3.1.1.4		
Pre-assembly area 2	3.1.1.5, 3.1.1.6, 3.1.1.7		

Figure 7.17: Snapshot of the Detailed Planning for working area 3.1.1

Both the Process Planning and the preplanning process were important inputs for the Detail Planning phase. Once a week, a planning meeting took place at the board to discuss, complete and "place" cards on the planning board at the area of work and to resolve any constraints that were in the way of this work. Similar to case study 2, participants of the meeting included: the site manager, site planer, supervisors, sub-contractors and the LCM manager. The heart of the detailed planning process was the Planning board (see Figure 7.18) which was positioned in the LCM area, as is common with all LCM instantiations. The Planning board was a physical Kanban system, like that used in case studies 1 (Chapter 4) and 2 (Chapter 5), which visualised and controlled daily work batches of which the content was prepared based on the preplanning activities described earlier and finalised at the weekly meeting.

As mentioned, on some of the later instantiations, a database was created in Access, which combined the erection concept, the detailed planning and logistic information, which enabled the LCM manager to print out the cards needed for the weekly planning meeting in advance. Daily batches were displayed on cards (either written or printed out), and visualised for a period of four weeks on the planning board. Examples and a description of the cards can be seen in Figure 7.24 and 7.25). During the meeting, the first week on the board was evaluated to determine if all work packages were completed. The 2nd-3rd weeks were adjusted, where necessary and the 4th week was newly planned (using the detailed planning form). The constraints in the daily construction process were discussed, solutions identified and actions defined and visualised on the action board in the LCM area. Problem cards were written and displayed in front of the work packages (cards) on the board where the constraint occurred. Buffer time and crane capacity were also an important focus of this meeting. In addition, another important aspect of this collaboration meeting was the evaluation and discussion of the KPI data gathered on On-Time-Performance and crane utility (Appendix E).

In addition to the planning board, all other elements of the LCM model were visualised in the LCM area such as a print out of the most recent Process Planning, the action plan for constraint removal, the KPI's, the plans of the plant where the cards were placed each day to visualise where work was being carried out on that particular day (Figure 7.19), a description of how the model works (roles and responsibilities) and the logistics board. It was the place where all meetings took place and it was the area onsite where participants at any level of the project could retrieve and contribute information using these visual tools. In addition to the weekly planning meeting, an assembly meeting took place daily at 7 am (times sometimes varied from site to site) with the same group of participants as above. The status of the action plan was discussed to ensure solutions were being implemented.

Figure 7.18: the planning board - on the x-axis the weeks and the days were shown. On the y-axis, the areas were displayed. The red problem cards can be seen in front of the work packages where they occur.

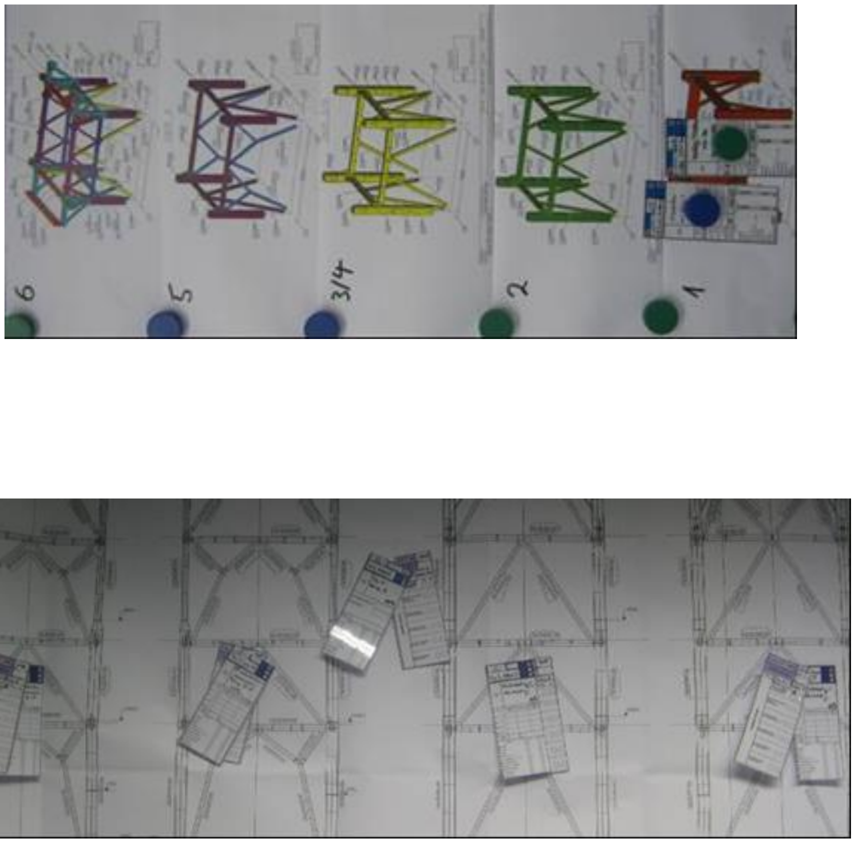


Figure 7.19: Visualisation of work in process on plans

7.4.2.5 The evening meeting / crane meeting

Based on the 4 week forecast of work visualised on the planning board, the crane capacity was also planned and visualised on a logistics planning board (similar to case study 2) 3 days in advance (Figure 7.20). A meeting to discuss the crane availability took place daily at 5 pm at the logistics board (placed right beside the main planning board). One of the goals of the meeting was to plan the crane capacity and adjust the status. The logistics board was divided into three sections for the current day and the following two days. On the x-axis the cranes were displayed and on the y-axis timeslots were displayed. Cards were placed to reserve crane capacity at a certain time of the day. A further goal of this meeting was to check the daily status of the work on the plans and to update the KPI's. If the cards were turned to the green side on the plans, this was a signal to the site manager that the work was complete and to check the work. The content of the completed cards was checked and cards were placed back on the board, green side up, if completed to an acceptable standard. If not, actions were defined and the card was placed back on the plans until the work was completed to an acceptable level of quality. A further focus of this meeting was also to check the action plan (as is also done in the morning meeting).

Figure 7.26 shows an overview of the main meetings that were carried out during LCM instantiations on the power plant sites. In addition to the meetings discussed in this section, there was also an internal meeting which took place weekly with the site manager, site planner and supervisors and an external meeting which included the subcontractors. These were short meetings in preparation for the detail planning meeting at the planning board.

Figure 7.20: Logistics board – visualised overview of crane capacity onsite

Figure 7.21: Visualisation of plans and work areas in LCM area.

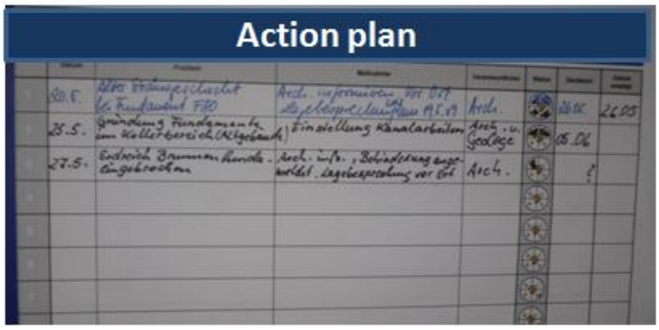


Figure 7.22: Visualisation of action plan in LCM area. Identification of constraints 2-3 weeks in advance. Definition and implementation of solutions.

Figure 7.23: Visualisation of KPI's such as OTP and Quality. Description of roles and responsibilities (far left).

Once the LCM model had been implemented physically onsite, all parties at all levels were trained on how to apply the model and were aware of their role in the implementation process. Unlike LCM instantiations at traditional construction sites, new companies were not continuously joining the project which meant there was a better overall understanding of how to use the model and the different elements.

7.4.2.6 Card description

There were different types of cards used on the planning board and some examples are shown in Figure 7.24 below.

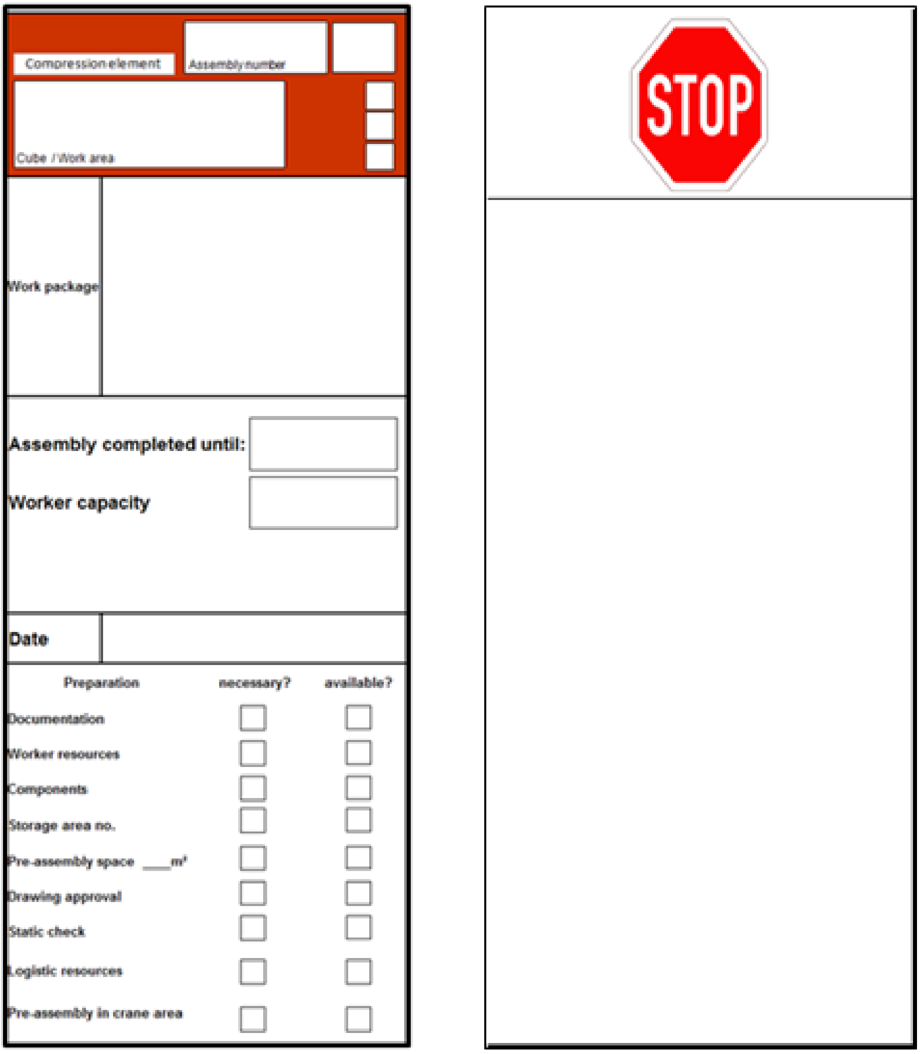


Figure 7.24: An example of a card for a daily batch of assembly work (left) and a card signalling with a “stop” sign that no work should be carried out in a particular area.

The planning board process was similar to that described in case study 1 (Chapter 4, Section 4.6.1). Once placed on the board, the blue top of the card (in the case above) was visible. It was clear to see by glancing at the board which company had work planned on any given day in what area over a 4 week timeframe. The following information was typically displayed on the card: 1) company logo, 2) the name of the work area and type of work 3) day or night shift 4) Whether a crane was needed or not 5) If so, how many hubs are there, how heavy are they and how long will the crane be needed for? 6) Has all the preliminary work been completed? 5) Has the assembly of parts been completed? 7) Worker capacity needed. The stop card was used to indicate that no work should be carried out in a particular area. Figure 7.25 shows some further examples of cards: the left card indicating areas that have been completed fully and need no further work – "Ende". It was also used for areas where there was a planned break in construction and work should not be carried out during this time.

Another important card was the problem card which can be seen to the right of Figure 7.25. This was placed in front of a work package on the planning board to visualise constraints in the daily construction process. Again, at a glance, it was possible to recognise not only the companies and locations of their work, but also whether they had anticipated a problem in the process. These problem cards were an important focus point of discussion during the weekly meetings. The LCM model strives to encourage the early detection of these problems and ideally, a main focus is to identify and visualise as many of these problem cards as soon as possible in weeks 3-4, so that there is enough time to react.

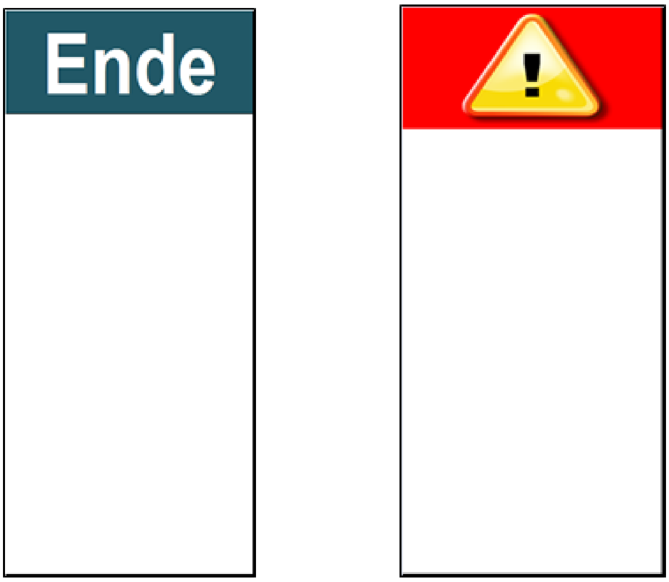


Figure 7.25: On the left, a card indicting the end of a construction process. On the right, the problem card on which constraints are visualised.

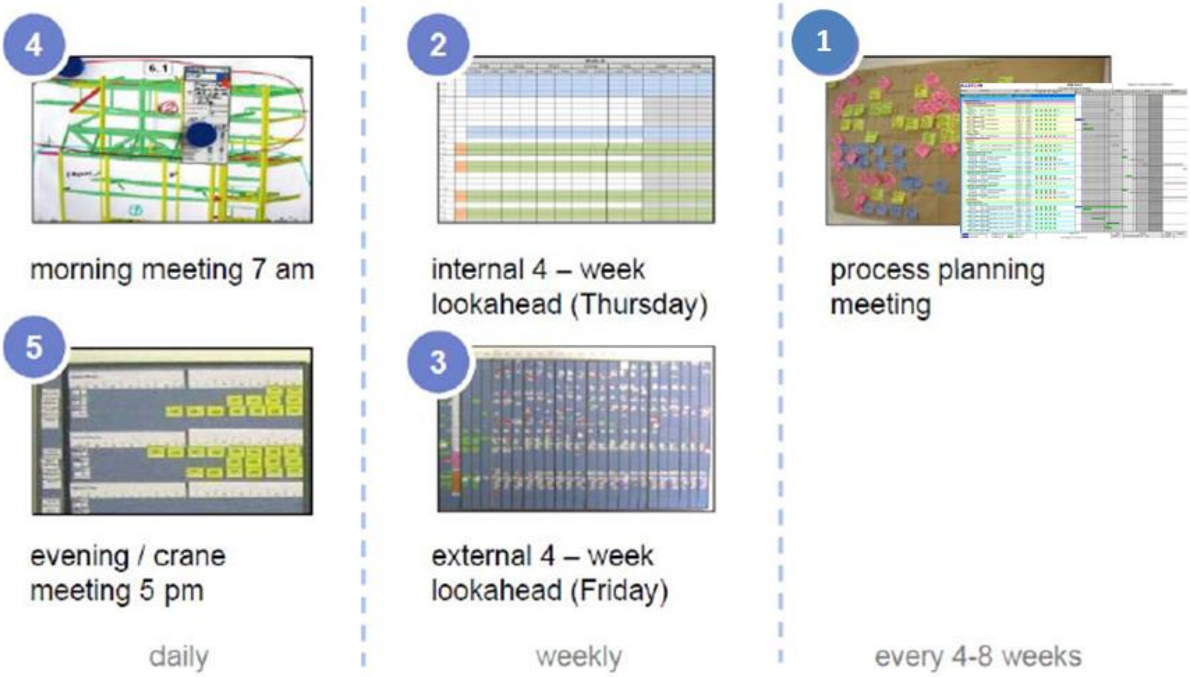


Figure 7.26: Overview of meetings as part of the LCM instantiations to power plant construction

7.4.3 Formative evaluation of version 3 (step 4)

Chapters 4, 5 and 7 presented three different versions of the LCM model. Chapter 4 presented version 1, which was the original version developed and applied to a new construction project. Chapter 5 presented version 2 of the model, which was a further development and adaptation to refurbishment construction and which also represents how the model is typically applied in practice today. This chapter presents version 3 of the model, which demonstrates how it was further developed and applied to suit power plant construction.

In the power plant instantiations, some further changes to the LCM model evolved, as mentioned in Section 7.3. Version 3 of the LCM model, adapted to power plant construction differs from version 1 and 2 in five main ways:

7.4.3.1 The OPA phase is less important

It was found that since the overall process in the each of the power plants was the same and the main players and important sections of the process were known, it was unnecessary to create an Overall Process Map each time. During the LCM instantiations to power plant construction, a greater need for more detail at a very early stage was identified. The implementation phase therefore began at the Process Planning phase unlike in case study 2.

7.4.3.2 Additional preparatory steps necessary at early stage

It was found also during the power plant instantiations, that a greater level of detail was needed for the Process Planning phase in contrast to version 2 in case study 2. Additional preparatory steps (carried out by the site manager, supervisors and subcontractors) for the Process Planning and Detailed Planning were needed to create an erection concept for the plant. The aim was to split down the plant into smaller sub sections and to define the individual parts needed to assemble each section. Each cube was then split down further into what were called working-areas (Figure 7.5 and 7.6) and then lifting unit (Figure 7.7). This breaking down of areas was a necessary step to clearly define activities later on and to provide a structure for visualising these activities on the planning board.

7.4.3.3 Further development of the PP tool

The Process Planning tool was also further adapted during the additional instantiations on the power plant sites. A new standard for the Process Planning tool was created in the program “Primavera”. This was a centralised planning tool used by the company, in which the participants didn’t need any further training and where all processes merged together. Previously, the Process Planning tool had been created in Visio, with which the company employees were not familiar with. The company could prepare and update the Process Planning tool without the help of the LCM manager when he was absent from the site.

7.4.3.4 Different participants in the PP phase

During the LCM instantiations to power plant construction, in contrast to version 2 in case study 2, the subcontractors were not involved in the Process Planning workshops. It was considered more important to involve the engineering and the construction management teams to resolve the issues around the component availability and suitability (a critical problem in the process) than to involve the subcontractors. The interface between engineering and construction during the power plant instantiations was a key issue and an important focus of the Process Planning was to improve transparency and communication between these two interfaces.

7.4.3.5 Additional pre-planning activities

In contrast to case study 2, a more detailled planning for the Detailed Planning phase was required on the power plant cases, to ensure that the work could be split down adequately for the cards used in the planning board. The single parts identified when developing the erection concept, were all allocated to the corresponding lifting unit in the ”Excel-part-list” as shown below in Figure 7.15. As part of the pre-planning, six weeks before the planned erection, the sub-contractors submitted a “detailed planning form” which was structured like the planning board to the supervisor (see Figure 7.16 and Figure 7.17). On this form the content for the work packages, the erection dates and the erection sequence of a complete week were defined for a four week period. On some of the later instantiations, this information was entered into a database and the cards were printed out in advance of the meeting – which improved preparation for the meeting and saved time.

Table 7.5 presents a summary of the new elements of version 1, 2 and 3, highlighting the differences between the implementation process and the visual elements applied by each.

Table 7.5: Summary of new elements of versions 1, 2 and 3 of the LCM model

Case study	Goal of case study	Visual elements of the LCM model	New elements	Implementation process	Measureable results
1	Development of the LCM model	1) the overall process analysis, 2) the daily planning board, 3) construction cards per company,4) visual KPI's, 5)action plans, 6) construction checklist, 7) an apartment clock, 8) an information board and 9) a logistics board	all	Parallel to execution phase	Some data showing improved on-time-performance and quality
2	Further improvement and application of the LCM model to refurbishment construction	1) the overall process analysis, 2) process planning tool 3) the daily planning board, 4) construction cards per company,5) visual KPI's, 6) action plans, 7) plans visualising work in process, 8) an info board and 9) a logistics board	1) Process planning tool 2) Detailled logistics board 3) Coloured plans to visualise work in process	1) Implementation carried out in 3 clear phases. Phase 1 is carried out before execution. Phases 2 begins just before execution and is carried out parallel to execution (monthly meeting). Phase 3 is carried out parallel to execution (daily and weekly meeting). 2) Work in process no longer displayed at area of work (apartment clock), but on visualised plans in LCM area. 3) more detailled logistics planning	1) KPI data on on-time-performance, quality and stability of PP (instantiation 2B) 2) Data on lead time 3) Data on constraint removal
3	Further application of the LCM model to power plant construction	1) process planning tool (primivera) 2) Excel part list 3) Detailled planning form 4) the daily planning board, 5) construction cards per company (manual and electronic) 6) visual KPI's, 7) action plans, 8) plans visualising work in process, 9) an info board and 10) a logistics board	1) Excel part list 2) Detailled planning form 3) Process Planning tool in Primivera	1) Implementation began at phase II (Process Planning Phase). 2) In preparation for the Process Planning, preparation activities were carried out in order to split down the plant into smaller sub sections (cubes) and to define the individual parts needed to assemble each section. 3) A preplanning step was carried out before the detailed planning phase. As part of the pre-planning, a detailled planning form was completed by the subcontractors weekly and signed-off by the supervisors. This was a proposal for the daily work packages for a 6 week timeframe.	1) KPI data on on-time-performance and crane utility 2)) Data on constraint removal

The following section presents an evaluation of the utility and applicability of version 3 of the LCM model.

7.5 Evaluation of utility and applicability (step 4)

An important focus of this section is to establish whether the LCM model was found to be useful based on five lower level criteria: 1) improvement in daily planning, 2) constraint identification and removal, 3) waste identification and removal, 4) improved transparency and 5) measurability of performance. Interviews with the LCM managers, the client and KPI data gathered from the four instantiations (Appendix E) are used as basis for the evaluation. The questions from the evaluation framework (Chapter 3, Figure 3.4 and 3.5) and those presented in Appendix B.3, were used as a guideline for the interviews carried out with the LCM managers and the client.

7.5.1 Limitations of the KPI data

Similar to case study 2, quantitative data on On-Time Performance and crane utility was gathered during the observation periods on four instantiations as part of case study 3 (Appendix E). A limitation of the data gathered is the lack of information on performance before the LCM instantiations. Before the LCM instantiations, no data was gathered on On-Time Performance or crane utility which meant no baseline existed for comparison after the LCM instantiation. While the data shows positive developments at times in the stability of on-time performance and crane utility during the observation period, the data itself is not conclusive. However, this data forms a basis for possible future comparisons.

In addition, further challenges were experienced when gathering the KPI's data during the instantiations. One challenge was that for the first time on the sites, performance was measured and some adversity was experienced at times. Not all participants were positive about the transparency of the information. Occasionally data was incomplete since site management could not participate in the daily meetings due to time constraints. The inaccuracy and incompleteness of the KPI data was also noted at times when the LCM manager was not physically onsite to ensure data was being gathered correctly.

7.5.2 Usefulness of the LCM instantiations

7.5.2.1 Improvement in daily planning through increased transparency

Before the LCM instantiations at the power plant sites, there was a lack of transparency in the daily planning of work onsite and no standard way of managing and controlling the work on all sites. There was also no information available on crane utility or On-Time-Performance as this was not made transparent or measured. There was a general feeling that cranes were not effectively utilised and scheduled work was not carried out as planned but no data existed to confirm this. In addition, there was no information on the reasons for crane-downtime and why work was not carried out as planned. For this reason, there was no sense of continuous improvement onsite as problems were not made transparent and adequate improvement measures could not be identified. Due to a lack of missing standard of managing and controlling all sites, it was difficult to compare performance between the different locations and to benefit from important learnings in practice between sites.

The feedback from the interviews with the LCM managers involved and the client indicate that a notable improvement in transparency, communication and daily planning could be achieved during the LCM instantiation and that as a result the cranes could be better utilised.

> "With LCM we could achieve a greater transparency of activities onsite, which ultimately helped us to better utilise our crane and personnel resources" (Client: Project Manager, Table 7.4).

> "The transparency of the planned daily activities over a four week period meant that we could get the most out of our available resources and identify and resolve the bottlenecks" (Client: Project Manager, Table 7.4).

The client also noted that the visualisation of the daily process using the Planning board improved the understanding of a highly complex process and in turn improved the reaction time to change and On-Time-Performance:

> "The LCM planning board helped us visualising the highly complex and highly unpredictable processes of commissioning. We achieved a much better reaction time and improved our on-time performance significantly" (client: project manager, Table 7.4).

Further evidence of the utility of the LCM instantiation is provided by the decision that was made to roll out the adapted version 3 of the model to 8 further sites after the initial instantiation 3A.

In general, the KPI data on all four of the LCM instantiations (3B-3E) to power plant construction appear (during certain periods) to support the client's view that a positive development in the stability of daily planning, crane utility and OTP was achieved during the instantiations (Appendix E, Figures: E.1, E.2, E.4, E.6, E.8, E.10, E.14 and E.15). It could be noted that for certain periods during some instantiations a stabilisation and improvement of crane utility (Appendix E, Figure: E.1, E.4, E.10 and E.14) and OTP % (Appendix E, Figures: E.2, E.6, E.8, E.12 and E.15) of the subcontractors could be achieved. It can also be noted from the data (especially in the sudden decreases in KPI’s from one week to the next), that certain other factors greatly influence the OTP % and crane utility and can only be made transparent through the LCM model but cannot be completely resolved: weather and technical issues mainly but also component issues to some extent (Appendix E, Figures: E.3, E.5, E.7, E.9, E.11, E.13 and E.16.).

For future LCM instantiations on power plants and further research studies, it would be important to consider how the model could be better used to improve the complicated component supply process and to better foresee the reoccurring technical issues. Furthermore a reoccurring reason for a low OTP % on all sites was a lack of co-ordination and missing information (Appendix E, Figures: E.2, E.6, E.8, E.12 & E.15). This was, for the most part due to the absences of the site manager and the LCM manager (who after a number of months was not on the site on a daily basis). The LCM model works most effectively when all roles participate 100%. The human factor is considerably important in this process and it can be noted from the data, that when participants failed to play their role in the co-ordination and provision of information, or were absent, the performance suffered as a result (Appendix E, Figures: E.3, E.7, E.9, E.13 and E.16)

Regarding the lead-time, according to the LCM managers and the client, this was improved in some areas of the power plants (main steel, secondary steel) – in some cases by up to 2 months.

> “By applying LCM, we were able to improve lead time in individual cubes of the power plant. The overall lead-time could be improved on one power plant by 2 months” (LCM Manager, Table 7.4).
>
> “LCM helped us to speed up our process significantly. We were able to complete our main steel part 20% ahead of schedule” (Client: Project Manager, Table 7.4).

However it was difficult to observe large improvements in the overall lead-time since any improvement in an individual cube was often undone by delays in a following cube. On one of the power plants, however it was possible to observe an improvement in the overall lead time by a number of months. On the other hand, on one site the lead time was actually longer than planned as a result of the problems occurring in the process (power plant E). According to the LCM project manager, improvements in the lead-time in areas or the overall plant were always on sites where the site management fully supported and participated in the LCM implementation process.

Finally, according to the LCM managers, the component issues (incorrect and missing components) were greatly improved but not eliminated as can be seen from the KPI data (Appendix E, Figures: E.3, E.5, E.7, E.9, E.11, E.13 and E.16.).

> "The improved communication between the engineering and construction interfaces as a result of LCM implementation, helped to better define component requirements which had a positive effect on on-time performance and crane utility" (LCM Manager, Table 7.4)

7.5.2.2 Improvement in constraint removal through increased transparency

Similar to case study 2, the usefulness of LCM in identifying and removing constraints could be noted. Transparency on issues and communication on solutions was improved through the monthly, weekly and daily discussions during the Process Planning Phase and Detailed Planning Phase.

> "Through the early identification of constraints, solutions could be identified and implemented earlier and delays in execution avoided" (LCM Manager, Table 7.4),

The use of visual tools for the Process Planning led to the identification of approximately 400-600 constraints at each of the four power plant sites. These constraints were mainly concerned with missing documentation for execution, missing releases of documents by engineering and incomplete information for the erection concept. Likewise, a similar number of additional constraints could be identified and removed during the Detailed Planning phase (also between 400 and 600 constraints per site). These problems concerned mainly the issues experienced during execution such as lack of unsuitable components or components that hadn't arrived and technical issues with the cranes.

7.5.2.3 Summary: usefulness of the individual LCM elements

Figures 7.27-7.29 below summarises the main findings with regard to the usefulness and applicability of the LCM elements that were adapted to power plant construction as described in section 7.3 of this chapter. On the basis of the feedback from the interviews with third parties (Table 7.4) and the documentation on the applications available, it appears that a majority of the LCM elements were useful in stabilising daily planning and in facilitating constraint removal through increased transparency. Some of the individual elements could be measured for their effectiveness e.g. the Process Planning tool, action lists, the planning board, construction cards etc., but mainly by measuring the number of constraints that were identified while using that particular element. Some positive developments in the stability of OTP % of subcontractors and the overall crane utility were noted. However, some limitations were also experienced when gathering the KPI data (Section 7.4.1). Furthermore, while the participants also indicated that the LCM elements helped in reducing waste on the construction site, this was difficult to quantify or to measure. Section 7.5.3 discusses the applicability of the LCM model in more detail.

