IMPROVEMENT OF CONSTRUCTION PROCESS BY ADOPTING LEAN CONSTRUCTION PRINCIPLES: A CONSTRUCTION MODEL DEVELOPMENT

by

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A thesis submitted to the University of Birmingham for the degree of

DOCTOR OF PHILOSOPHY

Department of Civil Engineering

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June 2021

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Abstract

Lessons learned from the construction industry have shown that adopting lean principles within construction processes can significantly enhance the overall success of a construction project. However, currently the potential benefits of such an approach are still not being fully realised in a uniform way. The application of lean principles in construction projects has an underlying aim to increase the value of projects and to eliminate construction waste, in order to achieve project targets of time, cost, and quality while reducing damage to the environment consistent with the underlying principles of sustainable development. This research project presents a newly developed framework that contains a set of lean methods and techniques to support the application of lean principles to construction project practice. In so doing the method helps those within the construction industry to more consistently achieve the full benefits that lean construction approaches can offer.

The aim of this research project is to investigate the lean construction techniques currently used in the industry and the principles of lean construction applications, particularly, the problems and challenges, and develop a new construction process model in which lean methods/tools can be integrated. This will provide an effective and efficient way for managing construction projects in the construction industry. A parallel aim is to improve the construction process to better manage construction waste, time and cost and to improve the levels of quality and sustainability achieved. The adaptation of lean principles with identified enablers has been assessed where a combination of different lean principles and techniques were considered as the main enablers to develop a framework for the construction process. The RIBA Plan of Work was used to integrate and incorporate several lean construction principles and techniques to develop a standardised model where both the construction stages and the associated activities of the construction process in projects can be described.

The underlying philosophy of the developed framework is to increase the efficiency of transformation activities (known as value-adding activities – processing). The innovative construction process models presented in this research are developed based on the core enablers that can be used to identify and eliminate waste in the construction process. These include set-based concurrent engineering (SBCE) integrated with the Last Planner® System (LPS) and lean thinking (LT) within traditional construction process activities. A number of

measurement and control methods and guidelines for implementation of the framework are presented. In addition, case study materials have been collected from the industry in order to test and validate the framework. The results provide useful information and guidance to the construction industry as a whole.

The novelty and contribution to knowledge of the research includes: improvement of construction process and performance through the development and implementation of an integrated lean-enabled pull flow construction process framework (i.e. pull flow control embedded within lean construction management) integrated with measurement and control methods within the RIBA Plan of Works. The research concludes by suggesting that the most effective way to implement lean methods and techniques in construction activities is to use the framework proposed and developed in this research which is integrated with the RIBA Plan of Work.

Dedication

This work is dedicated to Mahyar, Moonia, Kobra Fariba and Kazem.

The road to success is always under construction.

Acknowledgements

I would like to herewith express my sincere gratitude to Dr. Dexter Hunt and Professor Ian Jefferson, the supervisors of this study, for their valuable guidance and assistance provided for the successful accomplishment of this research. Throughout the research project, they have given me informative instruction, patient guidance and precious comments on my research. I have learnt valuable lessons in the process of this research study, which are important for my future study and career. I would like to thank them for their guidance and support throughout the PhD course.

I would like to give my appreciation to the practitioners, academicians and fellow students who provided me useful data, in-depth explanation and comprehensive information for my study.

I would like to thank Dr. Simon Blakey for his guidance and support during the final stages of this journey.

This thesis was copy edited for conventions of language, spelling and grammar by Anne O'Connell. I would like to thank her for proof reading of this thesis.

Finally, I would like to thank my family, Kazem, Fariba, Mahyar and Moonia, for their love, encouragement, patience and support in all of my endeavours in my life.

Mahsa Heidar Barghi

Birmingham, June 2021

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1 INTRODUCTION

1.1 Introduction

The application of lean principles in construction projects aims to increase the value of the projects and eliminate construction waste to achieve the project targets of improving quality and reducing construction time and cost, all of which is achieved whilst reducing damage to the environment – consistent with the underlying principles of sustainable development. This is exemplified most effectively by the Velodrome project, constructed as part of the 2012 Olympic Games (ICE, 2011).