LCM elements 1-8									
		1. Overall process map	**2. Process planning tool**	**3. Overall process planning action list**	**4. Process planning action list**	**5. Stability metric**	**6. Planning board**	**7. Construction cards**	**8. Problem cards**
1.USEFULNESS	**Daily planning**	Not useful	Useful when combined with pre-planning process	Not directly useful for daily planning	Useful in making constraints transparent	Not applied to power plant projects	Useful	Useful	Useful
	Constraint removal	Useful in making constraints transparent	Useful in making constraints transparent	Useful in removing 60-100 constraints	Useful in removing 400-600 constraints		Useful	Useful	Useful
	Waste	Not known	Waste reduced but could not be measured	Waste reduced but could not be measured	Waste reduced but could not be measured		Waste reduced but could not be measured	Waste reduced but could not be measured	Waste reduced but could not be measured
	Transparency	Useful in improving transparency	Useful in improving transparency	Useful in improving transparency	Useful in improving transparency		Useful in improving transparency	Useful in improving transparency	Useful in improving transparency
	Measureability	Could not be measured	Could not be measured: stability metric not applied here	Could be measured: up to 100 constraints were identified	Could be measured: 600 constraints were identified		Could be measured: OTP Metric	Could be measured: OTP Metric	Could be measured: see constraints removal
2.APPLICABILITY	**Adaptability**	Not applicable	Could be adapted	Could be adapted	Could be adapted	Could be adapted	Could be adapted	Could be adapted	Could be adapted
3.IMPORTANCE	**Theoretical contribution**	Dealt with in separate section							
		further development in practice by third parties							
		original development							

Figure 7.27: Summary of evaluation findings for elements 1-8

LCM elements 9-16									
		9. Logistic board	10. Logistic cards	11. Visualised colour-coded site layout	12. Material database linked to LCM	13. Complete cards visualised on "apartment clock" (now on plans).	14.Visualised action plan in LCM area	15. Metric for on-time performance	16. Metric for quality
1.USEFULNESS	Daily planning	Useful	Useful	Not used in power plant cases	Useful for card preparation and material planning	Not used in power plant cases	Useful in making constraints transparent	Useful in highlighting companies who could not deliver	Not used in power plant cases
	Constraint removal	Useful in making constraints transparent	No	Not used in power plant cases	Useful in making constraints transparent	Not used in power plant cases	Useful in removing up to 300 constraints	Useful in making constraints transparent	Not used in power plant cases
	Waste	Waste reduced but could not be measured (waiting time)	Waste reduced but could not be measured (waiting time)	Not used in power plant cases	Waste reduced but could not be measured	Not used in power plant cases	Waste reduced but could not be measured	Waste reduced but could not be measured	Not used in power plant cases
	Transparency	Useful in improving transparency	Useful in improving transparency	Not used in power plant cases	Useful in improving transparency	Not used in power plant cases	Useful in improving transparency	Useful in improving transparency	Not used in power plant cases
	Measureability	Could not be measured	Could not be measured	Not used in power plant cases	Could not be measured	Not used in power plant cases	Could be measured: number of constraints resolved	Could be measured	Not used in power plant cases
2.APPLICABILITY	Adaptability	Adapted from original planning board	Adapted from original planning board	Not used in power plant cases	N/A	Not used in power plant cases	Could be adapted	Could be adapted	Not used in power plant cases
3.IMPORTANCE	Theoretical contribution	Dealt with in separate section							

further development in practice by third parties

original development

Figure 7.28: Summary of evaluation findings for elements 9-16

LCM INSTANTIATION		
		ALL MODELS
1.USEFULNESS	Daily planning	Useful for improving daily planning. Some adaptations and additional tools needed. The OTP metric showed a positive trend in some periods and negative trends were often to as a result of factors that are difficult to influence or completely resolve: weather, technical issues and unsuitable / missing components.
	Constraint removal	The model helped to remove constraints early on in the planning process and during construction. On average on each site 700-1000 constraints could be removed.
	Waste	The feedback from the interviewees was that waste could be reduced but this could not be quantified adequately: buffer time and waiting time of crane being some examples
	Transparency	The interviewees opinion was that transparency was greatly improved
	Measureability	The OTP % and the crane untiliy could be measured on some of the sites but not all.
2.APPLICABILITY	Adaptability	The adaptation and application of the LCM method to the 6 power plant cases in this study is evidence that it is possible
3.IMPORTANCE	Theoretical contribution	Dealt with in separate section

Figure 7.29: Summary of evaluation findings for LCM Instantiations

7.5.3 Applicability of the LCM model

In case study 3, an important part of the evaluation was to determine the models applicability to power plant construction. Initial evidence on the applicability of the model to power plant construction is provided by the successful adaptation of the model to power plant construction during instantiation 3A and the roll out of this version of the model on 8 further power plant sites. To apply the LCM model to power plant construction, various elements was first adaped at each phase. For example, at phase 1, the Overall Process Map did not play a significant role in the LCM instantiations to power plant construction. As explained in Section 7.4.2, the Overall Process Analysis did not adapt well to this type of construction. Only the gathering of constraint points as a result of this step was useful. The list of actions identified could be tracked which meant there was some form of measurement of improvements that were implemented.

The Process Planning phase (Phase 2) of a typical LCM instantiation involves the application of 3 main elements: the Process Planning tool, the action list and the stability metric. The Process Planning tool for power plant construction was created in Primavera which was a further adaptation on previous implementations. According to the LCM project manager, the Process Planning phase helped to identify and reach the milestones so that work could be executed. Transparency of these milestones was important since a large amount of documentation was needed in order for work to be carried out as planned. It can be established from the feedback and the data available that it was possible to adapt and apply the Process Planning phase of LCM instantiation to power plant projects. From the interviews with the LCM managers, the feedback was that transparency and communication was improved – especially between engineering and construction where no communication occurred previously. The Process Planning phase was useful in providing a link between engineering and construction since both of these interfaces took part in the process planning workshops.

Finally, in Phase 3, the Detailed Planning phase of LCM instantiation, most of the elements of the model were applicable and useful in improving the daily planning of work and resources. The main visual tools used during the Detailed Planning Phase were: the planning board, action plan, construction cards, logistic cards, problem cards, other card types and the visualisation of cards on plans. However, findings from the interviews with the LCM managers, the client and an analysis of the documentation available, show that additional visual tools to support this process were needed: i.e. the detailed planning form and part list as part of the pre-planning process. This pre-planning process itself was a further adaptation of the LCM model to suit the power plant projects. The complexity and detail needed for daily planning was found to be greater in the power plant projects compared to traditional types of construction, according to the LCM manager who first applied LCM to this type of project. By developing this new process and the tools to support the preplanning process, the daily planning of work packages could be improved. Figure 7.30 below highlights this process, showing how the pre-planning tools feed into the planning board. It can also be noted from this diagram that in contrast to LCM instantiations on traditional types of construction, the master plan (step 1 in diagram) plays a more important role in the process since it is the basis of the assembly concept (step 2) which is then used to identify the parts list (step 3) which finally feeds into the daily work packages (step 4) that are displayed on the planning board (step 5).

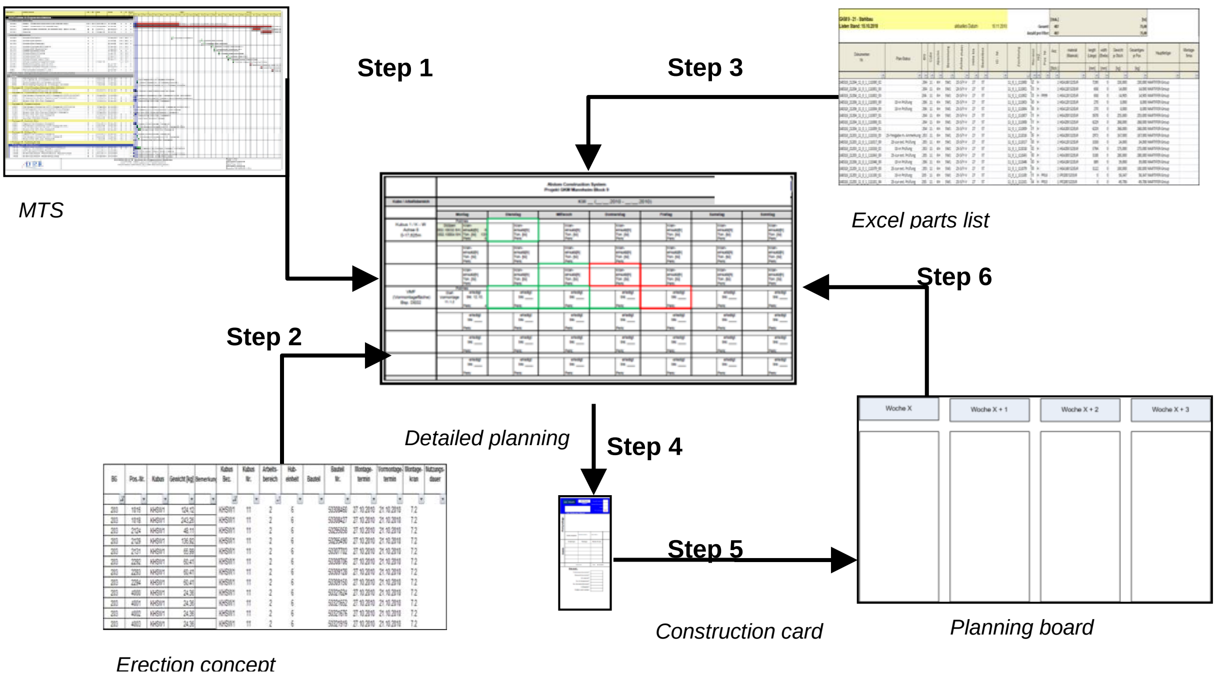


Figure 7.30: The additional pre-planning steps as part of the LCM models adaptation to power plant construction.

The planning and logistic boards were also applicable during the LCM instantiations at the power plant sites. The pull system onsite, through use of the planning board and the logistics board, ensured a focus on the specified 4 week time period in the 4 month forecast (Process Planning). This four week time period was broken down to a daily level on the planning board. The logistics board helped to visualise the available crane resources and allowed the companies to plan this resource 3 days in advance. Information was always readily available which supported communication and increased transparency. At any time it was possible to see what work was being carried out onsite on that particular day by just checking the LCM area to see what cards were placed on the plans indicating work in progress.

Although it was possible to adapt most of the visual tools of the LCM model to Power Plant construction, it wasn't always possible to conduct the planning meetings in a productive way. At times, the site manager could not be present due to time constraints and there was some adversity to this increased transparency, especially in the early stages.

7.5.3.1 Important criteria for future instantiations

The successful application of the LCM model to 9 power plant projects is evidence that it is possible to adapt and apply it to these special types of large projects with some positive effects in the transparency of work, daily planning and communication being noted. According to the LCM managers, the experience of these instantiations show that certain factors must be present to ensure a successful implementation: first of all from early on in the project adequate time should be spent training the companies and construction managers in the underlying concepts of the LCM model and the importance of their role in the process. It should be understandable to all what the benefits for their processes are, to improve participation. Another important factor is to aim to reduce workload (meetings) by introducing the LCM model, not increase it. It should be clear however, that an LCM instantiation is a learning process and positive effects will not be noted immediately from day 1.

Additionally, the LCM manager's experience gathered from the power plant instantiations identified further criteria which were found to be important when implementing the model. These criteria can be summarised as follows:

- A close co-operation between the construction specialists and companies is important; to adjust the detailed planning so that it is aligned with the overall optimised process.

- Good co-operation and participation in general in the LCM meetings.

- It is important to adhere to the area-, logistic and any other requirements that were agreed upon during the meetings.

- It is important that the improvement actions that were defined together in the workshops are implemented.

- The „Top-down, Bottom-up" co-operation is very important. A leader from the client side / construction management must set the goals and encourage improvement so that the workers on the site are motivated to participate in the LCM instantiation.

- It is important to take the ideas and knowledge of the construction workers seriously to ensure the effective implementation of the model.

- Close co-operation between engineering and logistics is needed to implement the "pull system" on the building site and ensure stability in planning.

7.6 Chapter summary

This chapter presented the data collected and analysed for case study 3 in part 3 of this research. The chapter was structured around steps 3-5 of Peffers, et al. (2007) model for Design Science application: 3) design and (further) development, 4) demonstration and 5) evaluation. The case study presented version 3 of the LCM model. This chapter highlighted the main further developments of the LCM model and described the process of application to power plant construction based on five instantiations. The chapter concluded with an evaluation of the model to establish its usefulness and applicability based on these five instantiations.

The next chapter presents the conclusions to this research work. A summary of the main findings are presented. In addition, the contribution and theoretical significance of the work is explained and recommendations for future research are proposed.

8 Summary of findings and contribution

8.1 Introduction

This chapter presents the main findings of this research work and discusses its contribution to theory and practice. The research work presented findings from a Design Science research effort, which focused on the development of a new model of applying Visual Management to construction projects, in order to improve transparency in planning and control. The research followed a Design Science approach to achieve the aims and objectives defined. The chapter also provides recommendations for future research in Visual Management application.

8.2 Achievement of the aim and objectives of the work

The aim of this research was the development of a Visual Management Model for production planning and control in construction. In order to achieve this aim, three objectives were defined:

- To understand the problem of a lack of transparency in production planning and control and Visual Management application in construction.
- To formalise the initial development of the model and associated method.
- To test the applicability of the model and formally evaluate its instantiations.

These research objectives have been met by following the research process presented in chapter 3, Figure 3.1. The objectives of the research were achieved in three parts which involved a literature review, an analysis of LCM development on a newly built construction project and an evaluation of its utility and applicability to refurbishment and power plant construction. Sections 8.3-8.5 present the main conclusions of each objective. Section 8.6 and

8.7 present the contributions and theoretical significance of the work. The chapter concludes with a proposal of areas for future research work (Section 8.8).

8.3 Objective 1: understanding the problem

An important focus of the literature review was to gain a deeper understanding of the research problem, which is a lack of transparency in the construction process. Some of the main findings from the literature review are that:

- the traditional approach to Project Management contributes to a lack of transparency in the construction process (Laufer & Tucker 1987; Johnston & Brennan 1996; dos Santos et al., 1998; Howell & Koskela, 2000; Howell & Koskela, 2000, 2001, Koskela, 2001; Howell & Koskela 2002a, 2002b, 2002b);

- there is need for increased transparency in the construction process (Chapter 2, Section 2.10.3);

- few examples of systematic Visual Management solutions to create transparency can be found in the literature (Picchi, 2004; Tezel, 2011; Chapter 2, Section 2.10.1); and

- barriers experienced in the implementation of existing systems of production planning and control such as the Last Planner System stem from a lack of clear communication, transparency and inadequate use of information (Alarcón et al., 2005; AlSehaimi et al., 2009; Kalsaas et al., 2009). These four findings are discussed further below.

8.3.1 Lack of transparency in construction

The findings from the literature review on the critique of traditional project management (Laufer & Tucker 1987; Johnston & Brennan 1996; Koskela, 1992, 1999, 2001; Howell & Koskela, 2000; Koskela & Howell 2002 a, 2002b, 2002c) reveal critical issues in production planning and control, which hinder effective communication and contribute to a lack of transparency in the construction process (dos Santos et al., 1998). Some of the main critiques are of the assumptions that:

- **the execution process is unproblematic and linear** (Section 2.7.1)*:* assuming that work can be carried out as planned which is not the case in reality. It is assumed that work flows from the point of authorisation of a task (section 2.7.2), that it is fully understood and that plans are feasible (Koskela & Howell, 2002a). It appears that no transparency of the execution process is required as the need to split the work down and question its feasibility against the current environment is not recognised.

  Transparency of flow and more meaningful, lower level plans need to exist and become more transparent, as current plans are not tested against reality (Chapter 2, Section 2.7.1), resulting in work being pushed into execution without taking the current status of the production system into account. More meaningful, lower level plans are needed that can be adapted according to the current status of the production system. Without transparency in processes however, it is difficult to observe the current status of the production system.

- **one way communication is adequate for the creation of sound commitments** (Section 2.7.2)*:* which means that there is little feedback on the feasibility of work in execution and daily issues in the construction process are discovered too late. There is no transparency of information between planning and execution, which makes it difficult to identify and communicate problems in execution and create sound commitments where all prerequisites have been met (Koskela & Howell, 2001). Transparency is needed to facilitate the two way communication for the creation of sound commitments, by making relevant information understood and accessible (Winograd & Flores, 1986).

- **tasks can be carried out as planned with no need for root cause analysis on problems** (Section 2.7.3)*:* there is little feedback on the causes of problems in the process or understanding the root cause, since control is focused on time and cost rather than on learning and improvement (Koskela & Howell, 2001). Instead of using measurement to control time and cost, transparency in the process is needed so that measurement can be used to communicate goals, share responsibilities and promote continuous learning (Formoso & Lantelme, 2000).

8.3.2 The need for transparency in construction

The importance of the principle of transparency for the construction process was clarified through a synthesis of the literature. It was found that transparency in the construction process is needed for three main reasons (Chapter 2, Section 2.10.3):

- **to facilitate a holistic view of the entire process and to implement flow:** in order to observe the construction process as a flow of activities and to achieve a holistic view of the overall process, a high capability of handling vast amounts of information is required. In order to overcome the difficulties associated with this additional information, production activities in construction must become more transparent.

- **to support continuous improvement:** in order to identify higher levels of improvements and understand what effect those improvements have on the overall process, it is necessary to make the process and information flow between the different interfaces transparent, and

- **to build trust and motivate process participants:** construction companies usually have few visual mechanisms to inspire, instruct or motivate workers to carry out their jobs more effectively, efficiently and safely (dos Santos et al., 1998). A construction project is a complex organisation that is subject to frequent change and challenging times. Transparency is important to deal with fluctuations and complexity so that emotional uncertainty is avoided and trust is built (Latham, 1994; Sirota et al., 2005; Crumpton, 2011).

8.3.3 Lack of systematic Visual Management solutions for creating transparency

The literature review identified Visual Management as a key approach to creating transparency (Koskela, 1992; dos Santos et al., 1998; Formoso, et al., 2002; Tezel, 2011). An important finding from the literature review on Visual Management application in construction is that most examples of Visual Management applications in construction are not systematic in nature, but mainly based on individual Lean tools taken from manufacturing and applied in an isolated way to parts of the construction process (Rother, 1997; dos Santos, 1999; Johansen et al., 2002; Arbulu et al., 2003; Picchi & Granja, 2004; Kemmer et al., 2006; Jang & Kim, 2007; Tommelein, 2008; Saurin et al., 2008; Tezel, 2011). Findings from the literature review revealed that broader solutions for Visual Management application are needed to (Section 2.10.1):

- **truly understand waste:** by considering the overall process and the interrelationship of all practices. Value-adding and non-value adding activities become clearer within the context of the entire process and higher levels of improvements can be identified by recognising the effects those improvements may have on other areas of the process.

- **Involve participants at all levels:** Broader solutions involve process participants at all levels, encouraging communication and creating a continuous improvement culture that extends beyond individual processes.

Finally, the literature presented some key findings regarding the barriers experienced during Last Planner implementation which are discussed below.

8.3.4 Barriers experienced during Last Planner implementation

Barriers to the application of existing systems of planning and control in construction such as the Last Planner System (LPS) were identified as part of the literature review (Section 2.9.7). The main barriers revealed were: 1) weak communication and transparency 2) minimum involvement of construction workers 3) inadequate training and preparation of participants 4) a lack of role definition of the project participants 5) information not adequately used 6) lack of time for implementing improvements 7) lack of integration of production supply chain.

It appears that the barriers experienced during the LPS implementation, stem from two key sources: one is a lack of commitment which results from the improper implementation of the system (Alarcón et al., 2005; Friblick et al., 2009; Kim et al., 2005; AlSehaimi et al., 2009) and the second is concerned with a lack of clear communication and inadequate use of information (Alarcón et al., 2005; AlSehaimi et al., 2009; Kalsaas et al., 2009). The barriers stemming from the latter indicate a process and environment that lacks transparency. Two-way communication is needed to create sound commitments and the principle of transparency plays a key role in providing a structure to facilitate the two-way communication process. In transparent processes, relevant information is made available and accessible so that people have a clearer understanding of different aspects of the current system of performance and are better able to make and communicate well founded decisions (Bauch, 2004; Nijhof et al., 2009). Visual Management is an important concept for making information transparent and in turn supporting two-way communication and the use of information.

The second key objective of this work was the formalisation of the initial development of the LCM model based on findings from the literature review and an evaluation of its application to different construction scenarios. The following section presents the final version of the LCM model and its associated method, as it is typically applied in practice today.

8.4 Objective 2: formalise the development of the LCM model and associated method

8.4.1 A Visual Management Model for planning and control in construction

The LCM model is a Visual Management Model which demonstrates how visual tools are applied systematically to improve transparency in the construction process. This section presents the final version of the model and its associated method and Section 8.4.4 explains how the LCM model demonstrates a systematic application of the individual tools identified by Tezel (2011) and Galsworth (1997), to improve transparency of information flow in the construction process.

Version 2 of the LCM model (case study 2) represents how the model is typically applied in practice today. Figure 8.1 below presents the final version of the LCM model, illustrating the individual visual tools that are typically applied (in the case of power plant application, additional visual tools are applied as discussed in Chapter 7, Section 7.4.2).

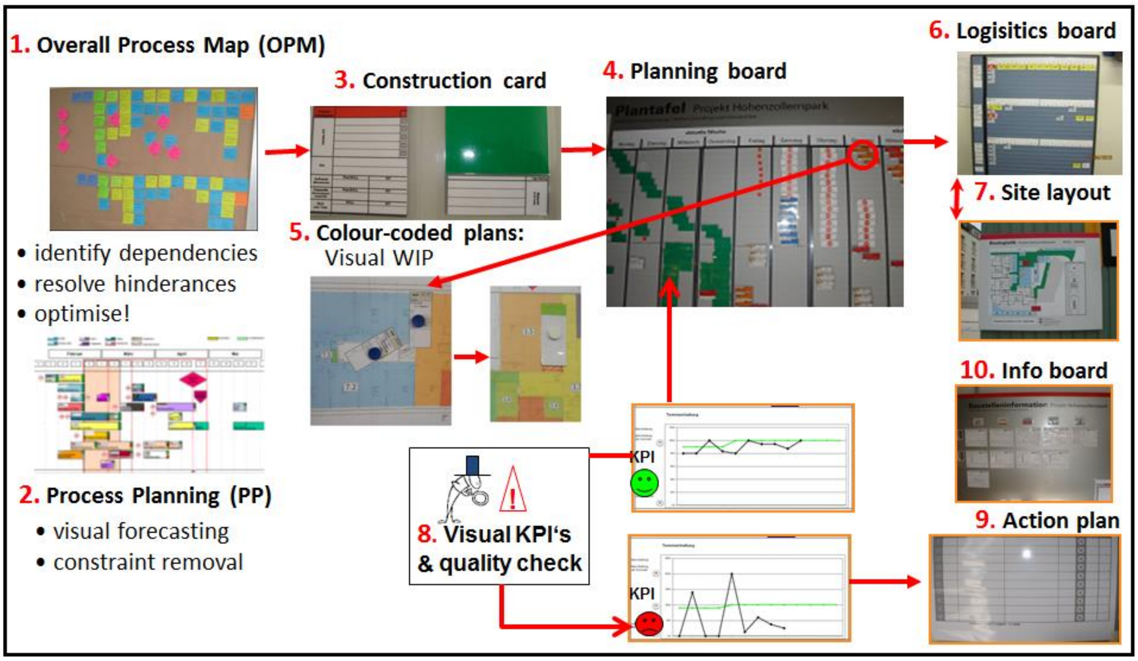


Figure 8.1: Final version of the LCM model

8.4.2 Visual elements of the model

The LCM model consists of 10 main visual elements which are explained below:

- **an Overall Process Map:** visualisation of the main construction processes, interfaces, interdependencies and constraints (Chapter 4, Section 4.5.1; Chapter 5, Section 5.4.2).

- **a Process Planning tool:** visualisation of the planned flow of work for 4-6 months, the work areas, the sub-contractors for each activity, constraints, milestones and readiness of work (indicated using green for ready and red if a milestone has not been reached) (Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2).

- **the construction card:** visualisation of daily packages of work to be carried out by sub-contractors (Section 4.6.1). Other cards included problem cards indicating constraints (Section 7.4.2, Figure 7.25) and logistic cards displaying the logistic resources planned.

- **the planning board:** visualisation of all daily work packages per work area, per day. This is situated at a central area on the construction site (Chapter 4, Section 4.6.1; Chapter 5, Section 5.3.2, Figure 5.6; Chapter 7, Section 7.4.2, Figure 7.18).

- **colour-coded plans:** visualisation of defined work areas. Construction cards are hung on colour-coded plans to indicated work in progress per area, per day and daily work packages that are awaiting quality approval (Chapter 5, Section 5.4.2, Figure 5.13; Chapter 7, Section 7.4.2, Figure 7.19).

- **logistics board:** visualisation of daily planned resources such as lifts, containers, cranes etc. (Chapter 5, Section 5.4.2, Figure 5.14; Chapter 7, Section 7.4.2, Figure 7.24).

- **site layout:** visualisation of site layout including defined areas for material storage. Logistic cards are hung on the site layout to indicate current resources (cranes, lifts, containers e.t.c) in use and by which company (Chapter 5, Section 5.4.2, Figure 5.13 (b)).

- **visual KPI's and quality check:** once completion status and quality of work is checked each day, data on the On-Time-Performance and quality of work of the subcontractors is gathered and visualised (Chapter 4, Section 4.6.1, Figure 4.12).

- **an action plan:** visualisation of defined improvement actions and persons responsible during the OPA, PP and DP phase (Chapter 4, Section 4.6.1, Figure 4.20).

- **an infoboard:** collection and visualisation of all relevant data (KPI's, current PP, roles and responsibilities, action plan etc.) on one information board and displayed in the LCM area (Chapter 5, Section 5.4.2, Figure 5.11).

The method of implementation associated with the LCM model during each instantiation is structured around three main phases: The Overall Process Planning phase (OPA), 2) the Process Planning phase (PP) and 3) the Detailed Planning phase (DP) (as explained in Chapter 5, Section 5.3.2). This method of implementation is a further output of the work and is explained below.

8.4.3 Method of implementation

Recommendations regarding the method of implementation were first proposed in case study 1 (Chapter 4, Section 4.7.3). The method of implementation was further developed and refined based on the further instantiations to refurbishment construction (Chapter 5, Section 5.4.2) and power plant construction (Chapter 7, Section 7.4.2). The method of application is structured around three phases, involving different tasks and various roles at each phase. The activities to be carried out at each phase and important considerations to note are as follows:

8.4.3.1 Phase 1: Overall Process Analysis (OPA)

The OPA is carried out once, 2-3 months before construction work begins (Section 5.4.2 and Section 7.4.2). The goal of the OPA is to produce an Overall Process Map (OPM) where the main construction processes and interfaces are visualised using different coloured post-it's on a large brown paper. Typically, an OPM is completed at the beginning of each LCM instantiation. The exception was found to be during the LCM instantiations to power plant construction where it was found unnecessary to recreate an OPM for each power plant location since the overall process in the each of the power plants was the same and the main players and important sections of the process were known (Chapter 7, section 7.4.2). As part of the Overall Process Analysis phase of an LCM instantiation, the following activities are carried out:

- **Definition of team members** to develop Overall Process Map: eg, key planners, construction management, client, LCM manager (Chapter 5, Section 5.4.2 and Chapter 7, Section 7.4.2). It is important to include the important interfaces between the planning and execution functions to ensure a feasible agreement is reached on the optimal flow of work of the construction process, the interdependencies and constraints.

- **Development of the OPM** by visualising the main processes, sub processes, interdependencies of the structure and constraints. Different coloured post-its are used to highlight different work areas, type of construction work, work processes carried out parallel and subcontractors responsible (if known). The construction activities are described (low level of detail) (Chapter 5, Section 5.4.2 and Chapter 7, Section 7.4.2). Discussions are facilitated by the LCM manager to ensure the overall process and interdependencies are understood and that there is agreement on the optimal flow of work and the removal of constraints. On completion of the OPM, the information is digitalised and a section of the main process is visualised in the LCM area.

- **Creation of action plan** displaying all constriants identified during the OPA. Each constraint and its cause is discussed in the group and a suitable action is defined to remove the constraint. A person responsible for removing the constraint is defined and target date for completion is specified (Chapter 5, Section 5.4.2 and Chapter 7, Section 7.4.2).

- **Definition of visual tools needed for Detailed Planning phase.** On completion of the OPM, the participants discuss and agree on the main structure and content of the remaining visual tools of the LCM model (Chapter 4, Section 4.6.1; Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2), which are needed for the Detailed Planning phase such as: 1) the planning board, 2) the types and contents of construction cards, 3) visual KPI's to be measured. The structure of the Planning board is defined: ie how many weeks will be displayed and what work areas will be shown on the board (eg. apartment, office, room, cube etc.). Different types of construction cards are defined depending on the type of work (construction cards for brick work, electrical work, plumbing e.t.c). Content for additional cards are defined if needed e.g: to visualise and control site resources such as cranes, lifts and storage areas.

- **Definition of frequency of meetings during the Detailed Planning phase** (Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2). The frequency of meetings during the Detailed Planning phase (ie: weekly meeting plus daily and / or evening meeting) and the roles involved are defined and communicated.

- **Decide on location of LCM area.** A suitable central location onsite for the LCM area is agreed on. Adequate space is allocated depending on the size of the visual tools and information displayed (planning board, colour-coded plans, infoboard e.t.c).

8.4.3.2 Phase 2: Process Planning (PP)

The Process Planning phase begins after the OPA, at least a month before construction commences and continues throughout the execution phase (Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2). The goal of the Process Planning phase is to reach an agreement between the participants on a long-term visualised plan of work and the constraints to be removed within the 4-6 month timeframe. During the Process Planning, activities per week, per company are visualised according to the optimal flow defined in the OPA phase (and using the colours defined in the OPA phase for the type of work). This long-term visualised plan of work is created in Visio.

During the LCM instantiations to Power Plant sites however, it was found that a more detailed Process Planning was needed (Chapter 7, Section 7.4.3). Additional preparatory steps (carried out by the site manager, supervisors and subcontractors) for the Process Planning were needed to first of all create an erection concept for the power plant. This included splitting down the plant into smaller sub sections and defining the individual parts needed to assemble each section. Each cube was then split down further into what were called working-areas (Chapter 7, Section 7.4.2, Figure 7.5 and 7.6) and then lifting units (Chapter 7, Section 7.4.2, Figure 7.7). This breaking down of areas was a necessary step to clearly define activities in the Process Planning and to provide a structure for visualising these activities on the planning board. During the power plant instantiations, the Process Planning tool was created in the program "Primavera" since this was a centralised planning tool used by the company, in which the participants didn't need any further training and where all processes merged together (Chapter 7, Section 7.4.3). As part of the Process Planning phase of an LCM instantiation, the following activities are carried out:

- **Definition of team members** (Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2) and communicate that this team will meet at least once a month for Process Planning, until the execution phase has been completed. The team should involve the same members as in the OPA phase but additionally, the sub-contractors should participate in the Process Planning. Members of the monthly Process

Planning meeting are: key planners, construction management, client, LCM manager and subcontractors.

- **Creation of the Process Planning tool** (Chapter 5, Section 5.4.2; Chapter 7, section 7.4.2) in preparation for the Process Planning meeting. In Visio, a first draft is prepared of the Process Planning tool by the LCM manager together with construction management to use as basis for discussion for the Process Planning meeting. This draft is prepared based on the flow of work defined in the OPA phase and the timeframe specified by the master plan. Construction activities are assigned a specific colour (according to the OPA) and timeframe. Milestones are visualised.

- **Conduct monthly Process Planning workshop.** Once a month, all participants meet to update the previous months PP tool (Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2). In preparation for the meeting, the workshop participants have reviewed the planned work in the PP tool and have made a note of any new constraints to be resolved. The LCM manager or the foreman facilitates the discussion to ensure that the flow of work is in accordance with that defined in the OPA and that solutions to all new constraints have been identified. Once all information has been gathered relevant to the PP in the next 4-6 months, the information is digitalised in visio and an updated version of the PP tool is distributed to all participants. A current version of the Process Planning tool is displayed in the LCM area.

- **Creation of action plan** displaying all constraints identified in the PP phases (Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2). Similar to the Overall Process Analysis phase, each constraint and its cause is discussed in the group and a suitable action is defined to remove the constraint. A person responsible for removing the constraint is defined and a target date for completion is specified (Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2).

8.4.3.3 Phase 3: Detailed Planning phase (DP)

The Detailed Planning phase begins when the execution process commences (Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2). The Detailed Planning phase consists of regular weekly, daily and evening meetings at the planning board to discuss, complete and “place” cards on the board at the area of work and to resolve any constraints that are in the way of this work. As part of the Detailed Planning phase, a daily quality check and status of work completion is carried out. Data is gathered on On-Time-Performance and quality of work and these performance measures are discussed during the daily meetings. Participants of the daily and weekly meetings are: the site manager, site planners, supervisors, sub-contractors and the LCM manager (Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2).

On the power plant sites, it was found that additional pre-planning activities were needed to support the Detailed Planning process during the LCM instantiations to power plant construction. The single parts identified when developing the erection concept at the power plant sites, were all allocated to the corresponding lifting unit in an ”Excel-part-list” (Chapter 7, Section 7.4.2, Figure 7.15 and Section 7.4.3). As part of the pre-planning on the power plant sites, six weeks before the planned erection, the sub-contractors submitted a “detailed planning form” which was structured like the planning board to the supervisor (Chapter 7, Section 7.4.2, Figure 7.16 and Figure 7.17; Section 7.4.3). On this form the content for the work packages, the erection dates and the erection sequence of a complete week are defined for a four week period. On some of the LCM instantiations to power plant construction, this information was entered into a database and the cards were printed out in advance of the meeting (Chapter 7, Section 7.4.3). As part of the Detailed Planning phase of an LCM instantiation, the following activities are carried out:

- **Preparation of visual tools and set up LCM area.** The LCM area should be set up and ready in advance of the first Detailed Planning meeting. This includes preparation and distribution of all construction cards needed. Positioning of planning board in the LCM area. Positioning of information board and display of information such as the OPA, PP, action plans, KPI's, role descriptions etc. Colour-coded plans are hung on pin boards, visualising the work areas.

- **Training of all participants** on how to use the LCM planning board, cards, when and how the daily quality checks are carried out, how KPI data is gathered etc.

- **Fill out construction cards** in advance of the weekly planning meeting onsite**.** Each subcontractor fills out his construction cards (daily work packages) and places them on the planning board in preparation for the weekly meeting. Constraints are visualised by filling out a problem card and placing this in front of the planned work package.

- **Conduct weekly meeting.** Each week, additional construction cards are placed on the planning board and the feasibility of all daily planned work packages are discussed during the weekly meeting. Particular attention is paid to identifying constraints and defining solutions. Improvement actions are displayed on the action plan and hung on the infoboard.

- **Conduct daily / evening meeting.** A daily and / or evening meeting is conducted with the foreman and subcontractors after the quality check has been carried out each day. Any quality issues are discussed and resolved.

8.4.4 Demonstration of a systematic application of VM

The LCM model shows how a large number of the visual tools classified in Tezel's taxonomy (2011) are applied in a coordinated way as part of a Visual Management Model. Tezel's Taxonomy, (2011) presented in Chapter 2, Section 2.5.3, is a compilation of 19 different Visual tools observed from research studies carried out on construction sites in both Brazil and Finland. 10 elements are directly demonstrated as part of the LCM model (Table 8.1), which is explained below and illustrated in Figure 8.2, while a further 4 elements are demonstrated indirectly as a result of an LCM instantiation (Table 8.2). Table 8.1 and 8.2

below present the elements classified by Tezel (2011), which are directly and indirectly applied collectively in the LCM model. Five elements classified in Tezel's taxonomy (2011) are not demonstrated by the LCM model.

Table 8.1: Visual tools classified by Tezel directly present in LCM

Tezels Taxonomy	
1	Site Layout and Fencing
2	Standardisation of the workplace elements
3	Pull production through the Kanban
4	Production levelling through Heijunka board
5	In-station quality (jidoka) through Andon
6	Visual signs
7	Visual work facilitators
8	Performance management through visual management
9	Distributing system wide information
10	Human resources management

Table 8.2: Visual tools classified by Tezel (2011) present indirectly in LCM

Tezels Taxonomy	
11	5S
12	Prototyping
13	Improvisational visual management
14	Poke-Yoke

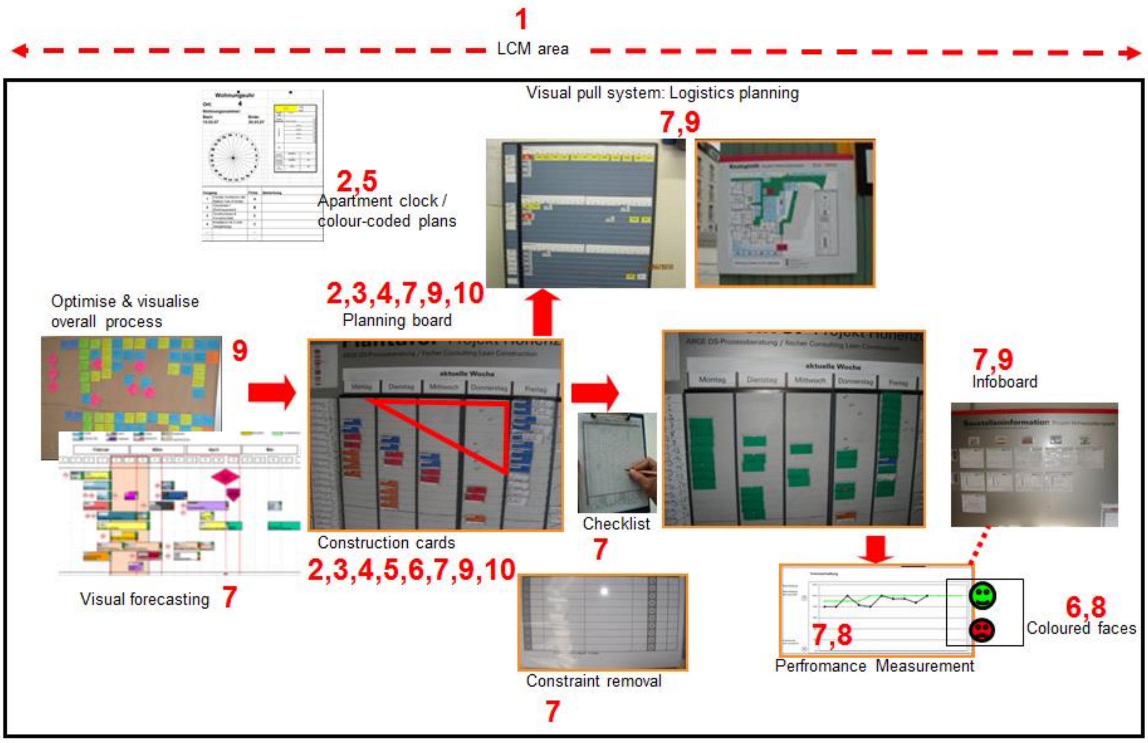


Figure 8.2: Systematic application of Tezel's classified elements using the LCM model (numbers 1-10 correspond to Table 8.1).

- **Site layout and fencing**

  The actual LCM area (Figure 8.2) is a clearly marked central communication area at the construction site. Clear information on work areas, companies involved, work packages, work in progress, planned work, performance measurements and constraints are visualised.

- **Standardisation of the workplace elements**

  The construction card (Figure 8.2) is a way of standardising a work package that can be completed in one day. This is also a way of being able to identify which company is responsible for which work (company logo and assigned colour). The apartment clock in case study 1 and the coloured plans used in case studies 2 and 3, are also a means of identifying a "process area" or "work station" on site. The hand of the clock displayed the current status of the construction process. In versions 2 and 3 of the model, the work areas are highlighted using different colours which are visualised on the plan in the LCM area.

- **Pull production through Kanban**

  The construction cards planned for the day, introduced a pull production philosophy for both completing daily work and for ordering material. The cards planned each week were small daily batches of work that were part of an overall standard process which reflected the optimal flow of work. Only when the cards were placed on the planning board, would work enter the Detailed Planning phase (3-4 weeks before execution).

- **Production leveling through Heijunka board**

  The construction cards and the planning board were used to eliminate work being carried out in "large batches" in areas. The work was leveled out according to the defined flow and pull system.

- **In-station quality (jidoka) through Andon**

  Regular quality checks are an important element of the LCM model. The construction worker turns the construction card around to the green side to indicate to the forman to check for quality. When quality problems arose, the forman would turn the card back around to indicate he was dissatisfied with the quality of the work. He would then highlight in red what should be improved. This system, involving mainly the use of coloured cards, helped to prevent mistakes from spreading to other areas of the site.

- **Visual signs**

  Visual signs showing a happy face when KPI's were improving and a sad face when the performance had deteriorated were displayed on the information board. The construction cards were also prepared showing a "stop" sign or "no entry" to indicate areas that cannot be accessed at a particular time onsite.

- **Visual work facilitators**

  The elements of LCM are all visual elements designed to facilitate the work of individual contractors, the construction workers and the foreman. The construction cards and the planning board were used to plan and visually display work to be carried out. The information board and the logistics board displayed relevant information on a number of important aspects concerned with the execution of work for example: the action plan, KPI's, information on storing and location of material etc. A construction checklist (in case study 1), which was also a type of a visual work facilitator, was used by the foreman to help him keep track of the agreed current work and that for the coming weeks. This checklist was usually used by the foreman alone but was distributed to the contracting companies and served as a type of summary of the previous meeting (in case study 1).

- **Performance management through visual management**

  A central element of the LCM model is the gathering and visualising of KPI's on the information board. Daily progress on quality and task completion are monitored and made transparent for all to see. The suppliers name and logo are displayed so this generates an added sense of responsibility if performance is dissatisfactory. If the KPI is satisfactory a green happy face is displayed and if not a red sad face is displayed.

- **Distributing system wide information**

  There are several examples of this type of visual tool evident in the LCM model. One such example is the information displayed on the logistics board and site layout (Figure 8.2) which indicates which resources (crane, lifts etc) are in use and where material should be delivered to and stored. The logistic cards display information on which company is using each logistic resource. Likewise, the construction card displays the detailed information and location of the construction work that is being carried out on that particular day. The Process Planning tool visualised in the LCM area gives an overview of the planned flow of work in the coming months and the constraints that need to be removed. The information board itself, which is an important element of the LCM model, displays information on KPI's, improvement actions that are being implemented and any other relevant information on important milestones or facts that concerns the construction project (e.g. new contractors, new workers, events etc.).

- **Human Resource Management**

  The planning board itself is a means of organising the work and workforce on the building site. By preparing the construction cards for the construction board, the work and its location is planned and communicated to the workforce and all persons from a central area on the construction site.

Tables F.1 and F.2 in Appendix F.1, present a more detailed overview of the visual tools classified by Tezel (2011) that are applied collectively during an LCM instantiation.

The remaining five elements classified by Tezel (2011) that were not found to be present either directly or indirectly during the LCM instantiations appear to be project specific and could be present in future instantiations. The five elements are:

- **Visual tools in the warehouse:** there was no warehouse for material on any of the case study projects.

- **Visual tools in the elevators:** signage on the elevators was not apparent on the case studies. In general, the use of signage on elevators and other areas of the construction site is an area of improvement for the LCM model. The use of visual tools throughout the site would help to improve transparency and communication throughout the site as well as in the planning and control of the construction process. Currently, all direct visual elements of the model are situated in the LCM area. This was not always the case since the apartment clock, as part of version 1 of the LCM model, was displayed at the area of work. Through the further development of the model, the function of the apartment clock was replaced by the visualisation of the cards on the colour-coded plans in the LCM area. This was done for the purpose of visualising all information of the process in one central area.

- **Sampling** with regard to coupling materials with their location of use was not noted during the case studies. This was noted as an improvement area on one of the Kaizen activities carried out onsite in case study 1, (Appendix D). How the LCM model can be directly applied to improve material availability at the area of work is a further area for improvement of the model.

- **Health & Safety information** was not visualised as part of the LCM instantiations and is an important additional visual element to consider for future instantiations.

- **On-site prefabrication:** this was only noted on the power plant sites where metal parts were assembled before construction. This was due to the nature of power plant construction. On the other case studies (newly built and refurbishment) pre-fabrication on site was not carried out.

In addition, the LCM model demonstrates how 3 of the 4 types of visual tools identified by Galsworth (1997) are also applied in a co-ordinated way as part of one model. Galsworth (1997) argues that Visual Management is realised by visual systems that consist of one or more types of visual tools as explained in Chapter 2, Section 2.5.1. These visual tool types are consciously designed to structure human behaviour. The four types of visual tools 1) visual indicators, 2) visual signals, 3) visual controls, and 4) visual guarantees) have different power indexes, which depends on the extent to which the message they send is likely to be adhered to and the potential risk or loss if people decide to ignore it (Glasworth, 1997). Figure 8.3 illustrates how each of the types of visual tools as defined by Galsworth, are applied as part of an integrated Visual Management Model. Section 8.7 discusses how the LCM model shows that the categories defined by Galsworth represent functions rather than tools.

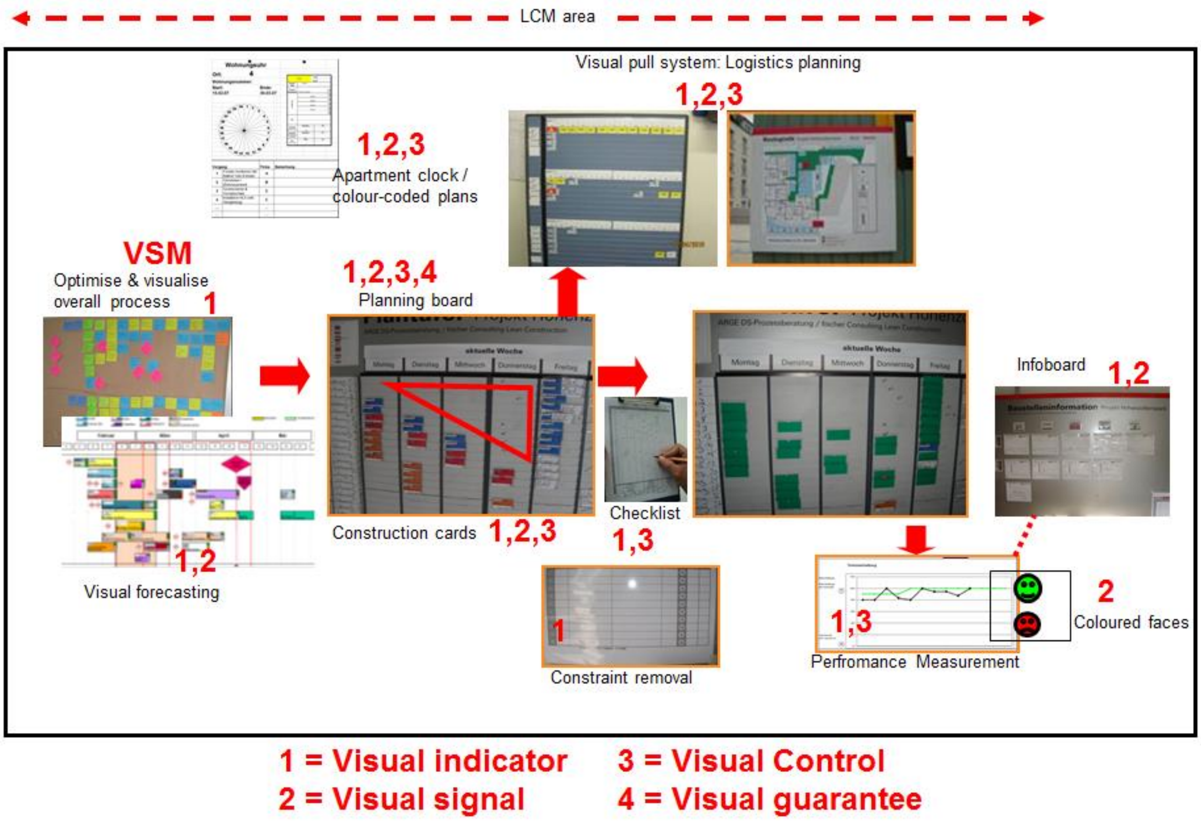


Figure 8.3: How each of the type of tools defined by Galsworth (1997) are demonstrated by the LCM model

In general, the visual elements of the LCM model are of three types: 1) they are indicators since they relay information in the hope of influencing behaviour (Figure 8.3, no. 1) they are signals since they attract attention with the intention of directing behaviour (Figure 8.3, no. 2) and they are controls since they determine what work can commence when and control the quality and completion of that work (Figure 8.3, no. 3). They also control the use of site resources such as cranes, lifts and containers. The fourth type of visual tool defined by Galsworth (1997) (visual guarantee), is only barely evident in the LCM model. The planning board could be classified as a visual guarantee since it is designed to limit the number of cards (daily work packages per company) that can be scheduled each day in a particular area. This ensures that (usually) one subcontractor works per day in a defined area. However the integration of additional visual guarantees into the LCM model is an area for further improvement for the future. A more detailed discussion on how the elements of the LCM model demonstrate a co-ordinated application of the types of tools defined by Galsworth can be found in Appendix F.1).

The third and final objective of this work was to test the applicability of the LCM model and to formally evaluate its instantiations. The following section presents the main findings from an evaluaton of the LCM instantiations to determine the models utility and applicability.

8.5 Objective 3: evaluation of the LCM instantiations

8.5.1 Usefulness for improving daily planning through increased transparency

The findings from the evaluation of the LCM model at each part of the research provide evidence that it is useful in improving transparency in the construction process. The feedback from the site management and the subcontractors in part 1 (Section 4.7.2) indicate that the use of visual tools in this co-ordinated way had made the daily operations onsite more transparent. The foreman in case study 1, indicated that the LCM model supported him in identifying and resolving problems in the construction process earlier, together with the sub-contractors. However, there are some limitations (Section 8.5.6) to the data that support these conclusions in part 1, since data was gathered for case study 1 in 2007 (2 years before this research began) and it was no longer possible to formally interview the project participants.

In part 2 and 3 of the research, findings derived from the interviews with the LCM managers (instantiations 2A and 3A-3E) and the foreman and client (instantiation 2B and 3A-3E) indicate that the model helped improve daily planning on site as a result of the increased transparency in the process (Chapter 5, Section 5.5.2; Chapter 7, Section 7.5.2). According to the LCM manager during instantiation 2A, the visualisation of the Process Planning (long-term) followed by a more detailed visualisation on a daily level using the Planning board (short-term), meant that problems could be detected earlier both in the long and short term (Chapter 5, Section 5.5.2). According to the client during instantiation 2B the additional communication supported by the visual tools in the Process Planning and Detailed Planning phases, led to more stable commitments and better quality levels (Chapter 5, Section 5.5.2). The transparency achieved through the visualisation of the Process Planning for 4 months, meant that problems could be identified and resolved earlier.

The feedback from the interviews with the LCM managers and the client involved in instantiations 3A-3E in part 3, also indicate that a notable improvement in transparency, communication and daily planning could be achieved during the LCM instantiations and that as a result, material requirements could be better defined and cranes better utilised (Chapter 7, Section 7.5.2). The client also noted that the visualisation of the daily process using the Planning board improved the understanding of a highly complex process and in turn improved the reaction time to change and On-Time-Performance (Chapter 7, Section 7.5.2). Regarding an improvement in the lead-time at the power plant sites, according to the LCM managers and the client, lead time was improved in some areas of the power plants (main steel, secondary steel) – in some cases by up to 2 months (Chapter 7, Section 7.5.2). Further evidence of the utility of the LCM instantiations to power plant construction is provided by the decision that was made to roll out the adapted version 3 of the model to 8 further sites after the initial instantiation 3A.

In addition, KPI data on On-Time-Performance, quality levels and the stability of the PP were gathered on the instantiations carried out in part 2 (Chapter 5, Figure 5.15-5.19) and data on OTP, crane utility and reasons for low performance in part 3 (Appendix E). A constant stability in the On-Time-Performance of the companies and a positive development in the quality of work could be noted at times from the KPI data gathered during instantiations 2A and 2B. A positive development in the stability of promises made in the Process Planning phase could be noted during some months in instantiation 2B (Chapter 5, Section 5.5.2, Figure 5.19). However, is was also noted that the stability declined when an issue with the delivery of material from the supplier could not be resolved quickly. The discussions on the feasibility of work began 4 months in advance at the Process Planning phase, which meant that constraints were being identified earlier. In addition, the construction cards representing daily packages of work by the subcontractors were prepared by the companies themselves and placed on the planning board, 3 weeks before execution. This also helped to achieve a stability in OTP, since any further problems in execution could also be noted at this stage allowing some time to resolve issues before the work should be carried out. The regular quality check meant that any issues were discovered soon after they occurred, preventing them from „spreading“ to other areas. Quality issues were discussed with the subcontractors as they occurred, which increased awareness of the importance of quality in day to day operations.

In part 3 the KPI data on all four of the LCM instantiations to power plant construction appear (during certain periods) to support the client's view that the daily planning, crane utility and OTP was improved during the instantiations (Appendix E, Figures: E.1, E.2, E.4, E.6, E.8, E.10, E.12, E.14 and E.15). It could be noted that for certain periods during some instantiations a stabilisation and improvement of crane utility (Appendix E, Figures: E.1, E.4, E.10 and E.14) and OTP % (Appendix E, Figures: E.2, E.6, E.8, E.12 and E.15) of the subcontractors could be achieved. It can also be noted from the data (especially in the sudden decreases in KPI's from one week to the next (Appendix E, E.1, E.4, E.6, E.8, E.10, E.14, E.15), that certain other factors greatly influence the OTP % and crane utility and can only be made transparent through the LCM model but cannot be completely resolved: weather and technical issues mainly but also component issues to some extent (Appendix E, Figures: E.3, E.5, E.7, E.9, E.11, E.13 and E.16.).

While some positive developments appear from the KPI data, there are also limitations to the data itself (Section 8.5.6). Since no data existed on the KPI measurements before any of the instantiations were carried out in parts 2 and 3 of the research to serve as a baseline to compare possible improvements, the findings from the KPI data are not conclusive. However, they provide a baseline for future possible comparisons.

8.5.2 Usefulness for improving constraint removal through increased transparency

It was found during the instantiations in part 2 and 3 of the research that the LCM model helped to identify and resolve constraints early. In case study 2, a total of 400 constraints were identified and removed throughout the three phases during instantiation 2A (50 at the OPA phase, 200 at the Process Planning Phase and 150 at the Detailed Planning phase) (Chapter 5, Section 5.5.2). During instantiation 2B, a total of 600 constraints were identified and removed (150 at the OPA phase, 250 at the Process Planning phase and 200 at the Detailed Planning phase). During instantiation 2B, the implementation of improvement actions were tracked weekly which showed a constant positive development in the implementation of improvement actions (Section 5.5.2, Figure 5.20 (a)-5.20 (c)).

Likewise in case study 3, the use of visual tools for the Process Planning led to the identification of 400-600 constraints at each of the four power plant sites (Chapter 7, Section 7.5.2). A similar number of additional constraints could be identified and removed during the Detailed Planning phase (between 400 and 600 constraints per site).

8.5.3 Usefulness for reducing waste

It was difficult to measure a reduction in waste during the LCM instantiations in part 2 and 3 of the research (Chapter 5, Section 5.4.2 and Chapter 7, Section 7.4.2). However, in case study 2, the effect of a reduction in buffer time between tasks could be partly measured, since the project was completed 2 months earlier than anticipated in instantiation 2A (Chapter 5, Section 5.5.2). Similarly, during instantiation 2B, a further extension of the completion date of the project by 6 weeks (due to unforeseen extra brick work) was avoided by being able to better utilise the transparent buffer times between activities (Chapter 5, Section 5.5.2).

In part 3, waste in the form of making-do as a result of the component issues (incorrect and missing components) was reduced but not eliminated according to the LCM managers. This is also reflected in the KPI data on the reasons for low OTP and crane utility (Appendix E, Figures: E.3, E.5, E.7, E.9, E.11, E.13 and E.16.).

8.5.4 Applicability of the model

The main findings from the instantiations in part 2 and 3 of the research (2A and 2B and 3A-3E) show that the LCM model could be further adapted from version 1 (case study 1) and applied to refurbishment (2A and 2B) and power plant (3A-3E) construction. In part 2, the development of the Process Planning tool and the addition of the Process Planning phase represent a generic improvement to the model, which further improved the link between the overall process and the planning board (Chapter 5, Section 5.4.3, Figure 5.21). In addition, further visual elements were added to measure the stability of the Process Planning, to improve the planning and orgainsation of site resources (Chapter 5, Section 5.4.3) and to visualise work in process on colour-coded plans (Chapter 5, Section 5.4.3).

During the LCM instantiations in part 3 of the research, it was found that most of the elements of the LCM model were applicable to power plant construction (Chapter 7, Section 7.4.3). However, the Overall Process Map was not particularly suitable or useful when applied to power plant construction. It was found that since the overall process in the each of the power plants was the same and the main players and important sections of the process were known, it was unnecessary to create an Overall Process Map each time (Chapter 7, Section 7.4.3). Despite this, the OPM did help to make some logistic elements more transparent and it did help to create a common understanding of the interfaces and the general functioning of a power plant site which was useful when adapting the LCM model to power plant construction during instantiation 3A. It also resulted in the early identification of approximately 100 constraints (Chapter 7, Section 7.5.2) on the sites which meant problems were being tackled early on.

Finally, during the LCM instantiations to power plant construction, it was found that it was necessary to create an erection concept at an early stage (Chapter 7, Section 7.4.2 and 7.4.3) and a more detailed pre-planning was needed for the Detailed Planning phase. To achieve the level of detail needed for the work packages for the planning board, additional visual tools were developed and applied such as a detailed planning form (Chapter 7, Section 7.4.3, Figures 7.16 and 7.17) and the excel part list (Chapter 7, Section 7.4.3, Figure 7.15).

8.5.5 Findings from the observational study

An observational study carried out in Brazil in part 2 of the research, to compare the LCM model to existing Visual Management practices observed there, found that the visual tools observed were applied mainly to: 1) create transparency 2) to promote discipline of the workers in their work process and 3) for job facilitation (Chapter 6, Section 6.2.3, Figure 6.1). On comparing the visual tools observed to the LCM model, three conclusions could be drawn:

- **Visual tools are used primarily to facilitate construction management.** Firstly, the reason for the application of the Visual tools on the sites visited, appeared to be to support the site engineer in his function of managing and controlling the site, rather than in providing a framework for two-way communication between planning and construction level by increasing transparency, as is the case in the LCM model (Section 6.2.3). Many of the visual tools applied on construction sites in Brazil were displayed not on the actual site but quite hidden in the site office. (16 out of 23 visual tools observed; Chapter 6, Section 6.2.3). The 7 visual tools observed onsite however, did encourage communication between the different levels: for example, the information on subcontractors performance displayed onsite was discussed weekly with the site management and discussions took place on how performance could be improved for future activities.