This research project presents a new framework model that contains a set of lean methods and techniques to support the application of lean principles to construction project practice. This will help enablers to overcome the barriers to existing construction process models which have been met with mixed success (Latham, 1994) and which are discussed later within this thesis. A combination of this proposed framework model which consists of a number of different lean methods and techniques, for consideration / application at different points in the construction process are incorporated into The RIBA Plan of Work leading to a holistic fully integrated tool of lean methods and techniques embedded chronologically to construction activities. Measurement and control methods have been developed in this study to control and manage cost, time, quality, and sustainability, which are all crucial to the success of construction projects – in both the short and long term. Recommendations are given to improve the implementation of lean construction in the construction process. Prior to this research, although lean construction techniques had been developed, there were still many problems related to how and when to apply these techniques in construction practices. The major reason for this is typically a lack of effective implementation framework/guidelines/methodology and control measures. In addition, many of the traditional construction process models currently used in the industry cannot be used efficiently and effectively, particularly, when lean methods and techniques are applied. A suitable form of integration is required, a key resonating philosophy of this research.

This study investigates the lean construction techniques currently used in the industry and the principles of lean construction applications, particularly, the problems using lean

construction techniques regarding project planning, construction waste management, project changes, risk and uncertainty management. New lean methods/tools that overcome these problems will be developed in this study, to provide an effective and efficient way of managing construction projects. Based on the findings from this research project, a new framework model and guidelines for the implementation of lean construction in the construction industry will be developed and case study materials will be collected from the industry to test and validate the new development. The results produced from this research will provide useful information and guidance to the construction industry.

The construction industry is one of the largest and most important industries in the world (Mahmoud and Scott, 2002; Salem et al., 2006). Traditional planning methods have been used to manage construction time, cost, and quality as well as sustainability of construction projects, but the problems and challenges remain when using traditional planning methods. Lean production in the construction industry may be one of the solutions to solve these kinds of problems (Alarcón, 1997).

Lean production aims to use less of everything, on site, to reduce time and cost overruns (Koskela, 2000, 2017). The green shoots for developing lean principles arose in the early 1900s, when overnight Henry Ford transformed car production by introducing the principle of the assembly line (Mossman, 2009). In a similar way, Engineer Ohno and Toyoda (1950s) developed the primary plan and coined the term lean production. According to Womack and Jones (1996) and Howell (1999), Taiichi Ohno, known as the father of the Toyota Production System, tried to find ways (through a lean ideology) to add value to the whole production system by removing waste or 'muda'. A new approach to manufacturing, the Toyota Production System (TPS) was subsequently introduced (Jacobs, 2010; Koladiya, 2017) to produce more with fewer resources. The improvement is focused on eliminating non-value-adding activities known as flow activities and to make conversion or value-adding activities more efficient. To demonstrate the nature of waste reduction, time and cost in TPS, the concept of 'lean' was adopted (Womack et al., 1990).

According to Bertelsen (2004), Lukowski (2010) and the Lean Construction Institute (2012), this approach was readily adapted within the manufacturing industry; however, it required numerous time-consuming techniques to be implemented within construction

projects. Further, Green and May (2005) stated that lean construction and lean production are "*variously understood as a set of techniques, a discourse, a 'socio-technical paradigm' or even a 'cultural commodity'* (p. 503)". Howell (1999), Lim (2008) and the Lean Construction Institute (2012) all showed that lean is about minimising waste, reducing cost and finishing the project on time, to increase value and to meet the client's requirements.

To differentiate this theoretical foundation from pure production activities, the term 'lean thinking' was adopted (Koskela, 1992, 2000; Sarhan and Fox, 2013). Herein, Koskela (1992) formulated the transformation–flow–value generation model of production, which is known as the TFV theory of production, which improve performance once applied to construction. According to Koskela (1992, 2000) lean thinking is a philosophy based on the concepts of lean production – *to improve the efficiency and quality of the UK construction industry*. Two organisations which are continuously working on the development of lean thinking in the construction industry are:

- Lean Construction Institute (LCI) in the US and
- International Group for Lean Construction (IGLC) in the UK.

Many researchers have stated that implementation of lean construction in projects can lead to many benefits and advantages (e.g. Koskela, 1992; Jorgensen and Emmitt, 2008; Lim, 2008; Abdullah et al., 2009; Bajjou and Chafi, 2018a).

Marhani et al. (2012, 2013) presented a list of key concepts of lean construction within the construction process, derived from the work of Koskela (1992), showing the interaction with the construction phases of preparation, design, pre-construction, construction and use. The need to integrate the two more fully has been identified by several researchers, including Abdelhamid (2003), Bertelsen (2004), Constructing Excellence (2004), Summers (2005), Mohd Yunus (2006), Salem et al. (2006), George and Jones (2008), Pepper and Spedding (2009), Seppanen et al. (2010), Puvanasvaran et al. (2011) and Small et al. (2011).