- **No evidence of a systematic application of VM could be found.** There did not appear to be any logic behind which tools were used and how they were displayed. The conclusion from the literature review that Lean tools tend to be applied in isolation on construction sites, rather than holistically, was reflected on these sites. There was no evidence to suggest that these tools formed part of an overall holistic application of Visual Management (Chapter 6, Section 6.2.3).

- **Similar functions of visual tools were observed.** Finally, it could be established that the functions of 13 of the visual tools, were similar to the functions of some of the visual tools of the LCM model. The purpose of many of the visual tools observed (15 from 23) was to assist the site engineer in production planning and control, which is one objective of the LCM model (Chapter 6, Section 6.2.3, Table 6.4).

8.5.6 Limitations of the research

As mentioned in section 8.5.1, there were some limitations regarding the data gathered during the LCM instantiations (1A; 2A and 2B; 3A-3E). The main limitation of the data from instantiation 1A was that the primary data for the case study was gathered by the researcher 2 years before this research work began, in her role as a consultant on the project. It was not possible to formally interview any of the project participants of case study 1, during this PhD research work. In addition, KPI data gathered on On-Time-Performance and quality during the observation period was largely incomplete. The concept of measuring performance was a very new concept onsite and since the foreman was not present on site each day, the data was not gathered adequately. However, based on the discussions with the foreman on site and the impressions gathered from the observations the researcher carried out onsite, some positive effects could be noted.

In part 2 and part 3 of the research, quantitative data on On-Time Performance, quality, crane utility and on reasons for low performance was gathered during the observation periods on instantiations 2A, 2B & 3A-3E. Before the LCM instantiations on all projects, no data was gathered on these KPI's which meant that no baseline existed for comparison after the LCM instantiations. While the data in most cases show positive developments at times in the stability of On-Time Performance, quality and crane utility during the observation period, the data itself is not conclusive. Despite this, the data forms a basis for possible future comparisons.

8.5.6.1 Limitations of the model

Some limitations of the model were also noted during instantiations 2A and 2B and 3A-3E. One limitation is that while the model creates transparency to identify problems in the process, this does not mean that these problems will always be resolved. During instantiation

2B for example (Chapter 5, Section 5.4.2, Figure 5.19), after a constant increase in the stability of the Process Planning over 3 months, the stability then consistently declined as a result of problem with a material supplier that could not be resolved. The supplier was experiencing difficulties in delivering the required material for the roof and since this was a key process, all other processes were affected. Despite a number of visits to the supplier's site, the problem persisted for several months. It is important to point out that while the LCM model can improve daily planning through increased transparency, it cannot remove obstacles caused as result of non-compliance (if companies choose not to participate adequately) and material production issues.

Likewise, a similar limitation can also be noted from the KPI data gathered during the instantiations on the power plant sites (Appendix E, Figures: E.3, E.5, E.7, E.9, E.11, E.13 and E.16.). The Just-In-Time availability of the correct components for assembly was a recurring problem during all power plant instantiations (3A-3E). While the LCM model, greatly improved the communication between the engineering and construction interfaces to better define the component specifications, the problem was not completely resolved. This shows again that while the LCM model can create clarity and foresee issues, completely resolving them depends on the close co-operation with additional interfaces such as with the suppliers of the material in this case.

A further limitation of the LCM model also noted during the refurbishment (2A and 2B) and the power plant instantiations (3A-3E) is the significance of the full co-operation of all participants, even in the absence of construction management or the LCM manager. A reoccurring reason for a low OTP % on all power plant sites was a lack of co-ordination of work and missing information (Appendix E, Figures: E.2, E.6, E.8, E.12 and E.15). This was, for the most part due to the absences of the site manager and the LCM manager (who after a number of months was not on the site on a daily basis). The LCM model works most effectively when all roles participate 100%. The human factor is considerably important in this process and it can be noted from the data, that when participants failed to play their role in the co-ordination and provision of information, or were absent, the performance suffered as a result (Appendix E, Figures: E.3, E.7, E.9, E.13 and E.16)

The following section 8.6 presents an overview of the main contributions of this research work.

8.6 Contribution

This research work contributes to the area of Visual Management and Project Management in construction. The contributions to the area of Visual Management include 1) the provision of a new systematic model and associated method for applying Visual Management for production planning and control in construction (Section 8.6.1) and 2) demonstrating how visual tools can be applied to manage information flow and support communication in the construction process, during an LCM instantiation (Section 8.6.1). The contributions to the area of Project Management in construction include 1) showing how Visual Management can be used to shed light on the deficiencies of traditional Project Management (Section 8.6.2) and 2) how the visual elements of the LCM model can complement existing systems of production planning and control for construction such as the Last Planner System, by reducing communication barriers and better utilising information as a result of the increased transparency (Section 8.6.3).

8.6.1 Contribution to Visual Management

8.6.1.1 A VM model for production planning and control based on the Lean concepts

According to the literature, there is a misconception that Lean application involves the application of individual tools to isolated areas of processes rather than focusing on the entire system by applying broader solutions (Liker,1996; Spear & Bowen, 1999; Liker, 2004; Lewis, 2008; Atkinson 2010; Boyle, et al 2010; Saurin et al., 2011). This is confirmed by fieldwork in construction (dos Santos & Powell, 1999; Arbulu et al., 2003; Kemmer et al., 2006; Jang & Kim, 2007; Tommelein, 2008; Saurin et al., 2008; Tezel, 2011). The importance of broader solutions in truly understanding waste and achieving higher levels of improvements was discussed in Chapter 2, Section 2.10.1. The LCM model provides a solution for broader applications of Visual Management to construction projects (Figure 8.4). During an LCM instantiation, several visual Lean tools are combined in a coordinated way, which create the transparency needed to implement flow and pull, clearly see the interdependencies between sub processes and define higher levels of improvements that benefit the overall process.

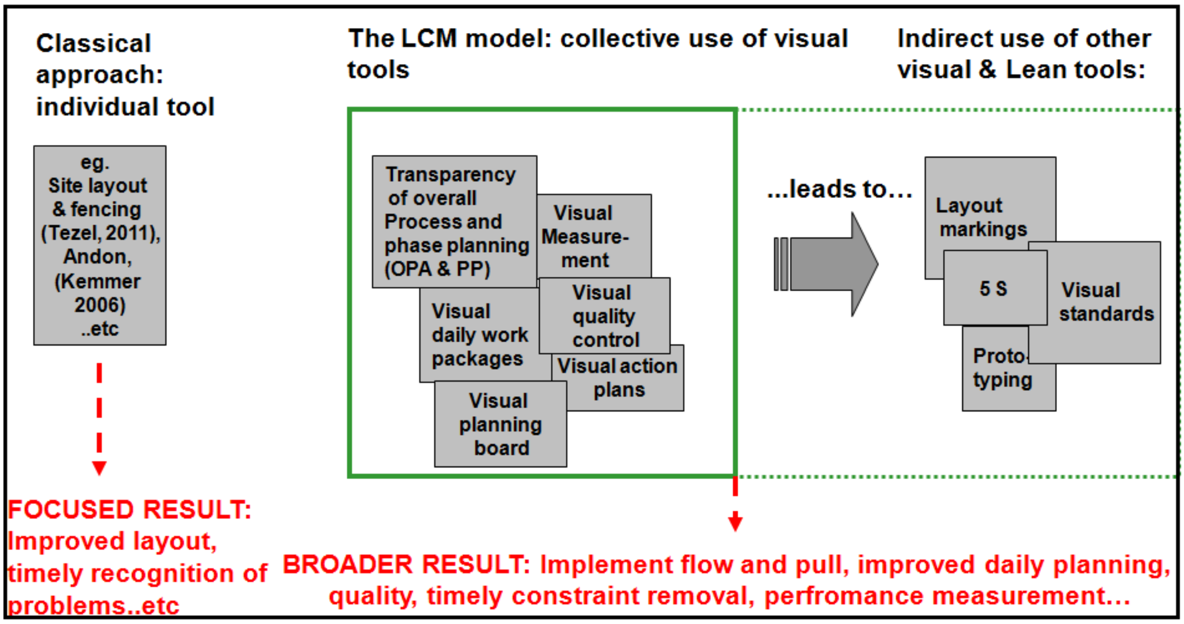


Figure 8.4: LCM – a systematic model of applying Visual Management

The systematic nature of the LCM model is illustrated in Figure 8.5 and also discussed in Section 8.4.4. Several visual Lean tools such as Kanban, Heijunka, VSM, Andon, Poke Yoke, are combined and applied in a coordinated way together during an LCM instantiation. A deeper discussion on how the visual tools of the Toyota Production System are evident in the LCM model can be found in the Appendix F.2. In addition, the systematic nature of the model is also demonstrated by showing how 10 visual tools identified by Tezel (2011) and three of

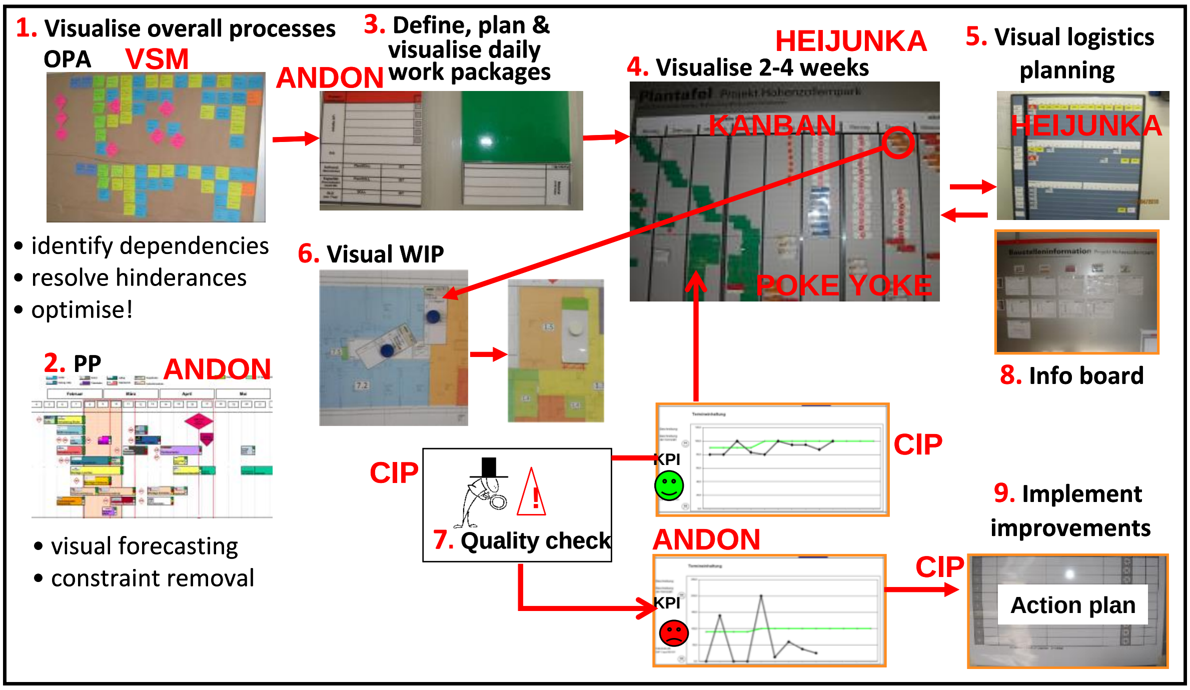


Figure 8.5: Coordinated application of visual tools from the TPS using the LCM model

the four types of visual tool defined by Galsworth (1997) are applied together in every LCM instantiation (Section 8.4.4).

8.6.1.2 How the visual tools of the LCM model support the flow of information

The LCM model uses visual tools to make information available at hand so one can see and understand the status of construction without calling a meeting with key participants in order to do so. Each LCM instantiation begins with the creation of an Overall Process Map (no. 1, Figure 8.6; Chapter 4, Section 4.5.1; Chapter 5, Section 5.4.2) which captures the initial high level information on the main construction processes and areas, the interdependencies between them, the critical interfaces and constraints. The exception to this is in the cases of the LCM instantiations to power plant construction (Chapter 7, Section 7.4.2). This information then flows into the Process Planning tool (no. 2, Figure 8.6; Chapter 5, Section 5.4.2; Chapter 7, Section 7.4.2), where a subsection (work to be completed in 4 months) of the overall process is focused on. Work areas are visualised, activity blocks to be carried out by companies are specified in more detail, milestones are defined and further constraints are identified (Chapter 5, Figure 5.5; Chapter 7, Figures 7.8 and 7.9).

A sub-section (3 weeks) of this information then flows into the visual planning board and from there, this information is dispersed to the remaining visual tools (no. 4-12, Figure 8.6; Chapter 5, Figure 5.6). The information on the 3 weeks of work taken from the Process Planning tool (no. 2, Figure 8.6) is split down into daily work packages called construction cards (no. 3, Figure 8.6; Chapter 4, Section 4.5.3, Figure 4.10; Chapter 5, Figure 5.6; Chapter 7, Figure 7.24) which are placed on the planning board (no. 4, Figure 8.6; Chapter 4, Figure 4.8 and 4.9; Chapter 5, Figure 5.6; Chapter 7, Figure 7.18) according to the optimal flow defined in the OPA (no. 1, Figure 8.6) and the PP (no. 2, Figure 8.6).

Visual tools no. 1-4 in Figure 8.6, funnel relevant information needed to create transparency in the process from the high level of process steps to the daily level of detail needed for execution. The information is then dispersed further through the process with the help of additional visual tools, with the aim of using this information for improved logistics onsite, better OTP and quality of work (Chapter 4, Section 4.5.4; Chapter 5, Figures 5.14-17; Chapter 7, Figures 7.20-7.22). No. 5, Figure 8.6 shows how the cards are hung on the plans providing information at a glance on what work is being carried out where on that day (Chapter 4, Figure 4.17 and 4.18; Chapter 5, Figures 5.12 and 5.13 (a) & (b); Chapter 7, Figure 7.21).

The information on the cards is also used to plan site resources such as lifts and containers (no. 6, Figure 8.6; Chapter 4, Figures 4.19 and 4.20; Chapter 5, Figure 5.14; Chapter 7, Figure 7.20), as the information is known on what work is being carried out where each day. Likewise, storage areas onsite are better defined as material is limited to what is needed in the specified timeframe (no. 7, Figure 8.6). Once this card is turned around to the green side on the plans (no. 5, Figure 8.6; Chapter 4, Figures 4.10 and 4.16; Chapter 5, Figure 5.13 (a) and (b), this is a signal to the foreman that the work is completed. The foreman then uses this information to carry out a quality check of the completed work (no.8, Figure 8.6; Chapter 4, Figure 4.16) and should quality issues arise, improvement measures are noted (no. 9, Figure 8.6; Chapter 4, Figure 4.17; Chapter 5, Figures 5.8 and 5.10) and persons responsible defined. If work is completed to an acceptable level of quality, this information is also captured, by replacing the card (green side up) on the planning board (no. 10, Figure 8.6; Chapter 4, Figure 4.16).

The performance of subcontractors in delivering promises that are of a satisfactory quality are measured using the information from no. 10 (completed work) and no. 8 (uncompleted work with quality issues). Finally results on performance are visualised using KPI's (no. 11) and displayed on the information board in the LCM area (no. 12, Figure 8.6; Chapter 4, Figure 4.18; Chapter 5, Figures 5.9 and 5.10, Chapter 7, Figure 7.23).

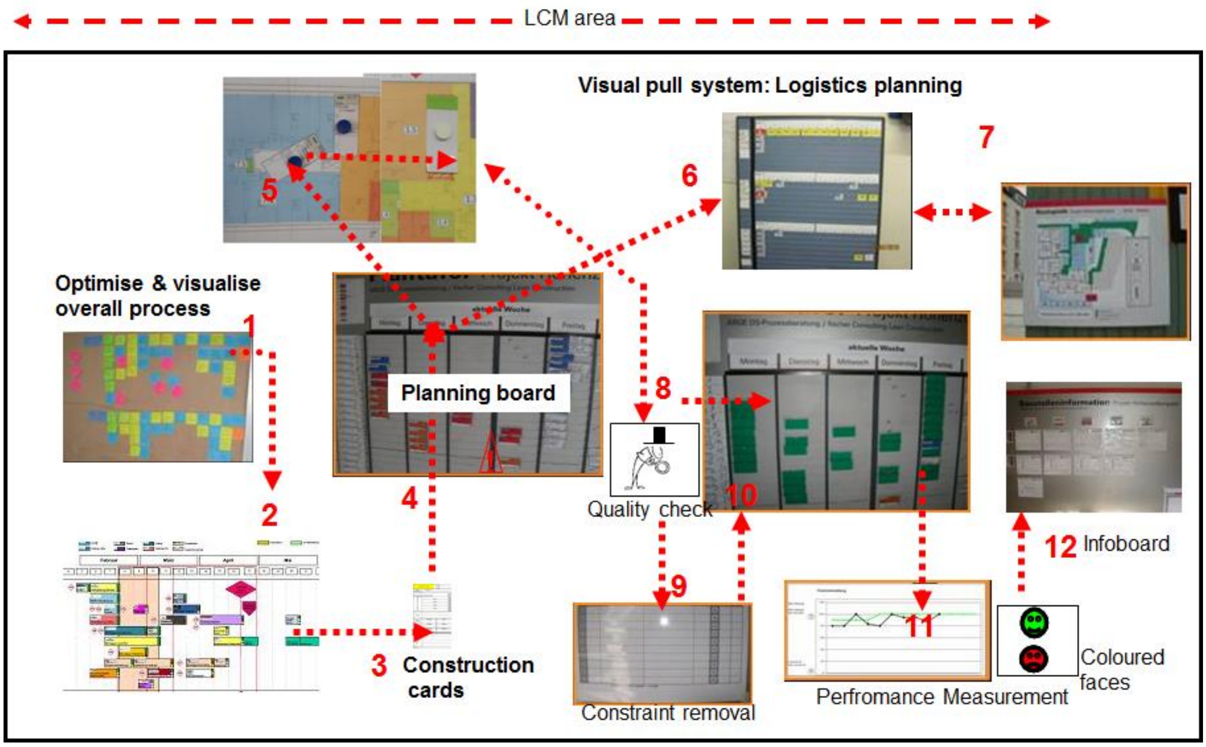


Figure 8.6: How visual tools are applied systematically to improve transparency and the flow of information in construction.

8.6.1.3 Discussion: Transparency of system wide information

The systematic nature of the LCM model enables it to extend its focus beyond the construction process itself, creating transparency in information related to system wide processes. This is demonstrated through the visualised logistics planning, the visualised performance measurement and the actual LCM area itself, which acts as a central information hub, where information on the construction process and its surrounding environment is gathered and displayed.

8.6.1.3.1 Visualised logistics planning

Like the planning board, the logistic board (Chapter 5, Figure 5.14; Chapter 7, Figure 7.20) and logistic cards visualises and controls the logistic resources onsite i.e.: cranes, lifts, containers etc. The information displayed on this visual tool is directly linked to the planning board, since the work packages that are planned determine what resources are needed. In this way the visual tools of the LCM model link important information from the construction process to the wider system. Tezel, (2011) identified visual tools that distribute system wide information in his research and the logistic board is an example of this.

8.6.1.3.2 Visualisation of performance measurement

In the LCM area, colour-coded plans of the project areas are displayed, on which the cards with the current work in process are placed. This means that at a glance, one can see what work is being carried out by what company in a particular area on that day. When the worker is finished his work, he turns the card around on the plans to the green side to indicate work is completed. This initiates the quality cycle, indicating to the foreman that work is ready for the daily quality check. If the work is at an acceptable quality level, he places the construction card back on the planning board green side up, indicating completion. He notes the On-Time-Performance (OTP) data and then updates the KPI information which is displayed in the area. The visualisation of KPI's contributes to the control of work at production unit level and a transparency of performance of all subcontractors on the project. Reasons are gathered for non-completion and actions are defined to resolve the issues. This list of actions is also displayed and monitored in the LCM area.

8.6.1.3.3 The LCM area

The LCM area itself is a central place onsite where all of the visual tools are gathered together, visualising information on the construction process and the wider system. Koskela (1992) discusses the idea of improving transparency by making processes directly observable

(Chapter 2, Section 2.3.2). The function of the LCM area is to make the most important processes and information central to the construction process, observable in a central communication area onsite. The LCM area is accessible at all times for all project participants, encouraging communication and discussions relating to work stability at any given time.

8.6.2 Contribution to Project Management

8.6.2.1 LCM sheds light on the deficiencies of traditional Project Management

As discussed in Section 8.3.1, the traditional approach to project management has been heavily criticised for hindering effective communication and the development of trust and team building between organisations involved in the procurement process (Chapter 2, Section 2.7). It follows the disciplinary hierarchy and separation of design and construction (Jagger, et al., 2001) and assumes an unproblematic, linear process (Koskela, 1992; Koskela, 1999; Howell & Koskela, 2000, 2001, Koskela, 2001; Howell & Koskela 2002 a, 2002b, 2002c) which leads to frequent project failures (Kharbanda & Pinto 1996), lack of commitment towards project management methods (Forsberg et al., 1996) and a slow rate of methodological renewal (Morris 1994). The LCM model sheds light on some of the deficiencies in production planning and control in the following ways:

8.6.2.1.1 Long and short term visual planning focused on execution

The main issue with the management as planning approach which is characteristic of traditional Project Management (Chapter 2, Section 2.7.1) is that plans are not tested against reality and an unproblematic completion of work is assumed (Johnston & Brennan 1996). In turn, plans push “tasks” into execution without taking the status of the production system into account.

The Process Planning tool and the Planning board are the main visual elements of the LCM model responsible for preparing work and questioning its feasibility in the long and short term. Each month, a predefined flow of work for a period of 4-6 months (from the OPA) is focused on during the Process Planning to remove all known constraints before the work enters the Detailed Planning phase. A 3-4 week subsection of the Process Planning is then split down into daily packages and visualised using the construction cards and planning board. The planning board (Chapter 4, Figures 4.8 and 4.9; Chapter 5, Figure 5.6; Chapter 7, Figure 7.18), which is the heart of the LCM model visualises the construction cards which are further questioned on a daily and weekly basis up to 4 weeks in advance of execution. This ensures a focus on identifying issues that arise as early as possible in the day to day construction environment. The close proximity of the planning board to the area of work, encourages timely feedback of progress and information should unforeseen issues occur. The planning board, is also a Kanban system "pulling" (rather than pushing) prepared daily packages from the Process Planning phase, into the Detailed Planning phase up to 3 weeks before execution.

8.6.2.1.2 Using VM to support communication

In general, one clear deficiency of traditional project management approach is that the planning processes dominate the scene with little offered on the execution process (Koskela & Howell, 2002a). During execution, it often not clear "who" manages production (Ballard, 2000) and there is little understanding of the flow of work onsite (flow is assumed from the point of authorisation) or the interdependencies between processes. Since work is thought to flow, it is assumed that one-way communication of information (from the top down) is adequate for the creation of sound commitments. This view has been challenged by Winograd and Flores (1986). They argue that the work in organisations is coordinated through making and keeping commitments (Chapter 2, Section 2.7.2).

The visual tools of the LCM model such as the OPA, the PP and the Planning board, provide a physical way to make the information flow on planned work transparent so that communication is facilitated both ways and between interfaces (from planning to construction worker level and vice versa), when forming commitments (preparation of construction cards) and defining effective improvement actions.

8.6.2.1.3 Using VM to facilitate learning and continuous improvement

The main criticism of control (Chapter 2, Section 2.7.3) in the traditional approach to Project Management is that there is no room for understanding the root cause of problems in the construction process and therefore no opportunity for prevention or continuous improvement. Since tasks enter the execution phase on the assumption that they can be completed (which is not the case), targets are often not met. Supervisors therefore are distracted from today's and tomorrow's tasks in order to produce a historical record of yesterday's problems and a justification for what happened (Laufer & Tucker 1987). As a result it is difficult to obtain quality feedback which can be used to implement improvements (Marosszeky, et al., 2004; Chapter 2, Section 2.2.1).

The LCM model addresses this criticism, since the application process focuses strongly on the creation of transparency, in order to understand problems and to learn to resolve them. A key focus of the OPA, PP and DP is the early identification of problems and the definition of improvement actions. The quality check mechanism in the LCM model onsite, provides feedback at regular intervals on quality of work so that problems are understood when they occur and improvements can be defined as soon as the problem is identified. The transparency created by the planning board makes it easier to anticipate what effects potential improvements might have on other areas of the process, thus enabling more well thought through solutions. The quality of work is an important focus of discussion during the weekly and daily meetings at the planning board to discuss preventative measures going forward. The construction workers receive timely feedback on the quality of work and have the opportunity to address issues that may be hindering them in their daily work.

8.6.2.2 How LCM can complement Last Planner implementation

The LCM model also contributes ideas as to how visual tools can be used to support communication by creating transparency during the process of implementation of the Last Planner System. As highlighted in the literature review, while the LPS has proven to be a very successful system in optimising the construction process, some challenges stemming from a lack of communication and inadequate use of information have also been experienced during implementation (Chapter 2, Section 2.9.7).

The visualisation and accessibility of information in the LCM model, supports the adequate use and communication of that information. The visual tools that make up the model encourage not only the full support of construction management but also the close involvement of the construction worker, bringing in their ideas, which was found to be a barrier in Last Planner implementations on some projects (Friblick et al., 2009). The LCM model also helps to improve communication between the different roles on a project, for example between the architect, general contractor and the owner which was also a challenge during some of the past implementations of the LPS (Kalsaas et al., 2009).

An explanation of how the visual tools of the LCM model can complement some of the processes of the LPS by improving transparency and communication is explained below.

8.6.2.2.1 Using visual tools to “make work ready” early on

The process of “making work ready” is an important part of the LPS (Ballard, 2000). Shielding production drives the “make ready” process in the LPS system where activities are screened so that quality assignments can be defined and work is then “pulled” into the process if it is ready for execution. (Ballard & Howell, 1998).

The Process Planning tool is one of the visual tools of the LCM model, used to make work ready in the long-term (4-6 months) and provides a way to visually monitor the preparation of work for execution by making milestones and constraints transparent (Chapter 5, Section 5.4.2). For a 4-6 month period, the Process Planning tool uses colour-coding and a similar concept to that of Andon to visualise which activities are running parallel, what the flow of work is in this defined period, the constraints, important milestones and the readiness of work. The use of visual tools in the Process Planning helps to link the phase planning with the production planning onsite, which was identified as a barrier during the LPS implementations in the Havlimyra case (Norway), (Kalsaas et al., 2009). The planning board also helps to make work ready in the short-term since it focuses on 3-4 weeks of daily work packages, the feasibility of which are questioned at the weekly and daily meetings.

8.6.2.2.2 Using visual tools to support the SHOULD-CAN-WILL mechanism

In the LPS, the look ahead process and weekly work plans are used to control workflow by using the SHOULD-CAN-WILL mechanism, which transforms activities that SHOULD be done into commitments that actually CAN be done and WILL be done (Ballard, 2000). The objective of this look ahead process is to form a backlog of sound work that can be executed realistically. It focuses on a time period of 3-12 weeks (depending on the project characteristics and the reliability of the planning process) and activities enter into the look ahead window 6 weeks before planned execution (Ballard, 2000), depending on the type of project.

In the LCM model, all the areas of the structure are visualised on the Process Planning tool making it possible to see at a glance which activities are running parallel and initiating discussions as to whether this is feasible and if further interdependencies have been overlooked. This visualisation supports the discussions that are essential in transforming what should be done into what will be done in the long-term. It provides a common communication ground for the discussions around the preparation of work and the removal of constraints. The discussions that are encouraged through the visualisation of the individual processes, lead to a common understanding of these processes and an earlier recognition of the problems that are in the way. This visual forecast is used by all participants and a large updated copy is posted monthly in the LCM area for all to see and as guide for the daily planning on the planning board. In addition, the planning board provides a link between the long-term Process Planning to execution by focusing on a sub-section of what should be done from the PP and transforming this into what will be done in the Detail Planning. The communication within this process of SHOULD-CAN-WILL of the LPS could be complemented by using such visual tools.

8.6.2.2.3 Using visual tools to facilitate work flow control

In the Last Planner System, the look ahead process has the job of workflow control (Ballard, 2000). The look ahead process in the LPS serves multiple functions which are achieved through specific processes such as activity definition, constraints analysis, pulling work from upstream production units and matching load with capacity. The following discusses how the visual tools of the LCM model can be used to support some of the processes needed for workflow control in the LPS.

- **A visual Kanban board for work flow control onsite**

  The Planning board in the LCM model is used to control work flow in the short term. It is the central visual tool of the LCM model that displays, links and co-ordinates a number of other different visual tools and processes with the common goal of controlling the flow of work at production unit level. It is a large board, placed on site in the LCM area and visualises daily work packages for each company and area on cards over a time period of 3-4 weeks. The work on the cards displayed on the board is directly linked to those activities displayed in that timeframe in the Process Planning tool, thus providing a further way of linking the phase and production planning.

  In this way, the board itself is a visual Kanban system, only allowing a small number (1-2) of daily packages to be placed in the slots per day for the next 3-4 weeks, thus the amount of work entering the process is controlled. If more than one card is placed in the slot, questions immediately arise as to whether it is possible for two companies to carry out two different activities in the same area. The board could also be compared to a visualised poke yoke system, as it eliminates the chance of two crews being unable to work in the same area at the same time.

- **Visualisation and control of work areas, crews and work completion**

  The structure of the planning board shows all of the areas of the project and the cards that are placed on the board represent the daily work packages to be carried out by the individual companies. At a glance, one can see on the planning board what company is in what area on any particular day or week. Completed cards are placed green side up on the planning board each day, so one can also see at a glance if planned work was actually completed.

This visualises the WILL and DID activities described in the LPS. Finally, a certain control of the buffer areas results from this visualisation on the planning board. One can see if there are a large number of areas vacant which is important to improve lead time. In the LPS, the PPC (percentage part complete) is used to control the work at production unit level. PPC is used to control whether the WILL was completed, whereas in the LCM model, this can be seen.

- **Using visual tools to match load with capacity**

The cards visually control work at production unit level and are a visual way of helping the sub-contractors to “match load and capacity” as is described in the Last Planner System. Matching load with capacity is concerned with “estimating the load various chunks of work will place on production units and the capacities of production units to process those chunks of work” (Ballard, 2000, p. 3-13).

Each construction card represents one day’s work by a company in a particular area. The companies use these cards as a guide to describe in detail the daily activity, how much capacity is needed and what material. By providing this information on work assignments, the construction card is also a Visual Work Facilitator (Tezel, 2011) since they are designed to facilitate the construction worker in his task by clearly describing the activity. The cards also indicate when work is ready to be checked when they are placed back on the plans in the LCM area, green side up. At a glance, one can see the status of work, if the quality of work is acceptable (green side up placed back on the Planning board if quality ok) and so assist the site management in quality control. The cards are also a visual way of leveling the construction load and are an important element of the visual Kanban system.

Problem cards are used to visualise the constraints in the construction process. As long as a problem card can be seen in front of a work package card, it is clear that the issue has not been resolved. A certain element of control of the constraints is introduced here since at every glance of the board, the constraints are apparent and until removal, will be the subject of discussions at the planning board.

The final section of this chapter discusses the theoretical significance of the work.

8.7 Theoretical significance

Vaishnavi & Kuechler (2007) explain that Design Science can contribute to better theories by 1) the artefact itself being the object for theorising how something is done (e.g. how to build more maintainable software) and 2) by exposing relationships between its elements, through better understanding and making them more visible, thus potentially falsifying or elaborating on previously theorised relationships. The development of the LCM model is theoretically significant in the sense that: 1) it facilitates a better understanding of the relationship between the visual categories identified by Galsworth (1997) and Tezel (2011) and the information flows that they support; and 2) it provides a test of and further confirmation for the Lean critique of Project Management.

8.7.1 Relationships between VM categories

The LCM model demonstrates the use of at least three of Galsworth's (1997) visual tools: visual indicators, visual signals and visual controls (Section 8.4.4, Figure 8.2). The model demonstrates that rather than being discrete tools, these elements represent different functions. This can be seen in that the majority of the LCM's individual elements represent more than one type of the visual tools identified by Galsworth (1997).

Galsworth (1997) identifies four categories of visual tools (Chapter 2, Section 2.5.1): a visual indicator relays information in the hope of influencing behaviour; a visual signal attracts attention by using visual stimuli; a visual control enforces almost complete human control and a visual guarantee strives to eliminate human error. Table 8.3 presents how each of the individual elements of the LCM model are examples of more than one of the three different categories of tools identified by Galsworth (1997) and this is explained further in Section 8.7.1.1. By demonstrating that the elements of the LCM model represent more than one of the categories defined by Galworth (1997) this shows that the categories are therefore functions rather than tools.

Since 14 of the visual tools (10 directly and 4 indirectly) identified by Tezel (2011) are also represented in the LCM model (Section 8.4.4, Table 8.1 and Figure 8.1), this shows that each of Tezel's categories can also represent more than one of the visual tools identified by Galsworth (1997).

8.7.1.1 LCM and Galsworths visual categories

The visual elements of the LCM model represent more than one of the categories of visual tools identified by Galsworth (1997) in the following ways:

- **The Overall Process Map (OPM):** is both a visual indicator and a visual signal since it relays information about the overall process with the intention that the process flow is carried out in this way (visual indicator) and it is a visual signal since attention is drawn to the constraints in the process since by highlighting these on red cards.

- **The Process Planning tool (PP):** is a visual indicator, a visual signal and a visual control. It is a visual indicator since it relays information indicating what activities should be carried out, what the milestones are and the companies involved etc. The PP tool is also a visual signal since it attracts attention to the readiness of work (a red circle beside the activity signals that an important prerequisite it missing and a green circle signals that all prerequisites have been fulfilled). It is a visual control since it focuses on specific activities in a defined timeframe and monitors the feasibility of these activities so that they can be executed as planned.

Table 8.3: Elements of LCM model representing more than one of Galsworth categories

	LCM element	Type of Visual tool according to Galsworth	Definition	Category identified by Tezel (2011)	Function in LCM	Visual concept
1	**Overall Process Map (OPM)**	Visual Indicator	A visual indicator relays information in the hope of influencing behaviour.	No. 9 (Table 8.2 & Figure 8.2)	Visualisation of main construction processes and interdependencies. Identification of constraints.	VSM, colour-coding
		Visual Signal	A visual signal attracts attention by using visual stimuli and enforces more more human control. It expects people to pay attention and directs behaviour (Example: traffic light, Andon board).			
2	**The Process Planning tool (PP) (LCM version 2 & 3).**	Visual Indicator	Definition as above	No. 7 (Table 8.2 & Figure 8.2)	Visualisation of activities, milestones, constraints, status of readiness of work, companies involved etc. within a 4-6 month timeframe.	Andon, colour-coding.
		Visual Signal	Definition as above			
		Visual control	A visual control limits human response in terms of height, size, quantity, volume, weight, width, length and breadth.			
3	**The construction card**	Visual indicator	Definition as above	No. 2,3,4,5,6,7,9 & 10 (Table 8.2 & Figure 8.2)	Definition and visualisation of daily work packages	Kanban card, colour-coding
		Visual Signal			Green side of card signals completed work, other side signals work in progress	
		Visual Control			Contents of card limits work to be done on any given day	
4	**The planning board**	Visual indicator	Definition as above	No. 2,3,4,7,9 & 10 (Table 8.2 & Figure 8.2)	Visualisation of planned daily workloads, who will complete them and where. Displays standard construction process, individual apartment and working days.	Andon, Kanban, Visual board, Colour-coding
		Visual Signal	Definition as above		Indicates where work is in progress and where work cannot be carried out (stop sign).	
		Visual Control	Definition as above		Planning board limits the work that can commence.	
5	**Colour-coded plans**	Visual indicator	Definition as above	No. 2 & 5 (Table 8.2 & Figure 8.2)	The colour-coded plans displayed information on what work was being carried out at a certain place by which company.	Andon
		Visual Signal	Definition as above		The construction card hung on the colour-coded plans, signalled either completed work (green) or work in progress so that the foreman knew when to check work for quality.	
		Visual Control	Definition as above		The colour-coded plans limited focus to that area of work only and that qualtity of work scheduled for that day. If the foreman identified problems in the quality these were noted and rectified immediately.	
6	**The logistics board**	Visual indicator	Definition as above	No. 7 (Table 8.2 & Figure 8.2)	Cards were placed on the logistics to plan and organise available site resources. The logistics board diesplayed information, signalled what resources were planned when and controlled and planned the use of the site resources.	Visual board, Kanban
		Visual Signal				
		Visual Control				
7	**Site Layout**	Visual indicator	Definition as above	No. 9 (Table 8.2 & Figure 8.2)	Cards hung on site layout to indicate where material was stored or to indicate logistic resources currently in use. When cards were turned around to the green site, this signalled that the resources were available.	Colour-coding
		Visual Signal				
8	**Visual KPI's**	Visual indicator	Definition as above	No. 7 & 8 (Table 8.2 & Figure 8.2)	KPI data on OTP an quality indicating daily performance of sub-contractors and signalling if performance was satisfactory (happy face / sad face). The visual KPI's were also a control as performance was monitored and corrective actions defined.	Display of visual control measurements
		Visual Signal				
		Visual control				
9	**The action plan**	Visual indicator	Definition as above	No. 7 (Table 8.2 & Figure 8.2)	The action plan documented and visualised improvement actions. For each action there was a person responsible and target completion date assigned. With regular checks this ensured that the actions were also completed.	Visual display of information on performance and control of improvement
		Visual control				
10	**The information board**	Visual indicator	Definition as above	No. 7 & 9 (Table 8.2 & Figure 8.2)	The information board displayed information for all involved on KPI's, improvement actions and any other relevant information to the site.	Visual display of information
		Visual Signal	Definition as above		The KPI's displayed on the infomation board were a signal to all how	
		Visual control				

- **The construction card:** is a visual indicator since it relays information on what should be carried out by which company on a particular day. It is a signal, since when hung turned around to its green side, it draws attention to completed work so that the foreman knows the quality check can be carried out. It is a control since it is used as a guide to check the work on a daily basis.

- **The planning board:** is a visual indicator since it displays what work will be carried out where over the next 3-4 weeks, with the intention that this work will be carried out as planned. It is a signal, since it draws attention to completed work (green cards placed back on planning board), vacant areas in the building where no work is being carried out (where no construction cards have been placed) and problem areas (where red problem cards are displayed). It is a control since it limits the work planned for the 3-4 week timeframe and it monitors the completion of that work.

- **Colour-coded plans:** are visual indicators since they relay information on the location of work in process on a particular day on the site. They are visual signals since they draw attention to the work in process by means of a construction card that is hung on that specific area on the plan. It also draws attention to completed work that is awaiting quality control (if the cards are displayed green side up). Likewise, attention is also drawn to areas were no work is being carried out (in the absence of a card). The colour-coded plans are also visual controls, since they limit the focus per day to the areas where cards are displayed and facilitate the quality approval of the work the cards represent.

- **The logistics board:** is a visual indicator since it relays information on what logistic resource is planned on a particular day (eg. crane, lift etc). It is a visual signal, since it draws attention (by means of a card) to what resource is planned and when and it is a control since it monitors and plans the available logistic resource capacity.

- **Site Layout:** is a visual indicator and a visual signal since shows the location of the logistic resources (indicator) and it signals if resources are available or in use (cards hung on areas to indicate in use, or turned around to green side to indicate resource is available again).

- **Visual KPI's:** is a visual indicator, relaying information on OTP and quality levels of work. It is a signal, showing if the KPI's are satisfactory (a happy face signalling immediately if performance is satisfactory and a sad face signalling immediately if performance is not satisfactory). The visual KPI's are also a control since they monitor performance and corrective actions are defined to improve performance.

- **The action plan:** is a visual indicator relaying information on problems and solutions. It is also a control, since it displays persons responsible for implementation of the solutions and target dates for completion.

- **The information board:** is a visual indicator and a visual signal since it displays system wide information on the construction process (ie: process information, KPI's, role descriptions, actions plans etc.). It is also a visual signal and visual control since some of the information draws attention to performance (KPI's) and monitors removal of constraints (action plans).

Furthermore, since the objective of project management is ultimately to direct behaviour, it can be seen that the controlling function is the key one, which determines the need for the other three. In order to exercise control, it is also necessary to inform (and also to receive information), as can be seen in the cards, for example. This function is represented by the information flows identified in the fieldwork. The signalling function operates as a facilitator for the informing and controlling functions.

8.7.2 The critique of project management

The development of the LCM model can be seen as providing further confirmation of the critique of traditional Project Management theory (section 8.6.2):

- **plans are not tested against reality and an unproblematic execution process is assumed** (Laufer & Tucker 1987; Johnston & Brennan 1996; Howell & Koskela, 2000; Howell & Koskela, 2000, 2001, Koskela, 2001; Howell & Koskela 2002a, 2002b, 2002b) (Chapter 2, Section 2.7.1).

- **it is assumed that one way communication is adequate for creating sound commitments** (Laufer & Tucker 1987; Johnston & Brennan 1996; Howell & Koskela, 2000; Howell & Koskela, 2000, 2001, Koskela, 2001; Howell & Koskela 2002a, 2002b, 2002b (Chapter 2, Section 2.7.2).

- **there is no root cause analysis on problems since tasks enter the execution phase on the assumption that they can be completed** (Laufer & Tucker 1987; Johnston & Brennan 1996; Howell & Koskela, 2000; Howell & Koskela, 2000, 2001, Koskela, 2001; Howell & Koskela 2002a, 2002b, 2002b (Chapter 2, Section 2.7.3).

In case study 1, where the LCM model was initially developed, work could not be carried out as planned as the master plan did not conform to reality and there was no flow of work in the construction process onsite (Chapter 4, Figure 4.3 and 4.4). The need for the visual planning board was identified to visualise and implement the flow of work onsite and to provide a structure for examining the feasibility of that work in the execution phase.

During following instantiations to refurbishment (2A and 2B), the same problem was noted (that work could not be carried out as planned) and a need for a further visual tool was identified that better linked planned work to executions so that feasibility was improved. The addition of the Process Planning phase in case study 2, facilitated "testing" the work against reality in the long-term and the identification of issues hindering execution as early as a few months before execution commenced. The Process Planning tool ensured that only work that had been approved and is feasible is “pulled” into the execution phase (Chapter 5, Section 5.4.2), rather than pushed.

Since work is thought to flow, it is assumed that one-way communication of information (from the top down) is adequate for the creation of sound commitments. Winograd & Flores (1986) argue that the work in organisations is coordinated through making and keeping commitments and this requires feedback on feasibility with regard to real world circumstances. The LCM model confirms the critique of the assumption that work flows in a linear way from the moment of authorisation and that one-way communication is sufficient for creating sound commitments (Koskela & Howell, 2002 b). In case study 1 and 3, communication issues and inefficient decision-making were evident (Chapter 4, Section, 4.3.1 and 4.3.2; Chapter 7, Section 7.4.1). The one-way communication of what should be done led to additional work, since sound commitments were not created: work that was not feasible would have to be rescheduled at the last minute (Chapter 4, Section, 4.3.3). During the power plant instantiations, there was little communication between the interfaces of engineering and construction, which meant that component requirements were defined much too late. Inadequate components for assembly arrived onsite as a result leading to rework and delays. The visual tools used during the OPA, the PP and the detailed planning phase facilitated communication and feedback between the key interfaces so that work could flow as defined.

During case study 1, it was also noted that there was no evidence of continuous improvement in the construction process (Chapter 4, section 4.3.4). It was evident that construction workers were focused on their own specific task and there was no incentive for improvements in the overall process. There was no feedback on problems in execution received from the construction workers involved in the process and different perceptions of quality of work were evident. This led to quality issues and lack of a standard for continuous improvement. This provides further confirmation for the critique since it is assumed that tasks can be completed, often this is not the case and supervisors are distracted from promoting continuous improvement in order to produce a historical record of yesterday's problems and a justification for what happened (Laufer & Tucker, 1987).

8.8 Further research

The importance of further research in certain areas became apparent throughout the course of this research. The further research recommended by the author is concerned with further improving the LCM model and Visual Management application to construction. These recommendations are based on the findings from the case studies and feedback from industry specialists.

- An important point to consider for future research is how the LCM model can be further adapted and improved to deal with the challenges of power plant construction i.e.: how can the model be improved to deal with the complicated component supply process of power plant construction and to better foresee the reoccurring technical issues.
- The application and integration of the LCM model to the design phase has yet to be investigated. How LCM can extend existing BIM tools to include planning and execution processes is an important focus for further study.
- Additionally, the use of further Lean concepts and methods such as 5S and Kaizen as part of LCM instantiations is an important area for future research to consider.
- An important focus of further research is an investigation of how the visual tools of the LCM model can be further extended to the work areas of the site (i.e.: to improve the visualisation of work onsite, location of material at the area of work, health and safety). In addition, it would be important to consider how visual guarantees can be better integrated into the model as this type of visual tool is currently barely evident in the model.
- Finally, a deeper study comparing and analysing the differences and similarities between the LCM model and existing systems of production planning and control in construction such as the LPS (based on instantiations in practice) is an important area for further study.

8.9 Final comments

An important focus of this investigation was to create a better understanding of the significance of the principle of transparency for the construction process and to provide a feasible solution as to how it can be achieved. It also demonstrated that this solution, the LCM model, is applicable to various different types of construction scenarios; residential, refurbishment and power plant construction being the examples studied in this thesis.

The findings of the research revealed that there is a lack of transparency in the construction process and few examples exist in the literature, which show how to apply Visual Management in a systematic way to create it. This research provided a detailed description of how the LCM model was developed, further developed and applied to three different types of construction scenario to create transparency in the overall process. Findings from the instantiations of the LCM model provide evidence that it is useful for creating transparency in production planning and control and it is applicable to different types of construction projects.

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Appendices

Appendix A: Lean application

A.1 The Toyota Way and holistic thinking

The importance of a holistic approach and philosophy as opposed to the application of individual, isolated solutions is a key factor which has determined Toyotas success from the very beginning. According to Fujio Cho, then president of the Toyota Motor Company (1999-2005) and who learned the Toyota Way from one of its inventors, Taiichi Ohno:

> "The key to the Toyota Way and what makes Toyota stand out, is not any of the individual elements.....but what is important is having all elements together as a system. It must be practiced everyday in a very consistent manner – not in spurts.

-Fujio Cho, then President, Toyota Motor Corporation (current president is Akio Toyoda, grandson of Kiichio Toyoda).

Ultimately, Toyotas aim is to be successful in the long run, forfeiting short-term profits for long-term growth and stability. In 2012, the Toyota Motor Corporation, reclaimed the title of the world's largest car manufacturer from General Motors, selling 9.75 million vehicles (compared to 9.29 for GM). Ironically, despite a stronger emphasis on the importance of growing leaders, developing people and continuous improvement, than on making money, it is also one of the most profitable car manufacturing companies in the world. This emphasis on long-term growth as opposed to short-term gain, can also be observed in the CEO salaries of the top 5 car manufacturers in the world (Toyota, Ford, VW, Daimler and GM): Aiko Toyota, President of the Toyota Motor Corporation, is by far the lowest paid, receiving an annual salary of less than one tenth of his best-compensated counterparts (Mukai, 2013).

It is well documented in the literature that the Toyota Way and "Lean" thinking as coined by MIT researchers, has led to the long-term success of the company.

A.2 Poor application of Lean: example

Liker (2004) illustrates a poor application of Lean and weak management understanding of Leans complexity by referring specifically to a US company, which won the Shingo prize for manufacturing. As a "best-practice" example, the company agreed to work together with the TSSC (Toyota Production System Support Centre) for mutual learning purposes. The TSSC is a company set up by Toyota in the US to work with US companies with the goal of teaching them about Lean. The goal of this mutual co-operation was to take one product line and use the concepts of the TPS to transform it. At the end of the 9-month project, the product-line was barely recognisable compared with its original "world-class" state. The KPI's of the production line had greatly surpassed those of the rest of the plant (Liker, 2004, p.11).

Some of the results were:

- 46% reduction in lead-time to produce the product
- 83% reduction in WIP inventory
- 91% reduction in finished goods inventory
- 50% reduction in overtime
- 83% improvement in productivity

The outcome of this co-operation was that it was established that this company was far from Lean at all. This finding and trend was further observed by Liker (2004) through his extensive experience of visiting and teaching at thousands of companies over the years. Liker (2004) concludes that the reason for this is that while US companies have embraced the Lean tools, it is not understood what makes them work together in a system (Liker, 2004, p.12).

A.3 Visual Management as a function of transparency

Visual Management plays an important role in the creation of transparency. Tezel (2012) identifies creating transparency as the primary function of Visual Management (Table A.1).

Table A.1: The functions of Visual Management (Tezel et al., 2009, P.83)

Function	Definition	Alternative Practice
Transparency	The ability of a production process (or its parts) to communicate with people (Formoso et al., 2002).	Information held in people's minds and on the shelves.
Discipline	Making a habit of properly maintaining correct procedures (Hirano, 1995).	Warning, scolding, inflicting punishments, dismissing etc.
Continuous Improvement	An organisation-wide process of focused and sustained incremental innovation (Bessant and Francis, 1999).	Static organisations or big improvement leaps through considerable investment.
Job Facilitation	Conscious attempt to physically and/or mentally ease people's efforts on routine, already known tasks by offering various visual aids*.	Expecting people to perform well at their jobs without providing them any aids.
On-the-Job Training	Learning from experience (Mincer, 1962) or integrating working with learning (Sumner et al., 1999).	Conventional training practices or offering no training.
Creating Shared Ownership	A feeling of possessiveness and being psychologically tied to an object (material or immaterial) (Pierce et al., 2001).	Management dictation for change efforts, vision and culture creation.
Management by Facts	Use of facts and data based on statistics (Gunasekaran et al., 1998)	Management by subjective judgement or vague terms.
Simplification	Constant efforts on monitoring, processing, visualizing and distributing system wide information for individuals and teams*,	Expecting people to monitor, process and understand the complex system wide information on their own.
Unification	Partly removing the four main boundaries (vertical, horizontal, external and geographic) and creating empathy within an organisation through effective information sharing*.	Fragmentation or "this is not my job" behaviour

* The definition made by the authors.

A.4 Challenges of implementing Lean in construction

The challenges experienced in applying the Lean concepts to construction process stem largely from the nature of construction projects and the traditional conversion model (Chapter 2, Section 2.6). The challenges revealed from the literature can be summarised under the following headings: 1) the unique circumstances of construction (Howell, 1999; Koskela, 2000; Ballard & Howell, 1998) 2) complexity (Williams, 1997; Bertelsen, 2003; Salem, et al., 2006) 3) activity-based approach (Miller, et al., 2003) and 4) difficulty in justifying research and training (Banik, 1999).

- **Unique circumstances of construction**

  One challenge appears to be as a result of the nature of construction as a whole. Construction is a different kind of production, which requires an adaptation of the Lean concepts to suit the nature of this industry. The main difference between manufacturing and construction is that manufacturers make products whereby construction projects involve the design and construction of unique and complex structures in highly uncertain environments under great time and schedule pressure (Howell, 1999).

  Koskela (2000) identified the "one-of-a-kind nature of projects, site production, and temporary multiorganisation" as key elements differentiating construction from manufacturing. The product uniqueness and the project form of organisation associated with construction have dominated thinking about production of the built environment so far as to discourage learning from non-project industries such as product manufacturing (Koskela, 1992). Ballard & Howell (1998) hold a similar view although they do acknowledge that other types of production also possess one or more of these characteristics (Ballard & Howell, 1998). Construction is essentially the design and assembly of objects fixed-in-place and consequently possesses, more or less, the characteristics of site production, unique product, and temporary teams (Ballard & Howell, 1998). This is a challenge for Lean application where long-term thinking and the development of standards are important aspects of implementation.

- **Complexity**

  A further challenge when applying Lean to construction is that construction projects are characteristically complex, unique, dynamic systems that must rely on an initial design that involves a number of subassemblies with variable specifications (Bertelsen, 2003). Williams (1997) characterises project complexity by two dimensions each of which have two further sub dimensions. 1) structural complexity: referring to number of elements of the product (structure) and the interdependence of the individual elements and 2) uncertainty: in *goals* and *methods* to complete tasks (Williams, 1997).

The complexity of construction projects, combined with the effect of on-site, one-of-a-kind production leads to high levels of uncertainty (Salem et al., 2006). In construction projects, significant uncertainty exists throughout the project. Weather conditions, soil conditions, owner changes, and the interaction between multiple operations can produce unique circumstances, which could be as critical as the planned activities and have a significant impact on project cost (Salem et al., 2006). Wild (2004) also refers to the UK industry as unfocused and uncertain: although new pressures for change now exist, historical data suggest a slow response (Wild, 2004). Wild (2002) also argues that historical research shows that construction is unmanageable: it is self-fragmenting and its projects are temporary multi-organisations involving players that assemble to carry out tasks, but keep their own organisations interest. This results in discrepancies in values and power differentials that result in both instability as well as problems in balancing the ends and means of a project (Wild, 2002). It is also difficult to see the source of problems in construction, since participants lack the language and conceptual foundation to understand the problem in physical production terms (Howell, 1999).

- **Activity-based approach**

  Another challenge stems from the activity based approach, where construction is viewed as a set of independent activities the performance of which is measured in cost and time (Chapter 2, Section 2.5.4). The relationship between contractors and sub-contractors is a transactional one (Miller et al., 2003), where all parties try to obtain additional value at lowest cost. Contractors find it difficult to see how innovations can add value to their existing operations making lean initiatives difficult. It is suggested that a closer relationship between contractors is necessary and some sort of a harmonisation (such a partnering) is needed for lean construction innovations to succeed (Miller et al., 2003).

- **Difficult to justify research and training**

  A further challenge in applying Lean to construction is that due to the relatively short time it takes to construct a building compared to the manufacturing process for a product (which can go on for many years), it is more difficult to justify research and training which is needed to aid the change process. According to Banik (1999), this lack of investment is damaging to the construction industry's capacity for innovation in process and technology and threatens its competitiveness in local and global markets (Salem et al., 2006).

A.4.1 Overcoming the challenges

Despite the challenges to be found in the literature, there is a general consensus that by applying the Lean concepts to construction, there is tremendous opportunity to improve contemporary practice and in turn reduce the time and cost of constructed facilities (Ballard & Howell, 1998). Lean Construction offers an alternative to contemporary practice since it (Howell, 1999):

- has a clear set of objectives for the delivery process,
- is aimed at maximising performance for the customer at the project level,
- designs concurrently product and process, and applies production control throughout the life of the project

Important factors to consider when applying Lean to Construction can be found in the literature. Alarcon & Conte (2003), identify the following significant factors to consider when applying Lean to construction:

- A clear methodology with well-defined and rigorous strategies is needed.

- Clear signals and a high degree of commitment from upper management.

- Establishment of a special organisation for implementation, with a clear and rigorous operation.
- Project managers and heads of departments are key officers both for leadership and commitment as well as in removing barriers to the implementation of what is being promoted.
- Knowledge of both the lean concepts and the implementation program is fundamental for the company’s personnel. This requires effective communication.
- The definition of functions, responsibilities and levels of authority of the company’s project managers and / or professionals.

In addition, Ballard & Howell (1998) present further important points to be considered when applying Lean to construction. According to the authors (Ballard & Howell, 1998) making construction lean has at least two parts: 1) claiming from construction what actually belongs to contemporary product manufacturing and minimising construction’s peculiarities in order to take advantage of Lean techniques developed in manufacturing, (e.g. manufactured housing, simplifying site production to final assembly and testing) and 2) Developing Lean techniques adequate to dynamic construction, the remainder that resists the first approach. A shared challenge for both is coordination of the specialist installers who occupy the front line, and through whom engineering and fabrication expertise is best applied (Ballard & Howell, 1998).

Appendix B: Data collection

B.1 Interview questions for observational study in Brazil

General

- When was the company formed and how many employees? What are the company's main business areas?

- Information about interviewee: name and role at the company.

- Do you have an organisation chart? (to clarify departments and roles)

Visual tools and Lean

- Have you heard about Lean? Have you heard about Visual Management?

- Does your company use Visual Management?

- If so, which visual tools / methods do you use and why?

- Where are these visual tools used: in the company, on construction sites, with suppliers? Describe this.

- How do you implement these visual tools? Who is responsible for monitoring and sustaining? What is critical in the implementation process?

- Describe the continuous improvement culture in your organisation: are people willing and open to suggesting and implementing improvements or does this come mainly from management? (Top-down, bottom-up or both).

- Are these visual tools manual or electronic?

- Is the impact of the visual tools measured? If yes, what results have been achieved so far?

- Whereabouts are these visual tools “visualised”?

- Do you see any down side to visual tools? If yes, what is this and why?

- What are your future plans for visual tools in your organisation?

- Does your company use any other Lean tools? If so, which ones?

- Have you any further points to add?

B.2 Focus groups

Table B.1: Basis for discussion during focus groups

	LCM element	Description	Tool	Has this element been used before on your project?	If yes, how does it compare?	Do you think element contributes to an improvement in transparency?
Phase 1	**Overall process planning**	Workshop carried out as before construction with all planning specialists. The main aims are: 1. Separation of project into suitable sub processes 2. Visualisation of all processes, interdependencies and interfaces 3. Definition of optimal process 4. Identification all known problems 5. Definition of solutions and persons responsible	1. Workshop 2. Overall Process Map: "Brown paper analysis" 3. Action plan 4. Lean Construction training			
Phase 2	**Process planning**	Workshop that takes place on a monthly basis with all planning specialists and construction companies involved. The main aims are to: 1. prepare a visualised illustration of planned construction work over the next four to six months (timeframe, company, colour-coded illustration of work "ready". Based on overall optimal process. 2. Proposal sent in advance to companies and planers to prepare 3. Identify problems and ressolve to stabilise work 4. Visualisation in LCM area	1. Workshop 2. Process Planning tool: Visualisation of 4 month timeframe 3. Action plan 4. Lean Construction training			
Phase 2	**Detail Planning**	Positioning and use of all elements of the LCM model in a central area onsite known as the LCM area. Planning board focuses on 3-4 week time frame. It provides a forum and physical means for all involved to communicate and visualise information on daily work packages. Problems are identifed and resolved and work is stabilised. The individual elements are as follows:	1.The daily planning board: Andon, Kanban, Visual board, Colour-coding 2. The construction card: Kanban card, colour coding 3. Visual control measurements (KPI's) 4.The action plan 5. Construction checklist (optional) 6. The apartment clock; Andon (in later projects, a display of colour-coded plans have been used instead of the apartment clock) 7. The information board 8. The logisitcs board 9. Weekly detail planning meeting on-site at area			
		1. The planning board: It has the following functions: a) Visualisation of daily work packages b) Visualisation of overall construction process and interdependencies c) Indication of where work is in progress and where work cannot be carried out (stop sign) d) Planning board controls the work that can commence				
		2. The construction card: Functions include: a) Definition and visualisation of daily work packages b) Signal work status: green side of card signals completed work, other side signals work in progress c) Contents of card controls work to be done on any given day				
		3. Key Perfomance Indicators: a) Data for KPI's (quality and On-Time-Performance) gathered by the foreman, displayed and discussed at the weekly site meeting.				
		4. The action plan: The action plan documents and visualises improvement actions (displays person responsible and target completion date).				
		5. Construction checklist (optional): a) Used by the foreman - provided an overview of where work was being carried out by whom on a daily basis (without having to go to the planning board).				
		6. The apartment clock / colour-coded plans: a) The apartment clock (or colour-coded plans) displayed information on what work was being carried out at a certain place by which company b) Signalled either completed work (green) or work in progress so that the foreman knew when to check work for quality c) The apartment clock limited focus to that area of work only and that qualtity of work scheduled for that day. If the foreman identified problems in the quality these were noted and rectified immediately.				
		7. The information board: a) The information board displayed information for all involved on KPI's, improvement actions etc.				
		8**. The logistics board:** a) Controlled material storage b) Visualisation of storage availibility				

B.3 Interview questions for foreman / client after LCM instantiation

General

- Have you worked with any Visual Management Models before?
- If so, which ones?
- How do you think your employees have participated during the LCM instantiation?