According to Jones (1996), lean construction is: "*A way to do more & more with less & less – less effort, less equipment, less time & less space – whilst providing customers with exactly what they want*".

Nowadays, construction projects have become more complex and customers expect more. The concept of lean thinking presents a new idea for preparation and supervision of the construction process with a focus on value for the customer and waste elimination (Abdelhamid, 2003; Alinaitwe, 2009; Al-Aomar, 2012; Khan, 2012; Heidar Barghi, 2013; AlSehaimi et al., 2014). Lean thinking has both positive and negative impacts on the environment. As the main goal of lean construction is improving customer prospects, an embedded sustainability vision therefore requires customers to value and ask for sustainability to be considered. The environmental feature of construction is now embedded by sustainability, not least the requirement to reach Net Zero by 2050 (Gov.uk, 2022). To achieve a more sustainable construction industry, important aspects are recommended: design for the smallest amount of waste, employ lean construction and reduce waste, reduce energy in construction and usage, do not pollute, protect and improve biodiversity, protect water resources, regard people and the local environment, and check and report (i.e. use benchmarks) (Koskela, 1992, 2000; Ballard, 2000; Abdelhamid, 2003; Alinaitwe, 2009; Al-Aomar 2012; Khan, 2012; Heidar Barghi, 2013; Sarhan and Fox, 2013; AlSehaimi et al., 2014; Tezel et al., 2018). For example, if the energy utilised and water wasted are reduced in a house, the environmental effects are enhanced in addition to financial performance by cutting the operation costs. To make the process of the construction work better, and for environmental sustainability, seven principal environmental issues should be analysed regarding avoiding pollution and decreasing waste throughout the construction process: energy, materials, water, biodiversity, waste, transport, and internal environment (Koskela, 1992, 2000; Ballard, 2000; Abdelhamid, 2003; Alinaitwe, 2009; Al-Aomar, 2012; Khan, 2012; Heidar Barghi, 2013; Sarhan and Fox, 2013; AlSehaimi et al., 2014; Tezel et al., 2018) Sustainable Development and its key components, as shown in Figure 1.1, will be discussed further in the main body of the thesis (see Chapters 4 and 5).

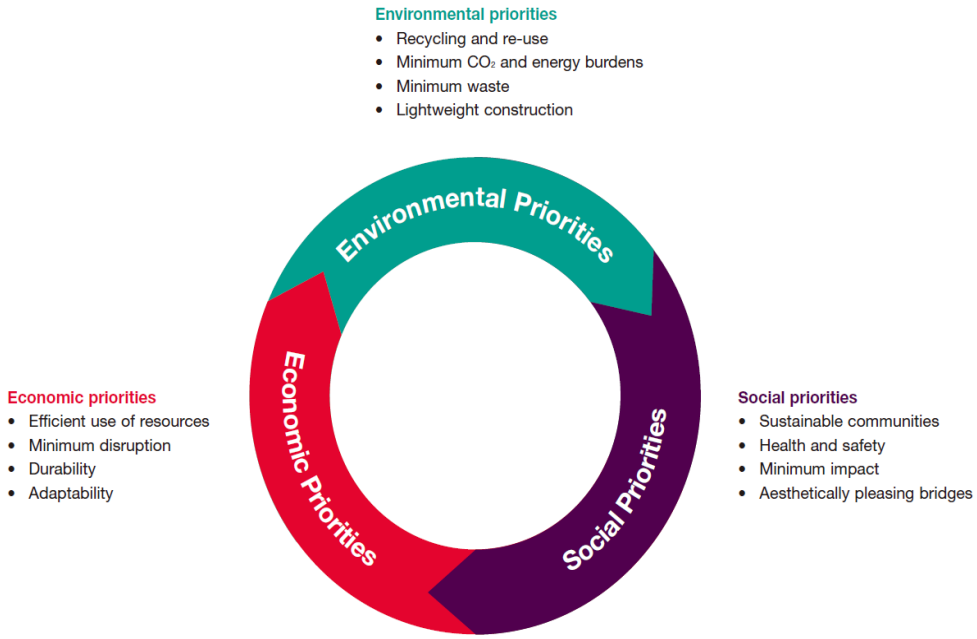


Figure 1.1 Sustainability cycle (Purvis et al., 2019)