LCM phases

Overall Process Analysis (OPA)

- How effective was the OPA in your opinion in defining optimal flow of work in all areas?
- How effective was the OPA in identifying interdependencies, constraints and developing solutions to remove them?
- How did you think the participants co-operated during the workshop sessions?
- What is your opinion on the length of time it takes to carry out an OPA?
- Do you think the level of detail is satisfactory?
- Do you think the OPA contributed to the early identification of constraints?

Process Planning Phase (PP)

- How effective was the Process Planning in connecting the execution process with upstream processes such as planning, material supply and approvals?

- How did you think the participants co-operated during the workshop sessions?

- What is your opinion on the length of time it takes to carry out a PP?

- Do you think the level of detail is satisfactory?

- Do you think the PP contributed to the early identification of constraints?

- Do you think the Process Planning tool was clear and updated regularly enough? Do you have any suggestions for improving the Process Planning tool?

Detailed Planning Phase (DP)

- How effective was the planning board in providing a structure for communication and co-ordination of daily work between subcontractors onsite?

- How effective was the planning board in creating transparency in the execution process and providing a structure for communicating and resolving problems?

- What is your opinion of the nature of the planning board, the construction cards, the information displayed on construction cards, the layout of the construction cards? How could these be improved in your opinion?

- Did the DP contribute to an improvement in the daily planning and co-ordinating of operations onsite?

- By measuring the performance i.e: quality and On-Time-Performance, do you think there was an improvement in mistakes made. Was a learning effect notable?

LCM Model in general

- What were the most notable effects of the LCM instantiation on the construction site in your opinion? E.g. better communication through increased transparency, improved lead time, more efficient co-ordination, better quality, more stability, better team work?

- Would you implement LCM again?

Appendix C: Kaizen during LCM instantiation 1A

C.1 Improvement of electrical assembly process for each apartment

Since the work was broken down and visualised on cards on the planning board, it was possible for the researcher (in her role as a consultant) together with the construction workers themselves, to arrange to observe a planned process with the objective of reducing waste in this process. One process that was observed was the electrical assembly process, which was an important process step in each of the apartment units (case study 1). A description of this observation is given below.

On the day of observation the researcher talked through the process with the construction worker to fully understand the process steps to observe. The process steps involved were:

- Assemble case
- Get material
- Detach and assemble
- Connect fuse and test
- Seize ventilator
- Solve any defects and replace cover
- Tidy up

The first main conclusion from the observation was that the time planned for this process greatly exceeded the time required in practice (Figure C.1). It was noted that almost 240 minutes were planned for this process when the time actually needed was approximately 140 minutes less than that. Without this visualisation and observation of this process, this fact would have remained unknown. The contractor now had an opportunity to review his planned capacity for this process and in turn improve its overall productivity. The second observation was the classification of the activities carried out into value-added, non-value added but necessary and non-value added but not necessary activities. In Figure C.1, the column on the right shows this classification. The orange colour represents the value-added activities: these were tasks carried out when the worker was working directly on the distribution box that had to be assembled. The light blue is the non-value added but necessary activities: tasks such as getting materials and opening packages. Finally, the dark blue colour represents the non-value added but not necessary activities such as searching for missing materials, excessive walking looking for tools (see spaghetti diagram, Figure C.1 below showing this walking) and defective material. By eliminating the “dark blue” activities (i.e by ensuring better preparation so that materials were not missing and less walking looking for equipment was needed) and reducing the “light blue” activities as much as possible the overall process could be further improved.

In total, the overall result (Figure C.1) was an improvement in productivity in the process by more than 50% for the rest of the apartments. This was measured based on before and after diagrams shown in Figure C.1 (initial situation and result). The difference between the time needed initially (240 minutes) and after improvements are implemented (102 minutes) is approximately 57%. In addition, extra walking was reduced and overall lead time was improved. The involvement of the worker in this process was also a positive aspect as they had an opportunity to express their own issues with this process and identify the future improved process themselves. For example, in this case, the worker was not happy with some of the tools that he had to use as they were outdated and time consuming. In general, once it was communicated to the construction worker why this process was being observed and the importance of his participation, he was positive about this activity. Effectively communicating the reasons for observing processes onsite was a key factor.

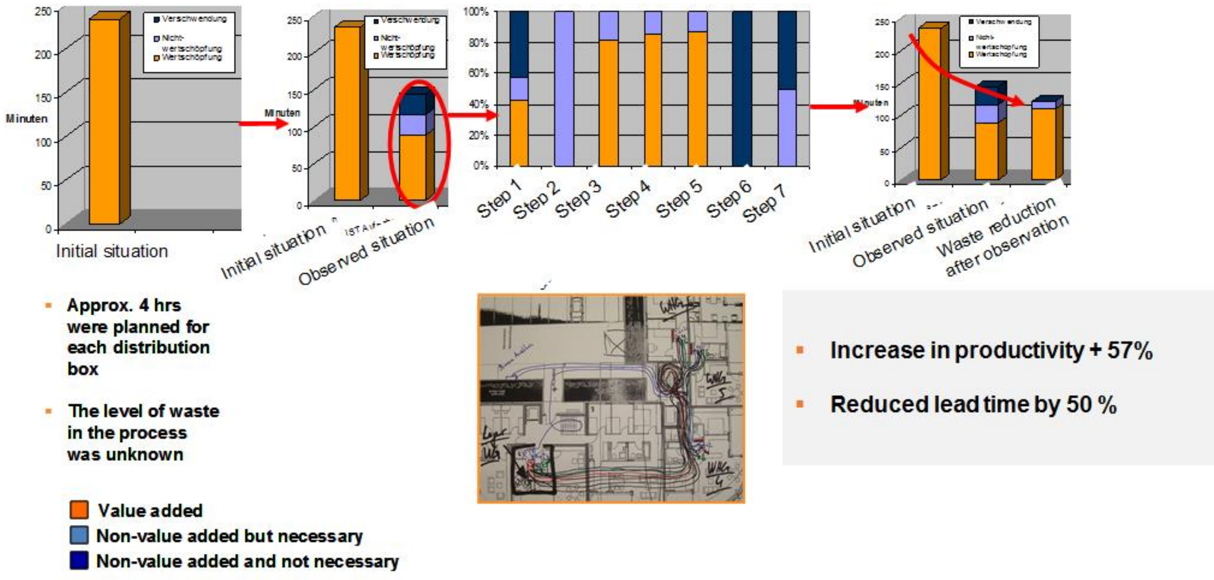


Figure C.1: Observation of the electrical assembly process

C.2 Improvement of the floor heating process

In addition, the process of installing floor heating in one apartment was observed in a similar way (Figure C.2). The initial observation was that all four workers could not begin their tasks as the contractor who had been in the apartment previously had left it in an unfit state for them to begin their work. Before the workers could begin they had to first sweep the floors and remove tape from the skirting boards that had been left there. These activities were non value adding activities and would have not been necessary had the previous contractor completed his work in a satisfactory manner (the quality control system in LCM prevents this since the foreman must review the work when finished). In general, there was a great deal of waiting observed in this process, gathering materials (each worker gathered his own materials individually) and walking around (see number 2 in Figure C.2). Four workers were involved in this process and it was observed that the process was uncoordinated and disorganised. There was a high level of non-value-added activities (both necessary and not necessary) identified (number 1 in Figure C.2).

The conclusion of the observation was that by reducing the walking, waiting and through better coordination of the team and better preparation, productivity could be improved by at least 25% on this process. (requiring a crew of 3 as opposed to 4, calculated on the basis that all of the non-value adding activities could be eliminated in the future).

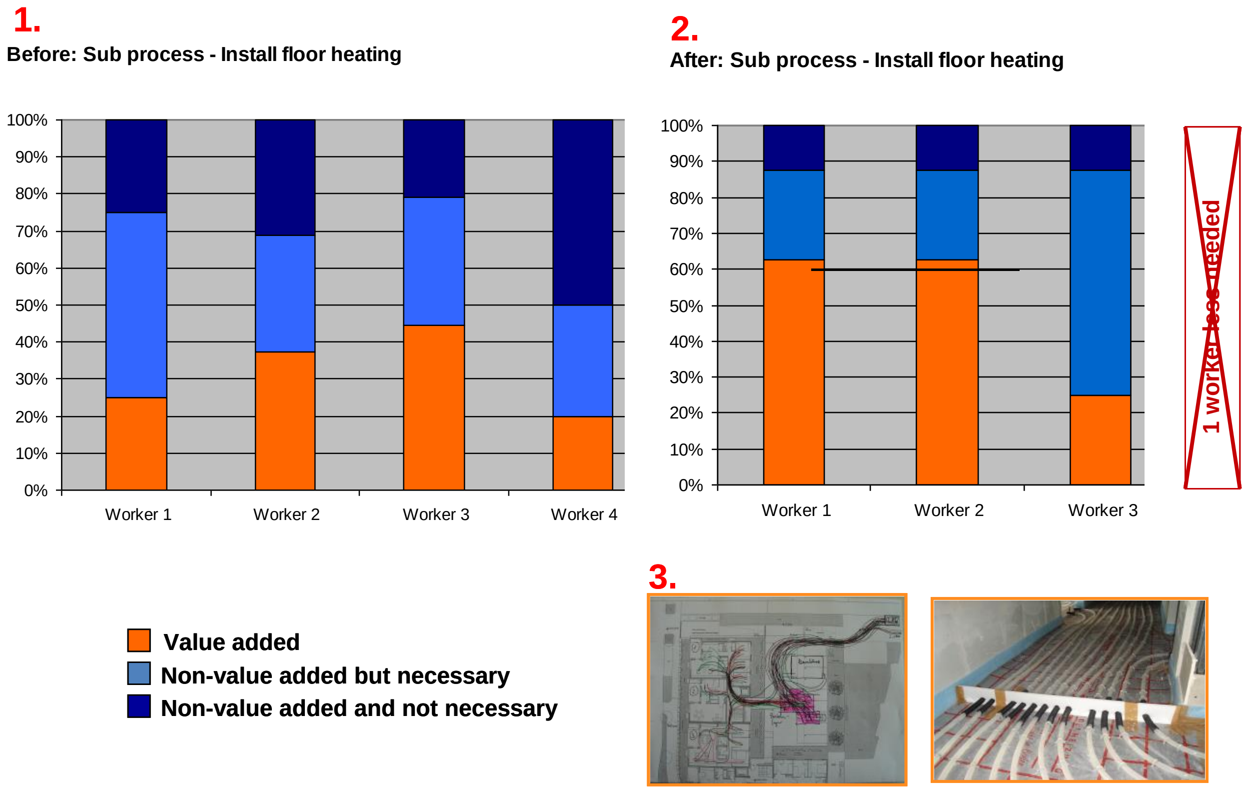
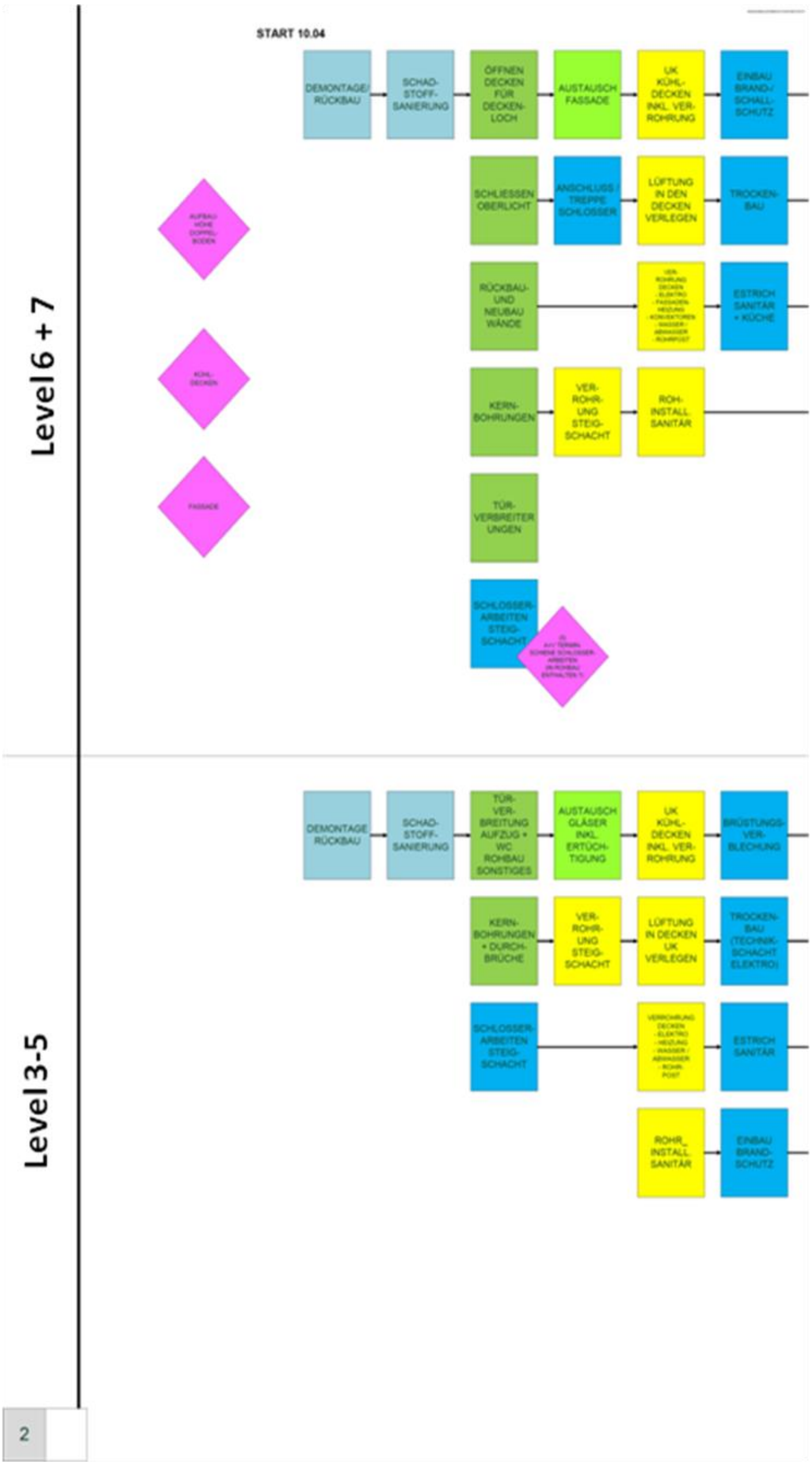


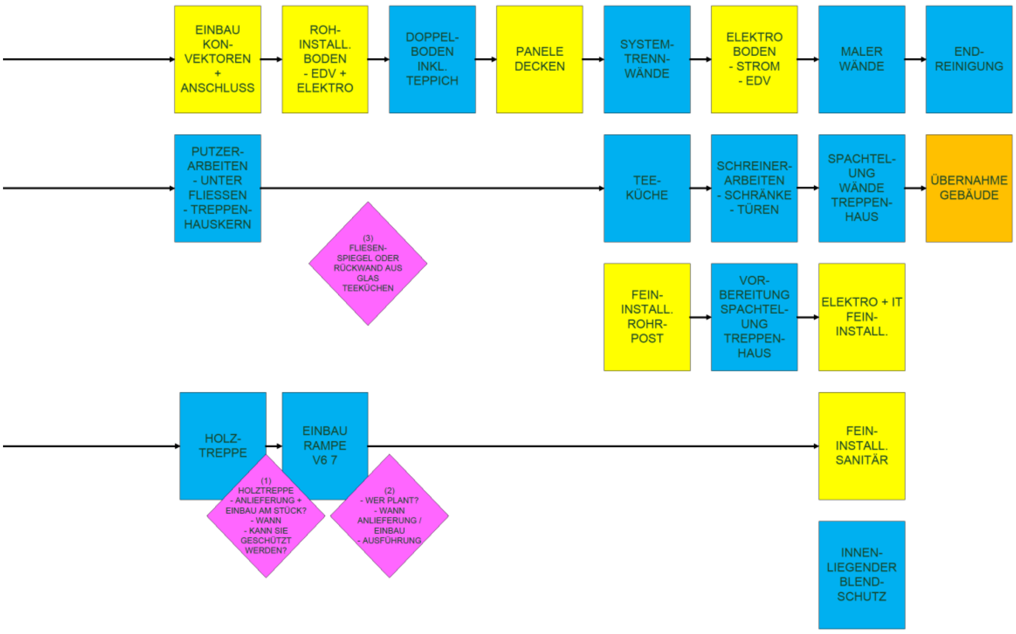
Figure C.2: Improvement of the floor heating installation process

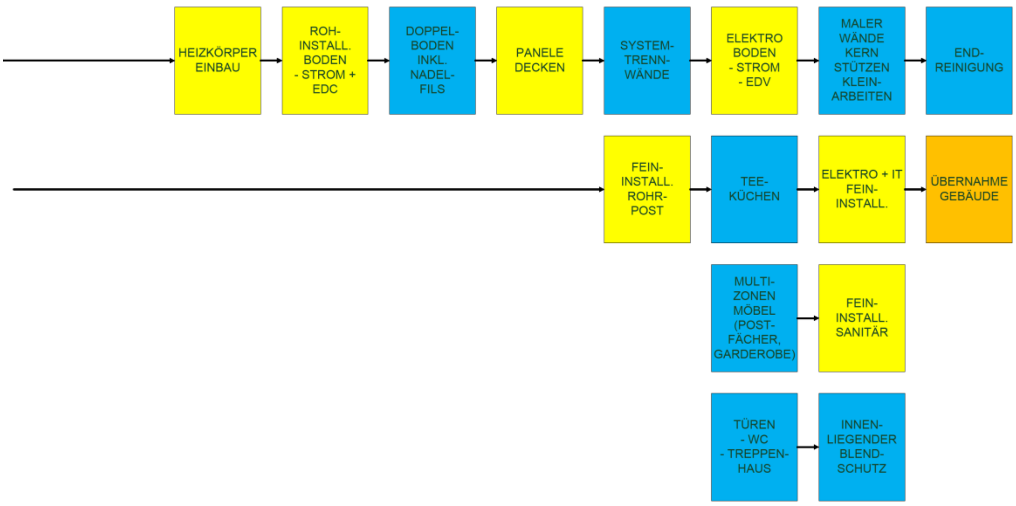
The above are just two examples of processes that were identified for observation and improvement during the LCM instantiation in case study 1. These sub processes were just two of many that could have been focused on and demonstrates the improvement possibilities on a small scale, that are identifiable if the construction process is transparent. It gives an insight into what could be achieved if visualising and observing processes was an integral part of the improvement process on a building site.

Appendix D: Example of Overall Process Map

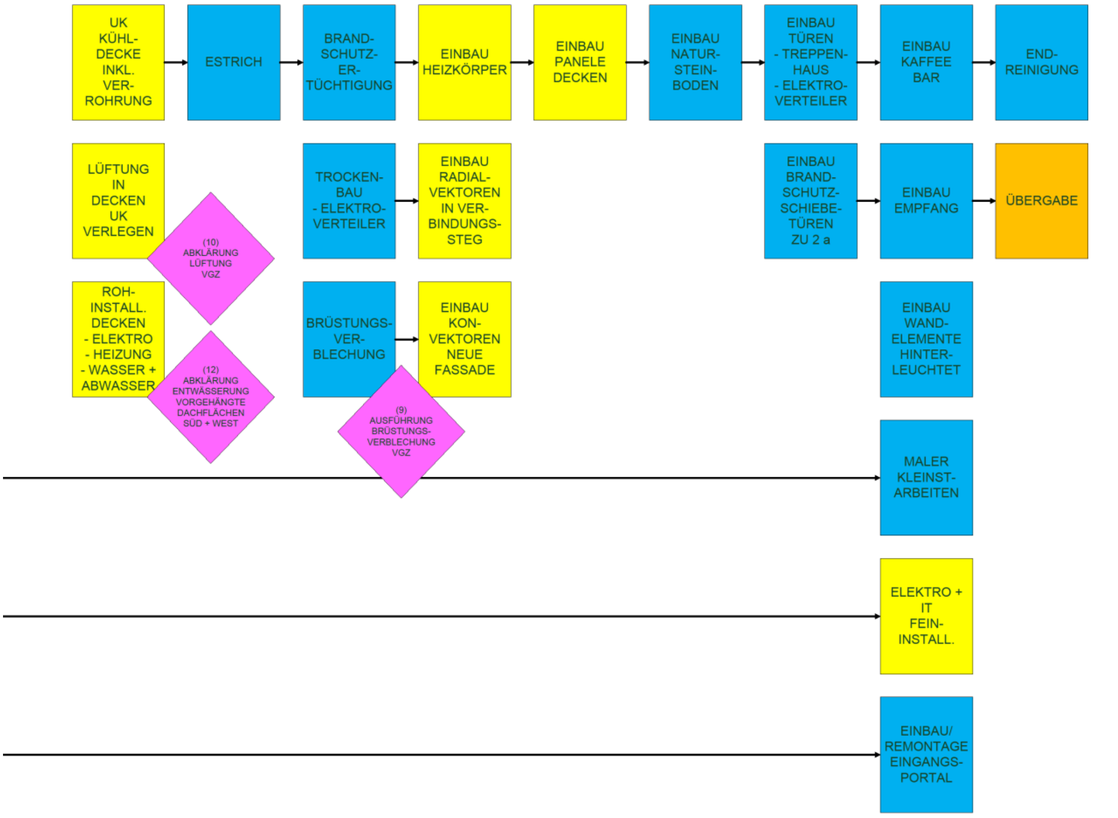
D.1 Example of section of OPA, instantiation 2B

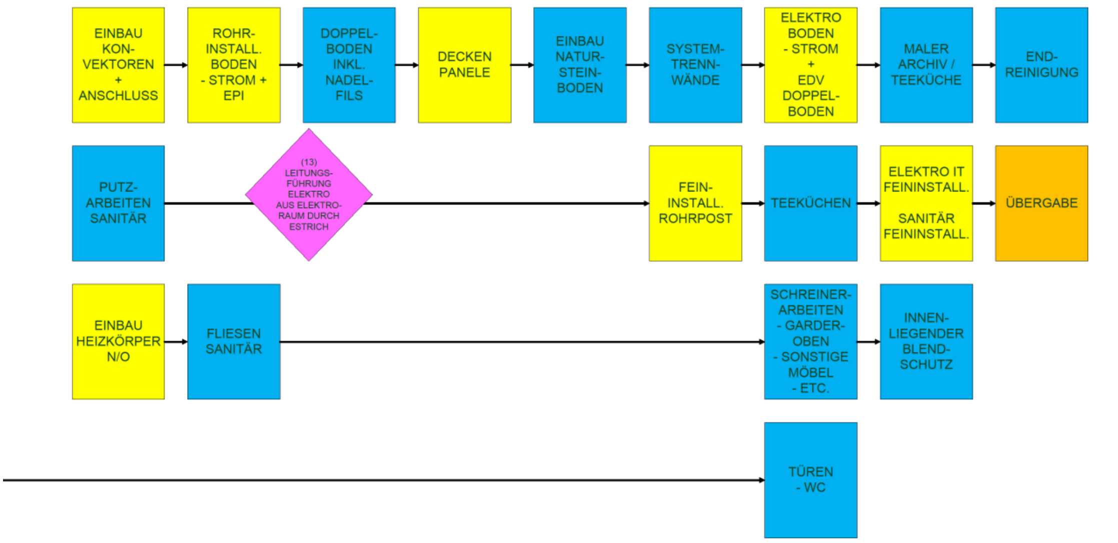


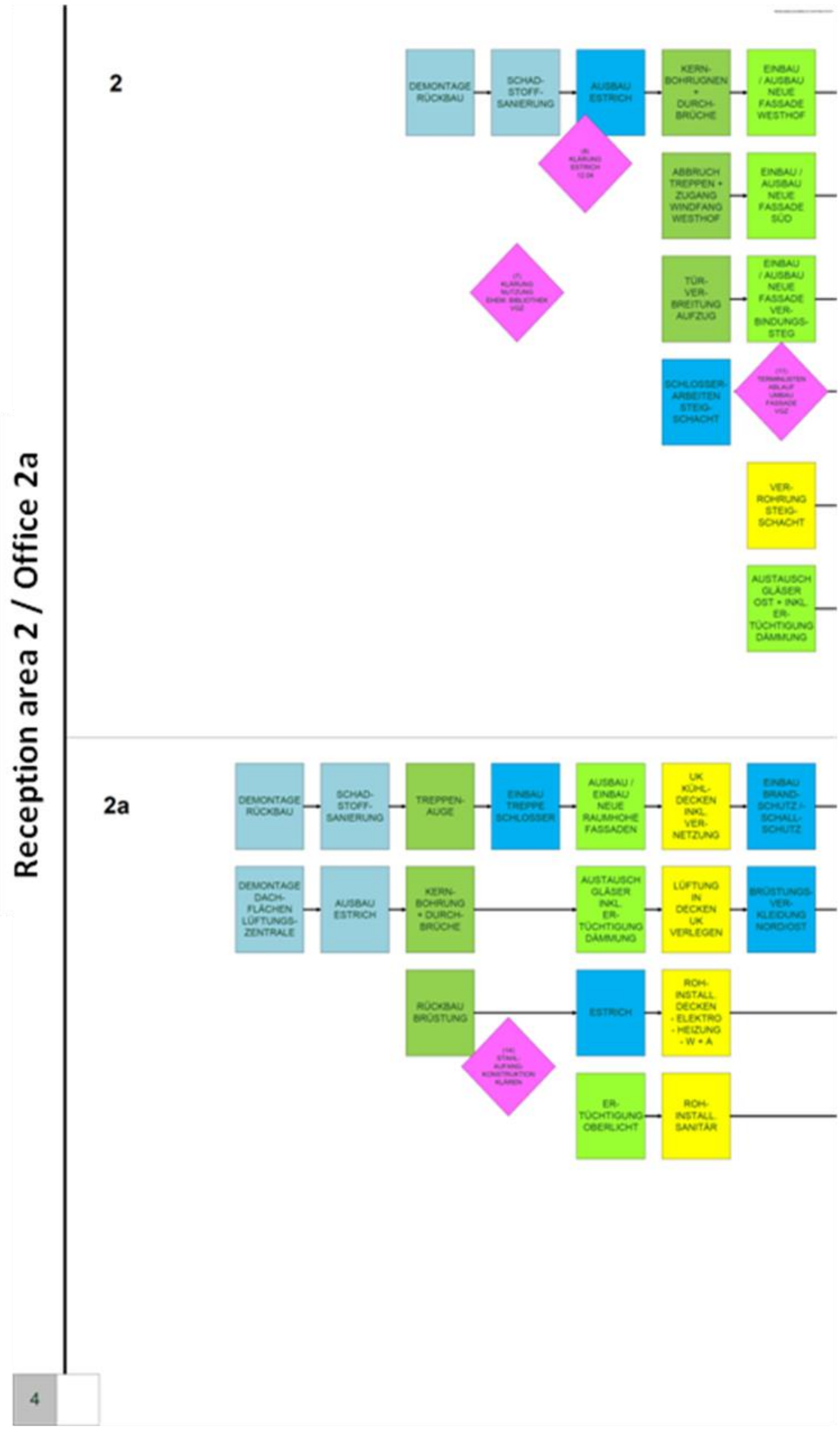

EINBAU KON- VEKTOREN + ANSCHLUSS
ROH- INSTALL. BODEN - EDV + ELEKTRO
DOPPEL- BODEN INKL. TEPPICH
PANELE DECKEN
SYSTEM- TRENN- WÄNDE
ELEKTRO BODEN - STROM - EDV
MALER WÄNDE
END- REINIGUNG
PUTZER- ARBEITEN - UNTER FLIESSEN - TREPPEN- HAUSKERN
TEE- KÜCHE
SCHREINER- ARBEITEN - SCHRÄNKE - TÜREN
SPACHTEL- UNG WÄNDE TREPPEN- HAUS
ÜBERNAHME GEBÄUDE
(3) FLIESEN- SPIEGEL ODER RÜCKWAND AUS GLAS TEEKÜCHEN
FEIN- INSTALL. ROHR- POST
VOR- BEREITUNG SPACHTEL- UNG TREPPEN- HAUS
ELEKTRO + IT FEIN- INSTALL.
HOLZ- TREPPE
EINBAU RAMPE V6 7
FEIN- INSTALL. SANITÄR
(1) HOLZTREPPE - ANLIEFERUNG + EINBAU AM STÜCK? - WANN - KANN SIE GESCHÜTZT WERDEN?
(2) - WER PLANT? - WANN ANLIEFERUNG / EINBAU - AUSFÜHRUNG
INNEN- LIEGENDER BLEND- SCHUTZ