Use of technology to assist the progression of improvements, to get the initial objectives in construction in advanced of standards across Cost, Time and Quality, is required. With the progress in technology and development in the industry, some conventional methods of design, management and performance in construction are not responding to the demands placed upon them and therefore are not delivering projects in the most efficient way. There are still, however, some barriers for teams and organisations to overcome and improvements to be made to act in a lean manner. For example, to reduce waste, the improvement should be focused on eliminating non-value-adding activities, known as flow activities, and to make conversion or value-adding activities more efficient. Improving flows in construction is the aim of lean construction, a relatively new production approach and a philosophy which stems from lean manufacturing. Lean construction presents a new well-organised method for construction projects (Alarcón, 1997). Lean is a philosophy of managing human organisations and so it involves techniques but between the philosophy. For example, Last Planner® is a tool for production control at site level (Ballard, 2013). Lean construction improves the quality of a project and at the same time reduces construction waste, imperfections, and cost of materials. Fortunately, lean construction techniques, methods, and tools such as the Last Planner® System have been tested on many different types of projects and they have proved to be successful, especially in those which are highly complex and have

a high degree of uncertainty (Ballard, 2013). However, their applicability and degree of success in different conditions still need to be examined.

Construction is a complex system. To be able to manage such complex systems, certain principles like conversation, cooperation and learning should be applied (Ballard, 2013). Lessons learned from the construction industry have proved that adopting lean construction can enhance project success. Whilst various lean techniques, methods and tools have been developed to support lean activities, problems can arise where they are used inefficiently and/or ineffectively. This research aims to develop the knowledge and a new lean method/tool that overcomes such problems and provides an effective and efficient way for managing construction projects in the construction industry.

Whilst not covered in this research, aspects such as technology and computer modelling software can smooth the progress of modelling and managing, not least Building Information Modelling (BIM), a tool that brings many advantages for design and planning works from early stages in design, focusing on the customer's needs and collaboration of teams. Such tools can bring many advantages both now and in the future (Ballard, 2013).

Project management is a crucial task of balancing the three targets of Cost, Time and Quality as shown in Figure 1.2, which includes Cost Management, Time Management, and Quality Management, under the umbrella of Sustainability.

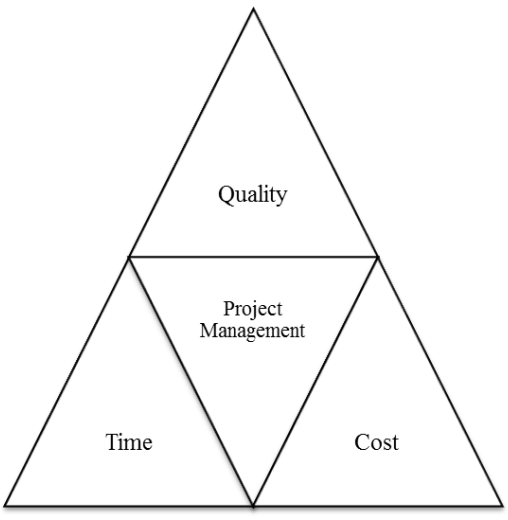


Figure 1.2 Project management triangle (Harris et al., 2006)

The research to be developed in this thesis focuses on the following points:

(1) A fully developed model with comments on each element; description of the model and the main challenges to applying lean construction (LC); problems/challenges (lack of implementation framework/guidelines/effective methodology); RIBA Plan of Work: Stage 5 – Construction; Stage 6 – Handover and Close Out; and Stage 7 – In Use.

(2) LC problems and challenges and description of modelling; conceptual construction framework with LC implementation models; conceptual framework for implementation of LC in construction phase model; methods of measuring cost, time, quality, and sustainability; methodology to measure each stage: cost – time – quality – sustainability.

(3) Control and measurement of cost, time, quality and sustainability by taking lean principles into account, based on responsibility and work of contractors.

(4) Methods for controlling cost, time, quality and sustainability.

This research project is organised chapter-by-chapter, as follows:

- Introduction to set out the problem statement – Chapter 1.
- Literature review including measurement and control, for example, management of Time, Cost and Quality – Chapter 2.
- Methodology used, detailed in Chapter 3.
- Chapters 4 and 5 present a proposed framework model of the construction process by adopting lean principles; this covers:
    - Stage 1: General model;
    - Stage 2: Develop each phase;
    - Stage 3: Method of controlling Cost, Time, Quality and Sustainability; use of a case study to use a practical case and to validate the proposed models, followed by analysis of results.
- Finally, it provides a discussion and validation of the work (Chapter 5) and draws conclusions (Chapter 6).

1.2 Problem statement

This chapter presents the problems and barriers in the construction industry. The construction industry worldwide has been described as a slowly progressing industry (Aziz and Hafez, 2013). Researchers often mention that there are many problems faced by construction projects, such as low productivity, poor safety, inferior working conditions, and insufficient quality (e.g. Koskela, 1992). These remain the main problems in the construction industry and should be eliminated to achieve project targets of cost, time, and quality (AlSehaimi et al., 2014). In addition, challenges such as the presence of foreign competition and a decline in skilled labour are growing problems (Olawale and Sun, 2010; The CIOB, CITB, 2021). Other problems in the construction industry include waste, variability, change, uncertainty, variation, constraints, and complexity. Also problems of Low productivity; Insufficient quality; Time over-runs; and Inferior working conditions, notably highlighted by Latham (1994) and Egan (1998). Further process-related problems exist including: waste, absence of clear indicators of quantitative parameters and a lack of documented studies; One-of-a kind projects, multi-level organisational structure, site production, projects lack the organisation which promotes cohesive partnerships, coordination and communication between multi-disciplinary professions, flexible contractual agreements and a customer focused objective (see Koskela, 1992). All of these can adversely affect the construction industry.

According to Sarhan and Fox (2013), the significant barriers to the successful implementation of LC in the UK are a lack of adequate awareness/understanding of lean principles; a lack of top management commitment; culture and human attitudinal issues; time and commercial pressure; fragmentation and subcontracting; nature of procurement and contracts; educational issues; a lack of process based PMSs; financial issues; and **the** Design/Construction dichotomy. Moreover, structural and cultural barriers make these problems worse (Sarhan and Fox, 2013). Further, according to Mossman (2009) and Bashir et al. (2010), transition of method problem, low productivity, delay in project delivery, errors in construction, stagnant productivity, budget overrun, project delay, low performance, poor performance etc., are problems that are faced by construction industry.

Areas than can help to overcome and tackle the abovementioned problems include constraints and control, planning, planning reliability, continuous learning and training,

culture (cultural matters), production control in construction, and the implementation of LC tools (Ballard, 2000; Green, 2002; Heidar Barghi, 2013; Lean Construction Institute, 2017).

New developments would be possible through new tools, technologies and developments such as the use of BIM or various types of computer-assisted tools, for example, TPS, Last Planner® System (LPS), concepts of flow, 5Ss, standard work, kaizen, Six Sigma, Design for Six Sigma (DFSS), Theory of Constraints, Kanban, KanBIM, and Plan-Do-Check-Act (PDCA), lean supply, sustainability (sustainable construction and development) and environmental sustainability, prefabrication; material change for a better environment, value management/engineering, risk management, designing a pull system, lean project delivery system (LPDS), integration/link between lean construction (tools) and BIM, etc. For example, Last Planner can reduce the variability in task duration (Alarcón, 1997; Bicheno, 2004; Dennis, 2007; Ballard, 2013; Heidar Barghi, 2013; Lean Construction Institute, 2014).

Nowadays, construction projects have become complex and dynamic, larger and more uncertain when compared to the past. Lean production is a production philosophy which uses less of everything on site to reduce time and cost overrun. For a large-scale project that surpasses its time and cost, these typically occur because there are hazards and problems like poorly consistent planning and incompetence by using too many buffers, which are supposed to be linked with traditional planning methods. Lean production is a method which tries to create maximum value, reduce the time and cost of construction, and reduce waste of resources. Lean production, with its typical high consistency focusing on customer and output variation at its minimised level, is therefore required.

Construction usually generates a large amount of waste (Oyedele et al. 2013; WRAP, 2020). To reduce construction waste, improvements should be focused on eliminating non-value-adding or flow activities and to make conversion or value-adding activities more efficient. The concept of lean attempts to answer a lot of the problems and imperfections and lots of improvements have been completed in recent years. LC improves the product quality and at the same time tries to decrease waste, imperfections, and material costs. It presents a new well-organised method of construction. Continuously during times, while the errors are removing from the base, the quality of product is improving (Heidar Barghi, 2013).

If the plan is disrupted, it may stop the whole project or it may produce several problems for the next phases of construction, which will increase the project's cost. Furthermore, if there is a problem in the delivery of material like an unpredictable delay, then serious loss and failure of production will take place. The negative effects of lean on the environment should also be considered. Lastly, a variation in material requirement is a key difficulty that occurs throughout the construction procedure (Ballard, 2013; Heidar Barghi, 2013).