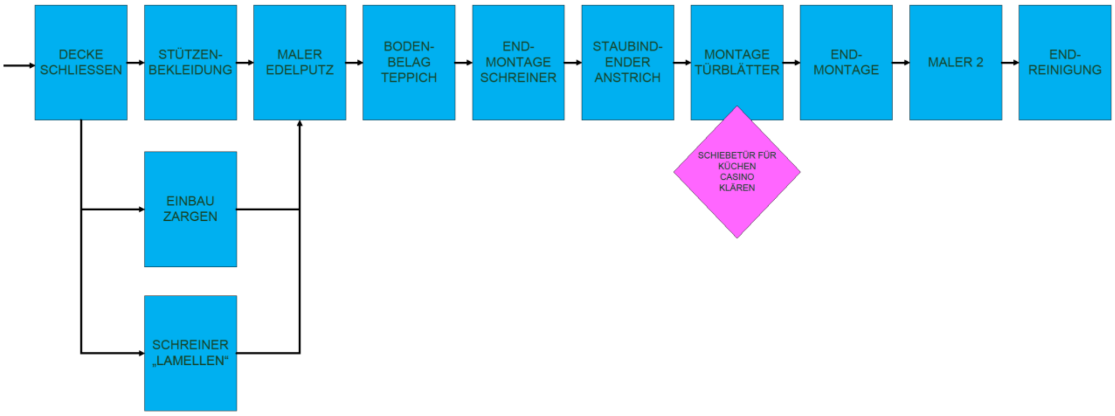

HEIZKÖRPER EINBAU
ROH- INSTALL. BODEN - STROM + EDC
DOPPEL- BODEN INKL. NADEL- FILS
PANELE DECKEN
SYSTEM- TRENN- WÄNDE
ELEKTRO BODEN - STROM - EDV
MALER WÄNDE KERN STÜTZEN KLEIN- ARBEITEN
END- REINIGUNG
FEIN- INSTALL. ROHR- POST
TEE- KÜCHEN
ELEKTRO + IT FEIN- INSTALL.
ÜBERNAHME GEBÄUDE
MULTI- ZONEN MÖBEL (POST- FÄCHER, GARDEROBE)
FEIN- INSTALL. SANITÄR
TÜREN - WC - TREPPEN- HAUS
INNEN- LIEGENDER BLEND- SCHUTZ

1


UK KÜHL-DECKE INKL. VER-ROHRUNG
ESTRICH
BRAND-SCHUTZ-ER-TÜCHTIGUNG
EINBAU HEIZKÖRPER
EINBAU PANELE DECKEN
EINBAU NATUR-STEIN-BODEN
EINBAU TÜREN - TREPPEN-HAUS - ELEKTRO-VERTEILER
EINBAU KAFFEE BAR
END-REINIGUNG
LÜFTUNG IN DECKEN UK VERLEGEN
(10) ABKLÄRUNG LÜFTUNG VGZ
TROCKEN-BAU - ELEKTRO-VERTEILER
EINBAU RADIAL-VEKTOREN IN VER-BINDUNGS-STEG
EINBAU BRAND-SCHUTZ-SCHIEBE-TÜREN ZU 2 a
EINBAU EMPFANG
ÜBERGABE
ROH-INSTALL. DECKEN - ELEKTRO - HEIZUNG - WASSER + ABWASSER
(12) ABKLÄRUNG ENTWÄSSERUNG VORGEHÄNGTE DACHFLÄCHEN SÜD + WEST
BRÜSTUNGS-VER-BLECHUNG
EINBAU KON-VEKTOREN NEUE FASSADE
(9) AUSFÜHRUNG BRÜSTUNGS-VERBLECHUNG VGZ
EINBAU WAND-ELEMENTE HINTER-LEUCHTET
MALER KLEINST-ARBEITEN
ELEKTRO + IT FEIN-INSTALL.
EINBAU/ REMONTAGE EINGANGS-PORTAL


EINBAU KON-VEKTOREN + ANSCHLUSS
ROHR-INSTALL. BODEN - STROM + EPI
DOPPEL-BODEN INKL. NADEL-FILS
DECKEN PANELE
EINBAU NATUR-STEIN-BODEN
SYSTEM-TRENN-WÄNDE
ELEKTRO BODEN - STROM + EDV DOPPEL-BODEN
MALER ARCHIV / TEEKÜCHE
END-REINIGUNG
PUTZ-ARBEITEN SANITÄR
(13) LEITUNGS-FÜHRUNG ELEKTRO AUS ELEKTRO-RAUM DURCH ESTRICH
FEIN-INSTALL. ROHRPOST
TEEKÜCHEN
ELEKTRO IT FEININSTALL.
SANITÄR FEININSTALL.
ÜBERGABE
EINBAU HEIZKÖRPER N/O
FLIESEN SANITÄR
SCHREINER-ARBEITEN - GARDER-OBEN - SONSTIGE MÖBEL - ETC.
INNEN-LIEGENDER BLEND-SCHUTZ
TÜREN - WC


Reception area 2 / Office 2a
2
DEMONTAGE RÜCKBAU
SCHAD-STOFF-SANIERUNG
AUSBAU ESTRICH
KERN-BOHRUGNEN + DURCH-BRÜCHE
EINBAU / AUSBAU NEUE FASSADE WESTHOF
ABBRUCH TREPPEN + ZUGANG WINDFANG WESTHOF
EINBAU / AUSBAU NEUE FASSADE SÜD
TÜR-VER-BREITUNG AUFZUG
EINBAU / AUSBAU NEUE FASSADE VER-BINDUNGS-STEG
SCHLOSSER-ARBEITEN STEIG-SCHACHT
VER-ROHRUNG STEIG-SCHACHT
AUSTAUSCH GLÄSER OST + INKL. ER-TÜCHTIGUNG DÄMMUNG
2a
DEMONTAGE RÜCKBAU
SCHAD-STOFF-SANIERUNG
TREPPEN-AUGE
EINBAU TREPPE SCHLOSSER
AUSBAU / EINBAU NEUE RAUMHOHE FASSADEN
UK KÜHL-DECKEN INKL. VER-NETZUNG
EINBAU BRAND-SCHUTZ / SCHALL-SCHUTZ
DEMONTAGE DACH-FLÄCHEN LÜFTUNGS-ZENTRALE
AUSBAU ESTRICH
KERN-BOHRUNG + DURCH-BRÜCHE
AUSTAUSCH GLÄSER INKL. ER-TÜCHTIGUNG DÄMMUNG
LÜFTUNG IN DECKEN UK VERLEGEN
BRÜSTUNGS-VER-KLEIDUNG NORD/OST
RÜCKBAU BRÜSTUNG
ESTRICH
ROH-INSTALL. DECKEN - ELEKTRO - HEIZUNG - W + A
ER-TÜCHTIGUNG OBERLICHT
ROH-INSTALL. SANITÄR
4


DECKE SCHLIESSEN
STÜTZEN-BEKLEIDUNG
MALER EDELPUTZ
BODEN-BELAG TEPPICH
END-MONTAGE SCHREINER
STAUBIND-ENDER ANSTRICH
MONTAGE TÜRBLÄTTER
END-MONTAGE
MALER 2
END-REINIGUNG
EINBAU ZARGEN
SCHREINER „LAMELLEN“
SCHIEBETÜR FÜR KÜCHEN CASINO KLÄREN

Appendix E: KPI data, case study 3

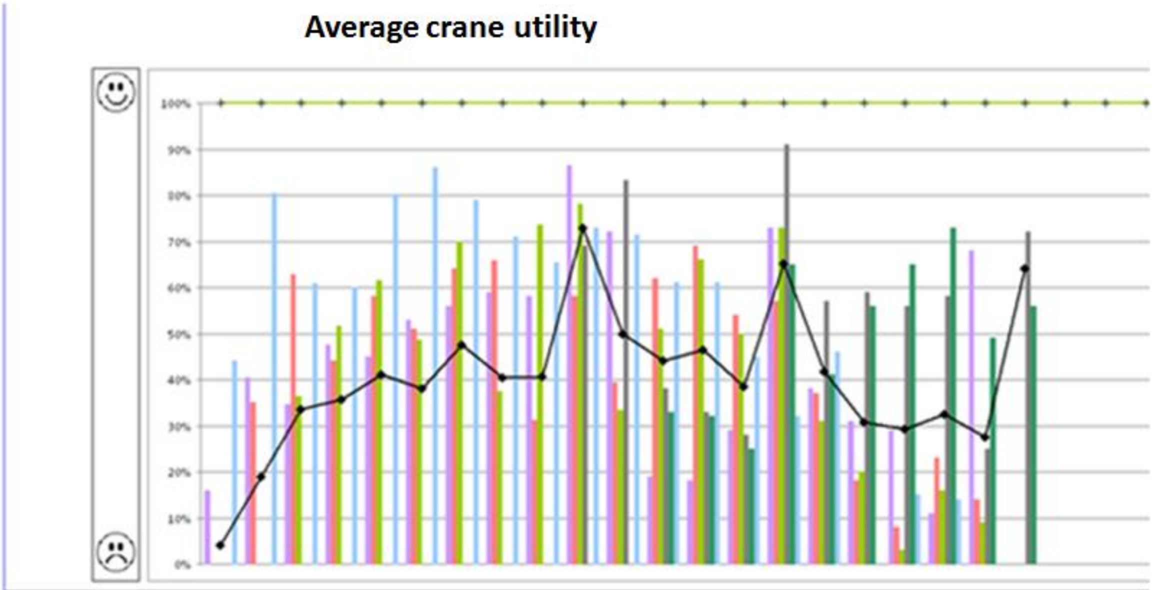
E.1 Findings from instantiations 3B-3E

The findings from the KPI data gathered on power plants B, C, D and E are presented in this section. Two important objectives of the LCM instantiations were to improve crane utility and to optimise buffer times through more realistic day to day planning of a transparent process. The main KPI's gathered to measure the effectiveness of the LCM model in improving crane utility and the quality of commitments, were On-Time-Performance and crane utility. Like in case study 1 and 2, On-Time-Performance was a measurement of how many cards were turned "green" per day compared to the total of cards that should be turned green. This metric highlighted any deviations to plan on a daily basis. The cards visualised were based on an optimised process focusing on the use of identified buffer times and an optimised lead time. The reasons for a low on-time-performance were also gathered so that actions could be defined to eliminate these in the future.

The crane utility was a measurement of how much time the crane was actively in use, was waiting or was used for an additional activity. This metric highlighted how efficiently the cranes were being used and indeed, highlighted the time that crane could not be used i.e. as a result of weather related conditions that could not be influenced.

E.2 KPI data gathered during instantiation 3B, power plant B

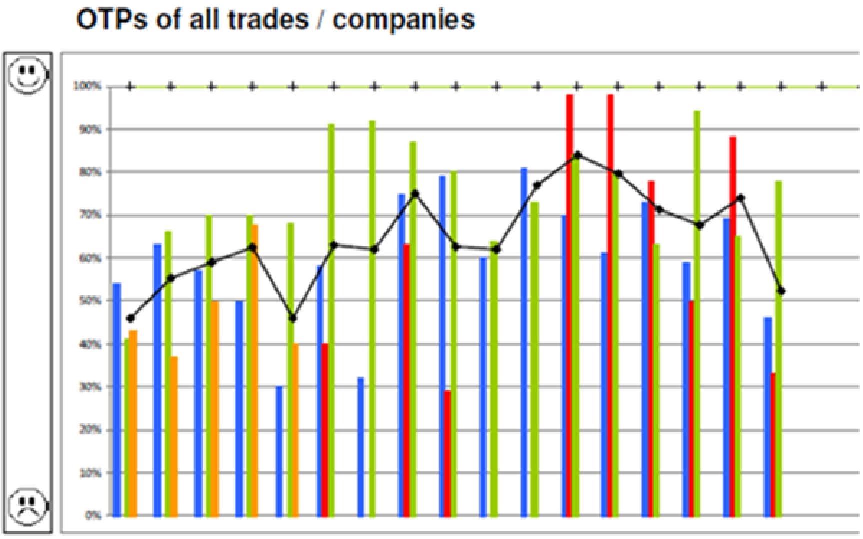
During instantiation 3B at power plant B, KPI data was gathered on crane utility, On-Time-Performance and reasons for low On-Time-Performance. One finding that could be noted from the KPI data at power plant B (Figure E.1) is that the overall crane utility improved from 4% to approx. 65% in the 21 week observation period. The transparency of what work was planned where and what cranes were available, led to a more efficient use of this resource. On review of the crane data, there was no further detailed information available on the crane downtime. The only further observation was that all cranes were never used at the same time. There were 3-4 workers who operated all cranes which meant that it was impossible to have full utility of all cranes at the same time (hence the maximum utility could not be 100%). According to the LCM manager, 6 cranes were needed to reach all areas of the plant but it was unclear as to whether this was the most effective and feasible solution.



Week	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
Average	4%	19%	33%	36%	41%	38%	48%	41%	41%	73%	50%	44%	47%	39%	65%	42%	31%	29%	33%	28%	64%		
Crane 1	16%	41%	35%	48%	45%	53%	56%	59%	58%	86%	72%	19%	18%	29%	73%	38%	31%	29%	11%	68%	-		
Crane 2		35%	63%	44%	58%	51%	64%	66%	31%	58%	39%	62%	69%	54%	57%	37%	18%	8%	23%	14%	-		
Crane 3		0%	36%	52%	62%	49%	70%	37%	74%	78%	33%	51%	66%	50%	73%	31%	20%	3%	16%	9%	-		
Crane 4										69%	83%	38%	33%	28%	91%	57%	59%	56%	58%	25%	72%		
Crane 5											0%	33%	32%	25%	65%	41%	56%	65%	73%	49%	56%		
Crane 6	44%	81%	61%	60%	80%	86%	79%	71%	65%	73%	71%	61%	61%	45%	32%	46%	0%	15%	14%	0%	-		
Target	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure E.1: Overview of crane utility, Plant B

Figure E.2 below shows the overall OTP % of the subcontractors at plant B over a 17 week observation period. A positive trend can be noted in the on-time performance: from the lowest levels of approx. 46% to reaching higher performance levels of up to over 80% within the 17 week timeframe (Figure E.2). The reasons for a low On-Time-Performance were gathered and a summary of these are illustrated E.3. At plant B, the data shows that almost a quarter of the reasons for a low OTP were weather related, followed by 20% due to “a lack of co-ordination / information”. This usually occurred when the site manager could not participate in the LCM process 100% due to time constraints and also due to the absence of the LCM manager which was also reflected. 10 % of the reasons for a low OTP % were due to missing components for assembly at the plant (Figure E.3).



Week	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Average	46%	55%	59%	63%	46%	63%	62%	75%	63%	62%	77%	84%	80%	71%	68%	74%	52%	
Company A	54%	63%	57%	50%	30%	58%	32%	75%	79%	60%	81%	70%	61%	73%	59%	69%	46%	
Company B						40%	-	63%	29%	-	-	98%	98%	78%	50%	88%	33%	
Company C	41%	66%	70%	70%	68%	91%	92%	87%	80%	64%	73%	84%	80%	63%	94%	65%	78%	
Company D	43%	37%	50%	68%	40%	-	-	-	-	-	-	-	-	-	-	-	-	
Target	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure E.2: Overview OTP of assembly companies, Plant B

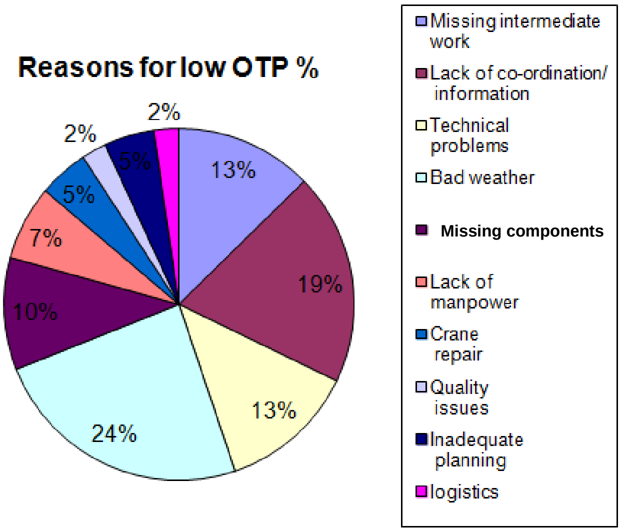
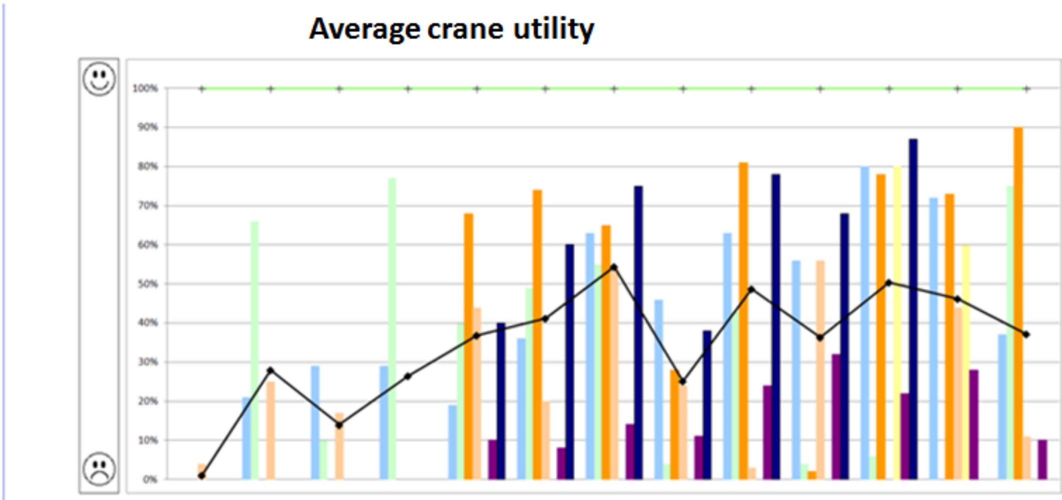


Figure E.3: Reasons for low OTP, Plant B

E.3 KPI data gathered during instantiation 3C, power plant C

KPI data on crane utility, reasons for crane downtime, On-Time-Performance and reasons for low On-Time-Performance were gathered during LCM instantiation C at power plant C. Power plant C was divided into two blocks: block D and block E. The On-Time-Performance of each of these blocks was measured individually.

With regard to crane utility at block D during an observation period of 13 weeks, the KPI data shows that the first three weeks of the observation time showed a low crane utility of under 30% (Figure E.4). From week 34 to 38 a steady increase in utility from 14% to 54% could be noted (Figure E.4). From week 38 to 39 there was a sudden decrease from 54% to 25% and from then on an increase to between 40 and 50% with some fluctuation for the remaining 5 weeks (Figure E.4). The reasons for the decreases in crane utility figures are shown in Figure E.5 below. Over 60% of the reasons for the crane downtime were as a result of weather and technical issues which are difficult to influence (Figure E.5). 25% of the downtime was due to missing components that hadn't arrived.



Week	32	33	34	35	36	37	38	39	40	41	42	43	44
Average	1%	28%	14%	27%	37%	41%	54%	25%	49%	36%	50%	46%	37%
Crane 1	-	21%	29%	29%	19%	36%	63%	46%	63%	56%	80%	72%	37%
Crane 2	-	66%	10%	77%	40%	49%	55%	4%	43%	4%	6%	0%	75%
Crane 3	-	-	-	-	68%	74%	65%	28%	81%	2%	78%	73%	90%
Crane 4	4%	25%	17%	0%	44%	20%	54%	24%	3%	56%	0%	44%	11%
Crane 5	-	-	-	-	-	-	-	-	-	-	80%	60%	?
Crane 6	-	-	-	-	10%	8%	14%	11%	24%	32%	22%	28%	10%
Crane 7	-	-	-	-	-	-	-	-	-	-			
Crane 8	-	-	-	-	-	-	-	-	-	-			
Crane 9	-	-	-	-	40%	60%	75%	38%	78%	68%	87%	?	?
Target	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure E.4: Overall crane utility at plant C, block D

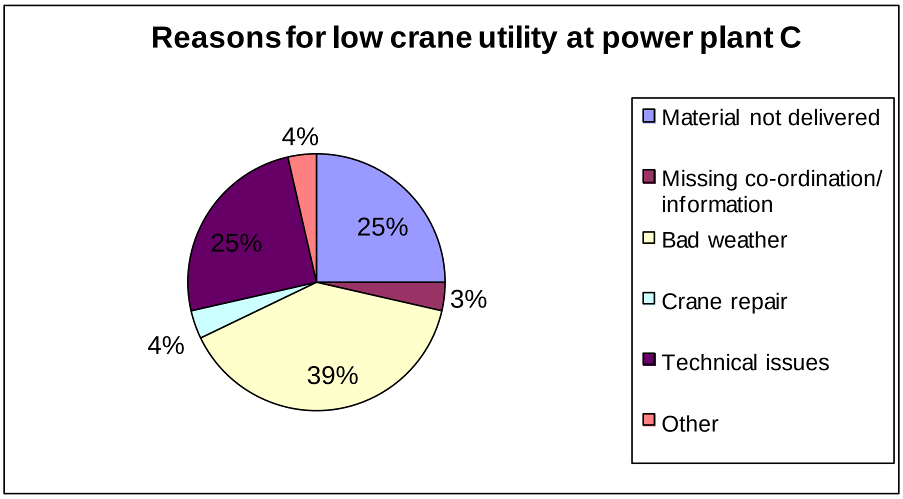
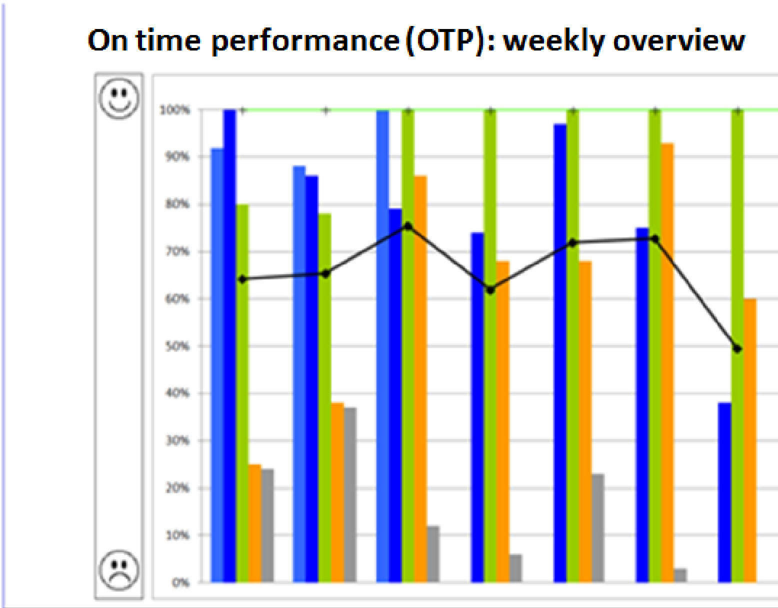


Figure E.5: Reasons for low crane utility at power plant C, Block D

The KPI data on On-Time-Performance over a 7 week period gathered from block D shows that the average OTP % was at approximately 66% during the observation period of 7 weeks (Figure E.6). The biggest drop in OTP % was between week 43 and week 44 where the largest deviation was noted at 23% (Figure E.6). It can be noted from the KPI data that the OTP % was stable for 6 of the 7 weeks during the observation period. The reasons for the drops in the OTP % during the observation period were analysed and the results illustrated in Figure E.7 below. As was the case at power plant B, 25% of the reasons for the drops in the OTP % were due to missing components (Figure E.7). A further 27% of reasons were due to bad weather which cannot be influenced (Figure E.7). In addition, at this plant, a further challenge that led to a drop in the OTP % was the lack of manpower: on some occasions, workers were taken from block D and sent to block E and vice versa. This led to worker capacity issues at different times in both blocks.



Week	38	39	40	41	42	43	44
Average	64%	65%	75%	62%	72%	73%	50%
Company A	92%	88%	100%	-	-	-	-
Company B	100%	86%	79%	74%	97%	75%	38%
Company C	80%	78%	100%	100%	100%	120%	100%
Company D	25%	38%	86%	68%	68%	93%	60%
Company E	24%	37%	12%	6%	23%	3%	0%
Target	100%	100%	100%	100%	100%	100%	100%

Figure E.6: On Time Performance, Plant C, Block D

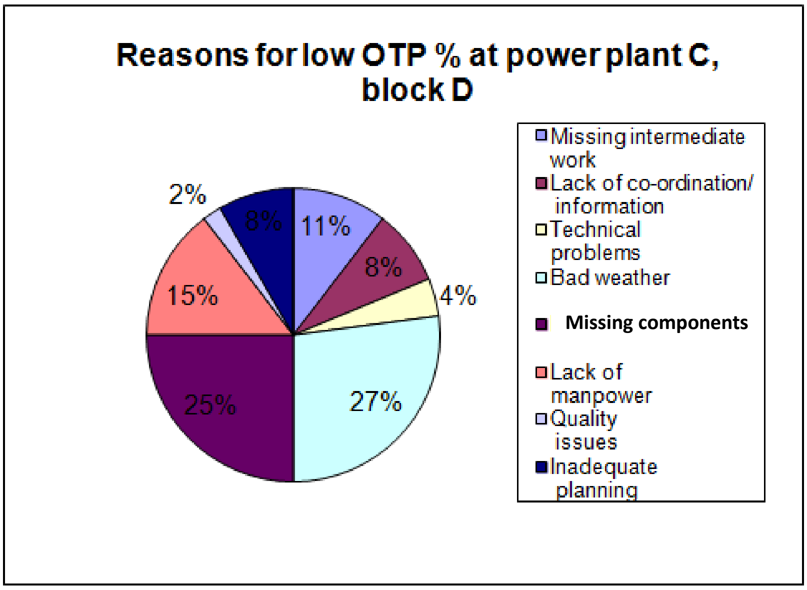
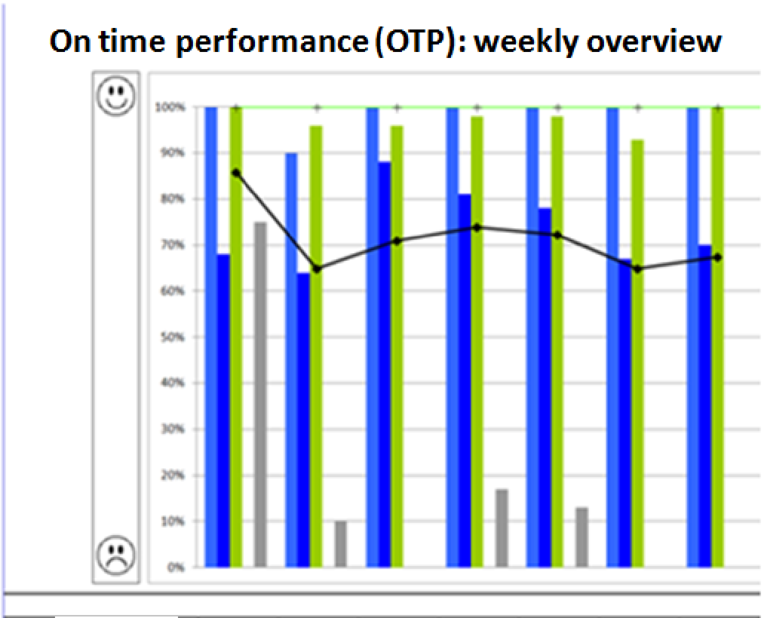


Figure E.7: Reasons for low OTP, Plant C, block D

At plant C, block E, the average OTP % was at 73% during the observation period of 7 weeks (Figure E.8). Similar to the data presented above, a relatively stable OTP % was noted during this time, with the largest drop being in the first week from 86% to 65% (Figure E.8). The reasons for the drop in the OTP % are illustrated in Figure E.9 below. It can be noted here that 39% of the reasons for the drop in the OTP was also due to missing components and 29% was as a result of a shortage of manpower brought about by the exchanges of manpower between the two blocks. In total almost 70% of the reasons for a drop in OTP are as a result of these two factors.