Lean processes observe the production procedure as a whole system, in which performance can improved by better covering many issues, i.e. material, labour, machines. Lean production can benefit the construction procedure and manage construction waste. Also, with the application of lean methods, the quality of work improves.

Construction is a complex production of a one-of-a-kind bespoke product. Customers, clients, external factors, and site conditions etc., are all sources of complexity. What is needed is to clarify the changeable and unpredictable events which occur on site and disturb the work. A complex system should be very responsive to primary situations or suffer very little variation.

Recommendations for improving lean production in construction include: Lean Six Sigma, kaizen, lean productivity, performance improvement, flow improvement, and continuous improvement amongst others (Takim et al., 2002; Aziz et al., 2013).

According to Mohd Arif Marhani et al. (2013), there are seven main barriers to implementing LC: managerial aspects, technical aspects, human attitude aspects, aspects of the process of LC, educational aspects, government aspects, and financial aspects. Thus, good strategies play a vital role when implementing LC to overcome these barriers. Among others are the development of systematic training and research actions on LC, and collaboration among construction companies. A proactive interaction between stakeholders can be inculcated, which results in a healthy competitive environment among the collaborating companies. Through the implementation of LC in local construction management processes, it is hoped that the construction industry will be provided with new knowledge, leading it towards a more sustainable and greener future. Future research in a similar area will be conducted on construction organisations that have implemented the LC concept by observing their practices on site. From the research presented in this thesis, with appropriate

methodology the actual key concept adopted in the construction projects can be investigated. Further suggestions on other possible tools could also be proposed to the industry to add value to its existing LC implementation (see Chapter 2 Section 2.4.7.3, Barriers to implementation of LC).

A key tool to support this is the RIBA Plan of Work. Stage 5 – Construction, Stage 6 – Handover and Close Out, and Stage 7 – In Use of the Plan of Work have been used in the work presented in this thesis to improve the construction process by adopting LC principles (see Chapters 2 and 3 for further discussion).

The adaptations of lean principles with enablers in the proposed framework model are identified and assessed; a combination of different lean methods and techniques as the major enablers are taken into consideration in the construction process. This framework is then integrated and incorporated into the RIBA Plan of Work to implement lean methods and techniques to the construction activities. The proposed model will resolve the problems (change, plan, design, etc.) and determine how to deal with them.

In the proposed new model, the following phases are included in Stage 5 – Construction of the RIBA Plan of Work: Phase 1 – Construction Planning; Phase 2 – Implementation; Phase 3 – Monitoring and Control; and Phase 4 – Review, as shown in Figure 4.4 (see Chapter 4). The next two stages, Stage 6 – Handover and Close Out (Stage 6 including maintenance) and Stage 7 – In Use, have also been developed, as shown in Figure 4.4 (See Chapter 4). In addition, Project Success (Time, Cost, Quality, and Sustainability), Lean Drivers, Sustainability, Methodology for each stage (activities methodology: planning, …etc), and an Activity Model are included in this thesis.

1.3 Aim and objectives

1.3.1 Overall aim

The aim of this study was to investigate LC techniques currently used in the industry and the principles of LC applications, in particular the problems and challenges, and through this develop a new construction process model in which lean methods/tools can be integrated. The goal of this research was to propose, define, develop, and test a lean-enabled system to support planning and control, value generation, and waste reduction daily on construction

sites. This will provide an effective and efficient way of managing construction projects for the construction industry.

1.3.2 Research objectives

The specific objectives of this research project are:

1. Critically review the practice of lean production and construction in industry. This includes a review of LC techniques, methods, and tools, to help benchmark best practice in applying them.
2. Identify problems and challenges by adopting LC in projects, forming the basis for the development of a new construction process model, particularly in the fields of time, cost, quality, and sustainability management.
3. Develop a new construction process model by adopting lean principles, which addresses these problems and challenges.
4. Collect case study materials from the industry to test and validate the proposed models, in terms of controlling the measurement of projects' cost, time, quality, and sustainability, and through this hone the modelling framework developed.
5. Develop guidance for LC projects, to support improvement in the construction process.

Table 1.1 sets out how each objective will be met and the methodology used to achieve this.

Table 1.1 Mapping of research objectives to methodology steps

Specific Research Objectives	Methodology Steps
• Critically review the practice of lean production and construction in industry, including a review of lean construction (LC) techniques, methods and tools, and benchmarking best practice of applying them.	• A literature review has been carried out to find out what was wrong with existing frameworks and what is needed to improve them; and to provide the key aspects of areas of uncertainty from the literature. • Review the applications of LC and tools such as Last Planner® System (LPS), Concepts of flow, 5Ss, standard work, kaizen, Six Sigma, Design for Six Sigma (DFSS), Theory of Constraints, Kanban, KanBIM, BIM, PDCA, Lean Supply, Toyota Production System (TPS) in the manufacturing industry and in different projects to examine their applicability to different conditions.
• Identify problems and challenges by adopting LC in projects, to form the basis for developing a new construction process model, particularly in the fields of time, cost, quality and sustainability management.	• Establish the definition of waste in the construction process, which forms a part of the Lean Thinking (LT) principle which requires the elimination of waste in a process. As such, identification of waste is established. • Identification of waste and value loss in a construction project shows how well organised and competent the system of project management is. Identification can be an excellent pointer and guide for the possible impact of the LC philosophy.
• Develop a new construction process modelling by adopting lean principles, which addresses problems and challenges.	• After defining and identifying waste, the lean enablers have been studied and identified; the available tools and methods of lean implementation are considered. Evaluation of the core enablers is the main focus in this study as they are used to drive the process and to support innovation of the construction process. Subsequently, a construction process framework model which adopts LT is proposed which includes waste identification, lean enablers, waste elimination, and recommended construction process activities.
• Collect case study materials from the industry to test and validate the proposed model while controlling measurement of the projects' cost, time, quality, and sustainability.	• The impacts of LC techniques; drivers of LC practice in organisations; challenges to the implementation of LC techniques and the outcome of implementing LC practice were ranked to demonstrate how the variables compare with one another. The ranking enables organisations to allocate priorities in making decisions.
• Develop guidance for lean construction projects.	• An integrated framework is presented that could serve as a guide to contracting organisations in using LC techniques to achieve an improvement on construction sites.

1.3.3 A description of the overall research methodology adopted

In this section the research methodology is explained in a little more detail.

1.3.3.1 Literature review

The literature review and associated searches included methods and models that have been developed for measuring and controlling Time, Cost, Quality, and Sustainability. Details are provided in Chapter 2.

1.3.3.2 Data mining (data in literature) and information collection

An extensive literature review was conducted for this research project, from which a questionnaire was developed together with semi-structured interviews, both used to collect quantitative and qualitative data. More detail on the development of the questionnaire and semi-structured interviews, including how and why they were used, set up and designed, including any limitations and ethical considerations, and from this how the questionnaire was subsequently analysed by appropriate statistical methods, is presented in Chapters 4 and 5. From these key conclusions were drawn, allowing the framework to be developed and tested with case studies from Iran, and then validated.

Ultimately, this research presents a proposed framework to model the construction process by adopting lean principles. Thus, a framework was developed to ensure a construction project follows the best process and meets time, cost, quality, and sustainability criteria, by following a number of stages.

1.4 Scope and limitation of the study

This thesis presents what ‘value and cost’ mean in the context of a construction contract only. As part of this, the barriers to implementation of LC are discussed in Chapter 2. These aspects will all be considered in the development of the final modelling framework produced.

2 LITERATURE REVIEW

2.1 Introduction

The construction industry can be considered as one of the largest and most important industries in the world (Mahmoud and Scott, 2002; Salem et al., 2006), not least because the infrastructure it provides underpins everything that society can do. Although traditional planning methods have been used to manage construction, key aspects, including waste, time, and cost are still considered to be the main problems in the construction industry (Alarcón, 1997, 2005; Jeonget et al., 1999; Solaimani et al., 2019).

The construction phase in the life cycle of a project contributes significantly to its overall performance. By adopting lean principles, the overall success of a construction project will be significantly enhanced; however, the many potential benefits that exist are still not fully realised in a uniform way (Lean Construction Institute, 2017). Any poor outcomes from the construction phase cause major negative contributions to a project through, delays, cost overrun, and a lack of waste minimisation (Lean Construction Institute, 2017), all of which adversely affect the overall performance of any project.

Lean production in construction has long been considered as a key solution to solve these kinds of problems. Lean production as a principle and mode of operation arose in Japan, a country well known for world-class manufacturing and the development of new production philosophies (Tezel and Nielsen, 2013; Gao and Low, 2014). The lean concept presents new ideas for preparing and supervising the construction process, with its focus on value for the customer and elimination of waste.