Week	38	39	40	41	42	43	44
Average	86%	65%	71%	74%	72%	65%	68%
Company A	100%	90%	100%	100%	100%	100%	100%
Company B	68%	64%	88%	81%	78%	67%	70%
Company C	100%	96%	96%	98%	98%	93%	100%
Company D	-	-	-	-	-	-	-
Company E	75%	10%	0%	17%	13%	0%	0%
Target	100%	100%	100%	100%	100%	100%	100%

Figure E.8. OTP, Plant C, Block E

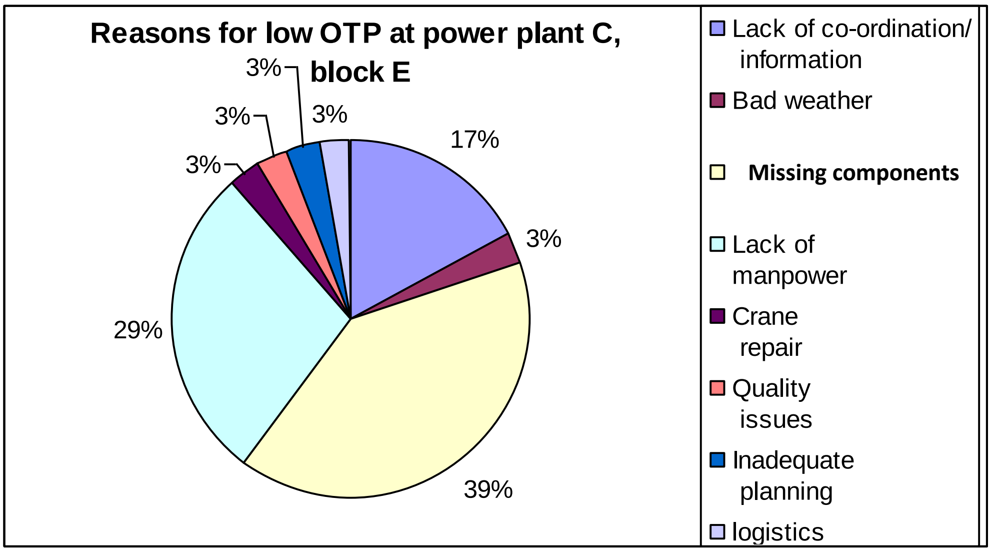
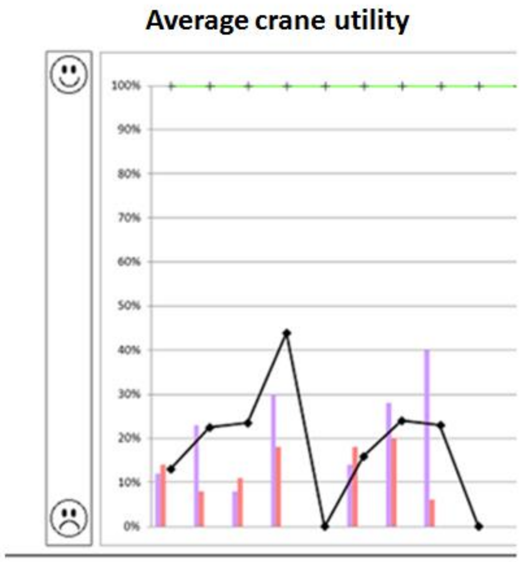


Figure E.9: Reasons for low OTP, Plant C, Block E

E.4 KPI data gathered during instantiation 3D, power plant D

During the instantiation 3D, data on crane utility, reasons for low crane utility, OTP and reasons for low On-Time Performance were gathered at plant D (Figures E.10-E.13). For the first 4 weeks, an increase in crane utility from 13 % to 44% can be noted (Figure E.10). A sharp fall to 0% in week 16 and a rise to 24% in the following weeks can also be noted from the diagram (Figure E.10). As illustrated in Figure E.11, over 60% of the downtime was due to bad weather and technical issues. While the weather cannot be influenced and it is difficult to foresee technical issues that occur, this could be an area for further development of the LCM model in future studies: how could the LCM elements be improved to better identify technical issues that occur in power plant construction?



Week	13	14	15	16	17	18	19	20	21
Average	13%	23%	24%	44%	0%	16%	24%	23%	0%
Crane 1	12%	23%	8%	30%	0%	14%	28%	40%	0%
Crane 2	14%	8%	11%	18%	0%	18%	20%	6%	0%
Crane 3									
Crane 4									
Crane 5									
Crane 6									
Target	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure E.10: Crane utility, Plant D

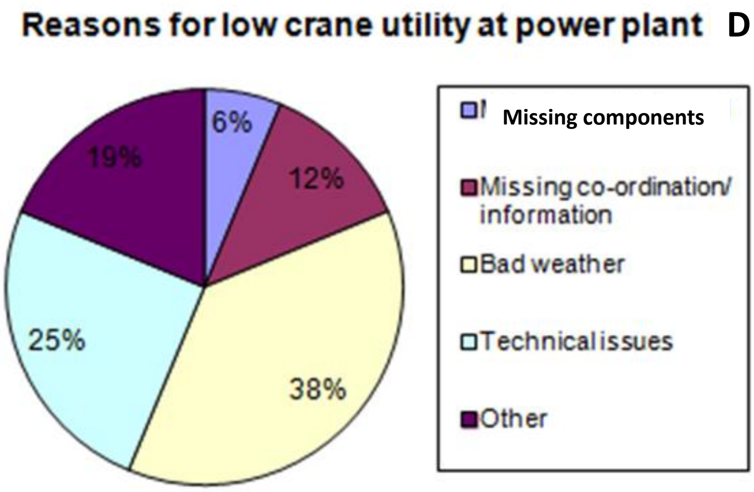
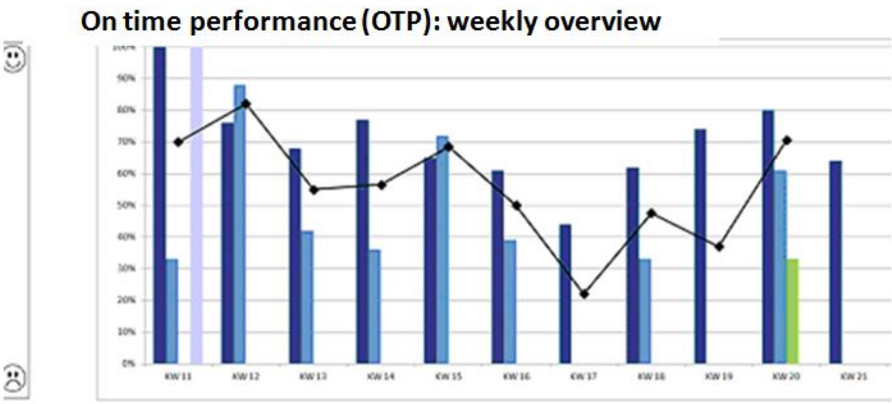


Figure E.11: Reasons for low crane utility, Plant D

The OTP at power plant D was also observed and data was gathered over a period of 11 weeks during the LCM instantiation. It fluctuated from its highest point in week 12 at 82% to its lowest point of 22% in week 17 (Figure E.12). 50% of the reasons for bad performance were inadequate planning and a lack of co-ordination, as is shown in Figure E.13. Similar to the other power plant sites, it was noted that if the site manager did not participate 100% in the LCM instantiation process and the LCM manager was also absent from the site, the incidents of “inadequate planning” and “a lack of co-ordination” contributing to a low OTP % were much higher.



Week	KW 11	KW 12	KW 13	KW 14	KW 15	KW 16	KW 17	KW 18	KW 19	KW 20	KW 21
Average	70%	82%	55%	57%	69%	50%	22%	48%	37%	71%	49%
Company A	107%	76%	68%	77%	65%	61%	44%	62%	74%	80%	64%
Company B	33%	88%	42%	36%	72%	39%	0%	33%	0%	61%	33%
Company C										33%	50%
Target	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Figure E.12: OTP, plant D

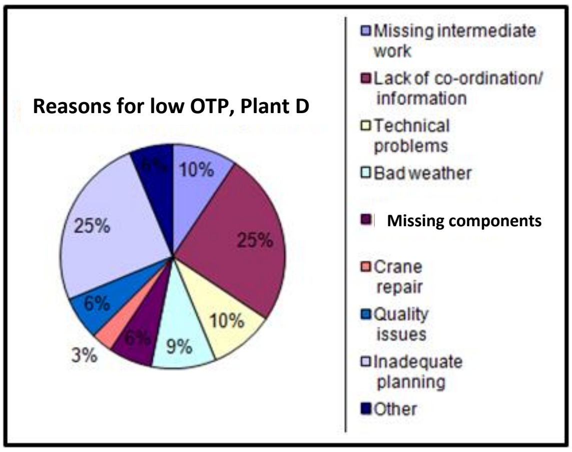
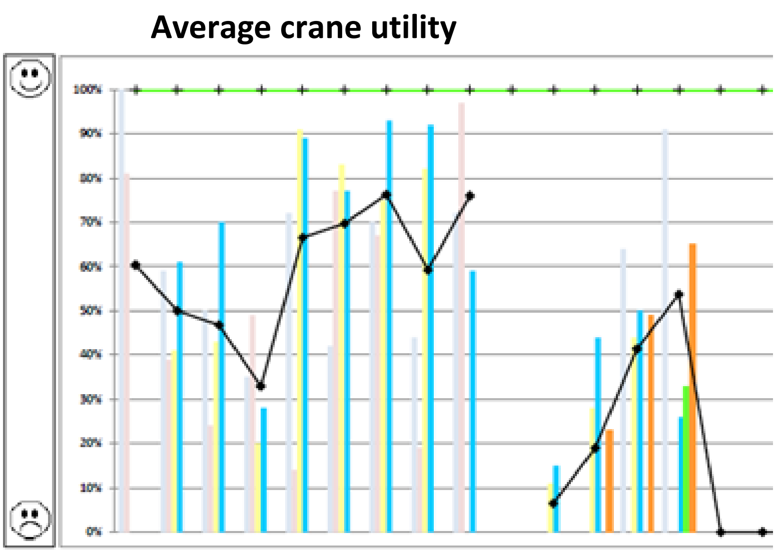


Figure E.13: Reasons for low OTP, plant D

E.5 KPI data gathered during instantiation 3E, power plant E

During instantiation 3E, data was gathered on crane utility, On-Time-Performance and reasons for low on-time-performance for a period of 12-15 weeks (Figures E.14-E.16). In general, a positive trend in the overall utility of the cranes can be noted (from week 45-48 and from weeks 1-4) at power plant B during an observation period of 15 weeks (Figure E.14). However a low crane utility in week 45 and a large drop from week 50 to week 1 can be noted (Figure E.14). There is no data available on reasons for the low level of utility in week 45 for the large drop in week 50, but according to the LCM manager it was weather and holiday related coming up to the Christmas period.

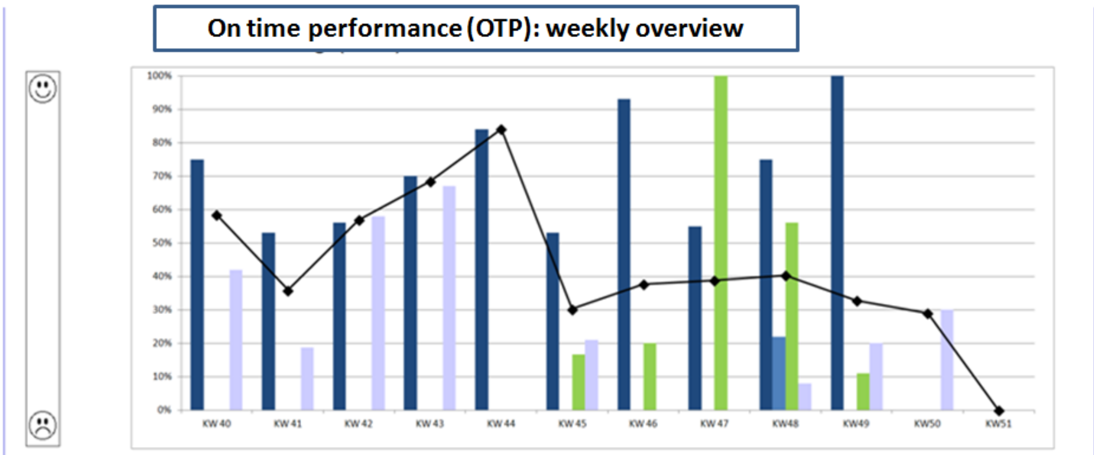


Week	42*	43*	44	45	46	47	48	49	50	52	1	2	3	4	5	6
Average	60%	50%	47%	33%	67%	70%	76%	59%	76%		7%	19%	41%	54%	0%	0%
Crane 1	100%	59%	50%	35%	72%	42%	70%	44%	72%	-	0%	0%	64%	91%		
Crane 2	81%	39%	24%	49%	14%	77%	67%	19%	97%	-	0%	-	-	-		
Crane 3	0%	41%	43%	20%	91%	83%	75%	82%	-	-	11%	28%	44%	-		
Crane 4	-	61%	70%	28%	89%	77%	93%	92%	59%	-	15%	44%	50%	26%		
Crane 5	-	-	-	-	-	-	-	-	-	-	-	0%	0%	33%		
Crane 6	-	-	-	-	-	-	-	-	-	-	-	23%	49%	65%		
Target	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure E.14: Overall crane utility, Plant E

At power plant E, a positive trend in the OTP % can also be noted between week 41 and 44 (Figure E.15). There was a sharp decrease in the OTP % of the subcontractors at power plant

E from 84 % in week 44 to 29 % in week 50 (Figure F.15). Also from week 45 to 48 a slight increase in the OTP % can be noted (Figure E.15). The reasons for the sharp drop in the OTP % and decreases in the OTP % by the subcontractors in power plant E were also analysed and are presented (Figure E.16). It can be noted that the largest issue was as a result of missing components 30%, followed by 28% of reasons as a result of inadequate planning (Figure E.16). As mentioned at the beginning of this chapter, the process of defining, sourcing suitable components and having it delivered on-time proved to be a huge challenge in power plant construction. The KPI data showed this to be a recurring problem on all sites. This problem was due to a number of reasons: material was sourced from other countries which added to the uncertainty of delivery dates and since engineering was sometimes carried out parallel to construction, the material that arrived was often no longer suitable, had to be sent back or reworked. While the LCM instantiation improved the communication between engineering and construction and in turn the material issues according to the LCM manager, it is apparent from the data that it couldn't completely eliminate the issue.



Week	KW 40	KW 41	KW 42	KW 43	KW 44	KW 45	KW 46	KW 47	KW48	KW49	KW50	KW51
Average	59%	36%	57%	69%	84%	30%	38%	39%	40%	33%	29%	0%
Company A	75%	53%	56%	70%	84%	53%	93%	55%	75%	100%	-	
Company B								0%	22%	0%	0%	
Company C						17%	20%	100%	56%	11%	57%	
Company D	42%	19%	58%	67%	-	21%	0%	0%	8%	20%	30%	0%
Target	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

* On-Time-Performance

Figure E.15: On Time Performance, Plant E

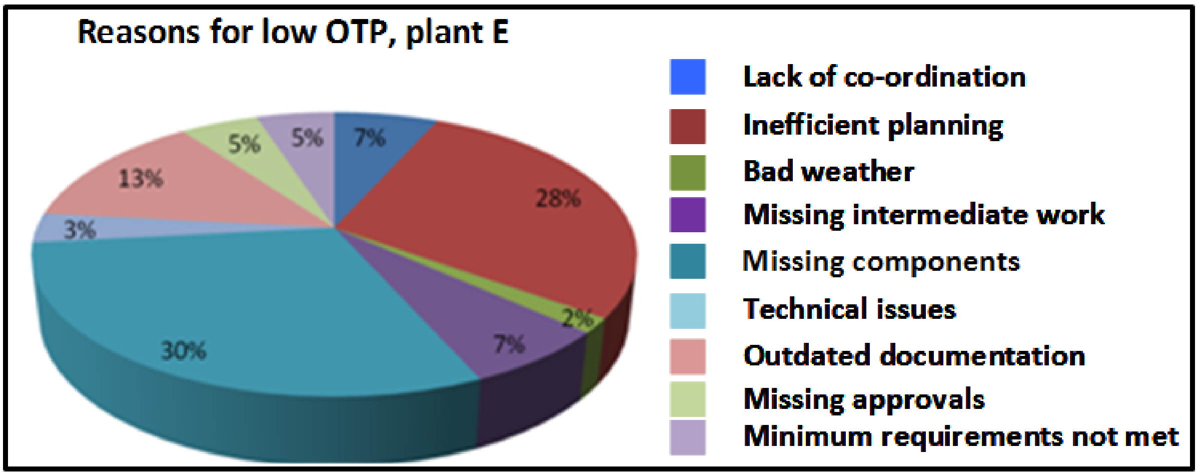


Figure E.16: Reasons for low OTP, Plant E

Appendix F: Relationship LCM and existing visual concepts

F.1 Tezels taxonomy and LCM

Table F.1: How elements of Tezel's (2011) taxonomy are evident directly in the LCM model

	Tezels Visual Management Taxonomy	Key traits	LCM element	How the LCM element demonstrates Tezels classification
1	Site Layout and Fencing	Provide transparency by making processes observable (Koskela, 1992)	LCM area	The actual LCM area is a clearly marked central communication area at the construction site. Clear information on work areas, companies involved, work packages, work in progress, planned work, performance measurements and constraints are visualised.
2	Standardisation of the workplace elements	Creation of standards for site elements: eg coloured helmets identifying crews, clear transportation routes for material	Contruction card, Apartment clock, colour-coded plans with numbering specifiying areas	The construction card is a way of standardising a work package that can be completed in one day. This is also a way of being able to identify which company is responsible for which work (company logo and assigned colour). The apartment clock in solution 1, is also a means of identifying a "process area" or "work station" on site. The hand of the clock displayed the current status of the construction process. In solution 2, the work areas are highlighted using different colours and visualised on the plan in the LCM area.
3	Pull production through the Kanban	Use of Kanban cards and colour-coding to control material	Construction card and planning board	The construction cards planned for the day, introduced a pull production philosophy for both completing daily work and for ordering material. The cards planned each week were small daily batches of work that were part of an overall standard process which reflected the optimal flow of work. Only when the cards were created would work be planned (by inserting the card in the pockets of the construction board) and in turn material required for that work could be ordered (in solution 2 the material order date is specified in the process planning). This controlled the amount of work planned in a 2-4 week timeframe.
4	Production levelling through Heijunka board	Levelling the load	Construcion card and planning board	The construction cards and the planning board were used to elimmate work being carried out in "large batches" in areas but rather, the work was spread out according to the defined flow and pull system.
5	In-station quality (Jidoka) through Andon	Indicating abnormalities using lights	Apartment clock, colour-coded plans, construction cards	Regular quality checks are an important element of the LCM system. The construction worker turns the construction card around to the green side to indicate to the Forman to check for quality. When quality problems arose, the Forman would turn the card back around to indicate he was dissatisfied with the quality of the work. He would then highlight in red what needed to be improved. This system, involving mainly the use of coloured cards, helped to prevent mistakes from spreading to other areas.
6	Visual signs	visual tools underlining desirable practices	"coloured faces" for KPI's, construction cards	Visual signs showing a happy face when KPI's were improving and a sad face when the performance had disimproved are displayed on the information board. The construction cards were also prepared showing a "stop" sign or "no entry" to indicate areas that cannot be accessed at a particular time onsite.
7	Visual work facilitators	Guide on how to carry out task	Construction cards, planning board, information board (KPI's, Action plan, role description), logistics board, checklist	The elements of LCM are all visual elements designed to facilitate the work of individual contractors, the construction workers and the foreman. The construction cards and the construction board were used to plan and visually display work to be carried out. The information board and and the logistics board displayed relevant information on a number of important aspects which influenced the execution of work in a positive way for example, the action plan, KPI's, information on storing and location of material etc. A checklist, which was also a type of a visual work facilitator, was used by the foreman to help him keep track of the agreed current work and that for the coming weeks. This checklist was usually used by the forman alone but was distributed to the contracting companies and served as a type of summary of the previous meeting. I
8	Performance management through visual management	Making progress transparent	Visualisation of KPI's,	A central element of LCM is the gathering and visualising of KPI's on the information board. Daily progress on quality and task completion are monitored and made transparent for all to see. The suppliers name and logo are displayed so this generates an added sense of responsibility if performance is dissatisfactory. If the KPI is satisfactory a green happy face is displayed and if not a red sad face was displayed.
9	Distributing system wide information	Readily available information on the wider construction process	Logistic cards, logistic board, construction cards, construction board, the process planning tool, the information board	There are a few examples of this type of visual management evident in LCM. One such example is the information displayed on the logistics board which indicates when a particular material should be delivered and where it should be stored. The logistic cards represent resources such as cranes and lifts that are in use. Likewise, the construction card displays the detailed information and location of the construction activity that should be carried out on that particular day. The process planning tool visualised in the LCM area gives an overview of the planned parallel work and the contraints that need to be removed. The information board itself, which is an important physical element of LCM, displays information on KPI's, improvement actions that are being implemented and any other relevant information on important milestones or facts that concerns the construction project (e.g. new contractors, new workers, events etc..).
10	Human resources management	Use of visual tools to organise and identify worker crews	Construcion cards, planning board	The planning board itself was a means of organising the work and workforce on the building site. By preparing the construction cards for the construction board, the work and its location was planned and communicated to the workforce and all persons, on a highly visual board at a central area on the construction site.

Table F.2: How Tezel's classifications are evident indirectly in the LCM model

	Tezels Visual Management Taxonomy	Key Traits	Element indirectly resulting from LCM instantiation	How the LCM element demonstrates Tezels classification
11	Site Layout and Fencing	Provide transparency by making processes observable (Koskela, 1992)	Floor markings	There are some examples of this visual management characteristic as a result of LCM implementation. One example is the use of floor marking to section off individual areas to store material that is being delivered onsite. The logistics board is used to visualise where these areas were located and floor markings were used to physically section off these areas.
12	5S	Order and standardisation	Designated material storage areas, less clutter	The overall organisation of the site is improved through use of LCM - less clutter on site and designated spaces for only material that is needed. As a result of the action plan in LCM, problems are resolved in a more timely manner which also improved the physical organisation of the site.
13	Prototyping	Visual standard	Visualisation of end product (eg: how electrical wires should be installed)	Prototyping was used mainly to visually demonstrate how the end product of a process should look to prevent quality problems. It was not a direct element of LCM but was developed as an improvement action to combat quality problems within the process.
14	Improvisational visual management	Visual indicators in written form eg: markings, notes	Floor markings, blocked off areas	As part of the improvement measures as a result of LCM to organise the material on the site, floor markings were applied manually to indicate where individual suppliers could leave their material.
15	Poke-Yoke	Eliminate mistakes	Blocked off areas with "X"	Some examples of Poke Yoke were used as improvement measures to combat issues identified in the LCM process. For example, it was a problem that workers would enter areas where floors and plaster were drying and in some circumstances this would have to be redone. Using the notion of "Poke-Yoke" to remove the likelihood of this happening, the entries to these areas were closed off with an "X" in the doorway so that entry was physically not permitted. The planning board itself can be described as type of poke-yoke as the chance of placing two many crews in the same area is elimminated (only a certain amount of cards can be placed in the slots).

F.2 LCM and the Toyota Production System

As explained in chapter 2, Lean tools such as Kanban, Heijunka, VSM, Andon, Poke Yoke which are the core elements of the LCM model, are visual in nature. Kanban is a visual indicator and a visual signal (Galsworth, 1997) that is used to realise pull-production in small batches (Monden, 1998). It is a visual indicator since it relays information (on cards) with the intention of influencing behaviour (only the specified quantity on the cards should be delivered. Kanban is also a visual signal since certain types of Kanban systems use visual stimuli to attract attention (i.e.: an empty container signals more material / parts are needed). Andon is a visual signal which indicates that there is a problem in the workflow. In the LCM model, the use of colour on the visual tools is a visual signal indicating problems, unfinished work, finished work etc and could be compared to the function of an Andon system in manufacturing. A Heijunka board is a visual indicator which relays information of what quantities should be produced when so that production is levelled and inventory is kept at a minimum. Poke-yoke is a type of visual guarantee since it is a mistake-proof device, designed to make sure that only the right thing can happen without speaking a word. Finally, a value stream map visualises material and information flow (Liker, 2004).

There are a number of ways in which the LCM model can contribute to and relate to the literature presented in Chapter 2. First of all, the LCM model is a collection of visual tools from the Toyota Production System (TPS), the constructs of which are based on the Lean principles of Value, Value Stream, Flow, Pull, Perfection (Chapter 2, Section 2.2). The planning board itself is a type of Kanban system, controlling the volume of work entering the construction process. The planning board is filled with cards, similar to Kanban cards, which display the information on what should be "produced" where, in what quantity and by whom. The planning board is also a type of Heijunka system, since it intends to level the load of construction work coming into the process. Rather than completing large sections in one area, the work is spread out according to the optimal flow which is defined as part of the process. The idea of Andon, is also evident throughout the LCM model. The green side of the card indicates completed work and the cards with stop signs indicate no entry into a certain area for example. Red and green faces indicate whether metrics are satisfactory or not and different colours and logos are used to represent different subcontractors. Finally, the slots of the board limit the amount of cards that can be placed in any area at a particular time which can be compared to a type of poke yoke system. However this not considered to be a particularly good example of a poke-yoke system since it does not completely eliminate error and the event of the wrong card being placed in the wrong slot.

The LCM model also provides an example of how a number of visual Lean tools can be applied together in a systematic way to achieve a broader application of Lean on construction sites. It addresses the importance of considering the entire system when implementing Lean tools, as opposed to the application of individual tools to isolated areas.

F.3 LCM application of tools defined by Galsworth

The Visual Indicator

The Visual Indicator relays information in the hope of influencing behaviour (Chapter 2, Section 2.5.1). Each of the elements of LCM model represents an example of a Visual Indicator. The planning board is a visual indicator since it provides a framework for visualising information on all of the planned daily work over a 2-4 week timeframe. The construction card itself that is displayed on the planning board is also a visual indicator since it indicates who will complete what, this week and where this work will take place. This vital information is essential for the day to day running of the construction site. The Key Performance Indicators are an example of a Visual indicator which is used for control purposes. Data for KPI's, such as quality and on time performance are gathered by the foreman, displayed and discussed at the weekly site meeting.

When noted that KPI's were not developing in the desired way, actions are defined to make improvements so this information is being used to control a better result. The action plan is also a visual indicator and a visual control since it documented these improvement actions, displayed who was responsible for their implementation and specified a target date. If the target date is not reached, questions are asked until finally the improvement action is implemented. The apartment clock / coloured-plans are also examples of a visual indicator, since they display information on what work is being carried out at a certain place by a certain company. This information is displayed at the actual area of work (in the case of the apartment clock). The information board and the logistics board are further examples of visual indicators: the information board displays information on KPI's, improvement actions and other relevant to the site, while the logistics board displays information as to where material should be stored onsite. Finally, the construction checklist (case study 1) is a type of visual indicator for the foreman himself: it provides him an overview of where work is being carried out and by whom on a daily basis (without having to go to the planning board). The foreman uses the checklist on his rounds as a guideline to where work should be checked on that particular day.

The Visual Signal

The Visual Signal attracts attention by using visual stimuli (Chapter 2, Section 2.5.1). The visual signal is also evident throughout the LCM model. The planning board gives out a signal to the construction worker and foreman by using colour coded cards. At a glance, one can see if the cards are on the planning board or not (if they are not on the planning board and are hung on the colour-coded plans, this signals work in progress), if the cards are displayed on the green side on the board, this signals that work has been completed, has been checked and meets the expected quality standards. If stop signs are displayed this signals to all the areas where work should not be carried out (perhaps due to a drying process). The construction card itself is the actual visual signal of this system. The apartment clock / colour-coded plan is also an example of a visual signal, again using the construction card. When work is in progress, the construction card is hung on the apartment clock (or colour-coded plan) at the area of work indicating work in progress. When the card is hung on the apartment clock / colour-coded plan green side up, this signals to the foreman that the construction worker is finished and the work can be inspected. Should the work not meet the quality standard, the foreman turns the card back around, indicating that there is work to be redone and he then highlights in red on the apartment clock (or action plan) notes of what must still be completed. The information board is also a visual signal since it displays KPI's and other information. The KPI's have a green happy face when they are developing in a positive manner and a red unhappy face when they are not. This gives a signal as to the general progress on the site. Finally, the logistics board and site layout can also be considered to be a visual signal. They signal which resources are available and which are in use.

The Visual Control

The Visual Control enforces almost complete human control (Chapter 2, Section 2.5.1). The planning board is also a type of visual control system. It displays only the work that should be completed in a specified timeframe and only that work can commence. It thus limits the amount of work that can be carried out at any one time. Likewise the construction card itself is a visual control as it specifies a particular job to be completed by a designated company on a given day. The construction checklist (case study 1) used by the foreman is a type of visual control since it indicates to the foreman which work should be checked on that particular day.

The apartment clock / colour-coded plan is another example of visual control: it limits focus to that area of work only and that quantity of work scheduled for that day. If the foreman identified problems in the quality these were noted and rectified immediately. Finally the logistics board is also a type of visual control. It displays in colour which spaces onsite are available to store material and in turn these are marked out onsite to make sure only this space is used.

The Visual Guarantee

The Visual Guarantee strives to eliminate human error (Chapter 2, Section 2.5.1). Visual guarantee is not strongly evident in the LCM model. Since the process is mainly manual, mistakes can be made (especially cards being lost, which perhaps surprisingly, have not been an issue on any of the sites). However, the slots on the planning board do provide a type of poke yoke system, only allowing a limited number of cards in a particular area on the board. However, this does not guarantee that the correct card will be placed in the slot and so is not considered to be a good poke-yoke example. Table 8.3 in section 8.7 presents an overview of how each of the elements of the LCM model represent more than one of the visual tools defined by Galsworth (1997).

Application of Galsworth and Tezel's ideas with LCM

The above section discusses how the visual tools defined by Galsworth (1997) and those identified as part of Tezel's research work (2011) can be applied together in a holistic way during an LCM instantiation. This demonstration also illustrates the relationship between the visual tools identified by Galsworth (1997) and Tezel (2011). Table F.3 illustrates the relationship between the different elements of the LCM model and the categories identified by Galsworth (1997) and Tezel (2011). 14 visual tools identified by Tezel (2011) can be identified directly and indirectly (Table F.1 and F2) as part of the LCM model.

Table F.3: Relationship between elements of LCM model and categories identified by Tezel and Galsworth.

	1	2	3	4	5	6	7	8	9	10
LCM	***Overall process map***	***Process planning tool***	***Construction board***	***Construction card***	***Key Performance Indicators***	***Action plan***	***Construction checklist***	***Apartment clock***	***Information board***	***Logistics board***
Galsworth	Visual Indicator	Visual Indicator Visual Signal Visual Control	Visual Indicator Visual Signal Visual Control Visual Guarantee	Visual Indicator Visual Signal Visual Control	Visual Indicator	Visual Indicator	Visual Indicator Visual Control	Visual Indicator Visual Signal Visual Control	Visual Indicator Visual Signal	Visual Indicator Visual Signal Visual Control
Tezel	9	9	3,4,7,9,10	1,2,3,4,5,7,10	6,7,8	9	7	2,5	9	7,9