LC is a new production approach and philosophy established from the idea of lean manufacturing. LC has been tested on many different types of projects around the world and has been proved to be successful (Alarcón, 1997, 2005; Green and May, 2005; Lean Construction Institute, 2012; Aziz et al., 2013; Issa, 2013; Marhani, 2013). According to Solis et al. (2013), lean construction is a relatively new concept to construction project management.

Sir Michael Latham in his 1994 report set out a vision for a world-class construction industry as one that "*is of high quality which can dramatically improve productivity*". Thus, teamwork is the key. Following on from this, The Egan Report (1998) set out the key aspects on which to focus:

- The customer;
- Commitment to people;
- Integrated teams and processes;
- Committed leadership; and
- A quality-driven programme.

Egan identified that The Movement for Innovation, M4I, was a necessary start to make the cultural change easier (Green, 2002). M4I encourages best practice and innovation through key performance indicators, demonstration projects, and regional cluster groups. Great emphasis was also placed on 'Respect for People: Our Biggest Asset,' as featured in *Egan – The Industry's Response* (Egan, 1998).

Construction Excellence was set up as the umbrella organisation taking forward a variety of change initiatives. Since the 1990s, a cultural shift in the construction industry has been seen (McGeorge and Palmer, 2002). According to Latham, "*implementation starts with clients, and they are at the core of the procedure and their requirements have to be met by industry*" (McGeorge and Palmer, 2002).

Clients have a key role in activating a cultural shift in the industry by accepting the concepts of management, such as:

- Value management;
- Constructability;
- Benchmarking;
- Re-engineering;
- Partnering; and
- Total quality management (TQM).

Thus, performance measurements (and associated benchmarking) have become ever more critical to business success and as such this area has been subject to a considerable amount of research and attention (Mahmoud et al., 2002; Takim et al., 2002; Yu et al., 2007; Yang, 2010; Aziz et al., 2013). Many tools and frameworks have been developed to address progression in the area. In the construction industry, both the Egan and Latham reports supported performance improvement, with performance measurement being a key element. For example, see the work of Bassioni (2004), Chen et al. (2019), Claude (2019), Clarissa (2019), and Yusof (2019), amongst others.

Today, construction projects are becoming ever more complex, dynamic, large, and uncertain, compared to those encountered in the past. The process of delivering high-performance building has led to a more complex construction practice through the increment of specialised processes. This has affected construction sequencing and timing, leading to workflow variability and excess in the estimated construction time and cost (Ochoa, 2014).

In the built environment, to improve productivity and quality for sustainable development a study by Pheng (2012) highlighted the need for an integrated management system, particularly in developing countries, where construction has been disjointed, impacting project productivity and quality. Allied to this is research conducted in the Middle Eastern Gulf region, which showed an increase in construction projects meeting challenges to complete on time and within budget (Mohamed, 2016). After identifying and assessing common implementation methods, and a growing body of evidence, the 'new' LC method has the potential solve these problems.

The literature review has several aims which are identified within the respective sub-sections outlined below:

- Section 2.1 identifies the problem with current construction processes in terms of:

  (1) The total amount of waste produced,
  (2) Time overruns, and
  (3) Cost delays;

- Section 2.2 introduces the methodological process adopted to undertake the remainder of the literature review;

- Section 2.3 outlines current waste generated both globally and within the UK, showing the negative impact that construction waste has;

- Section 2.4 identifies and critically evaluates a range of waste minimisation techniques to evaluate the most appropriate for adoption within building design, construction, maintenance, and operation, to minimise cost, time, and waste. By contrasting and comparing these alternatives the conclusion is drawn that LC is the most appropriate option currently available to the construction industry;

- Section 2.5 provides a brief overview of BREEAM within the context of how it might afford itself or not to help waste minimisation;

- Section 2.6 introduces the concept of waste minimisation and management, highlighting good practice within the area; this includes an introduction to Waste & Resources Action Programme (WRAP), Site Waste Management Plans (SWMPs), Life Cycle Assessment, and associated standards; and

- Section 2.7 identifies and critically evaluates construction management tools that allow for the seamless integration of an LC approach within a shared framework of briefing, designing, delivering, maintaining, and operating buildings. By comparing and contrasting a range of alternative construction management methods/techniques, the RIBA Plan of Work (version 2020) is identified as the most appropriate option to take forward.

2.2 Methodological process for undertaking literature review

The methodological process adopted to undertake the literature review is described in this section. Several databases were searched for appropriate literature, including but not limited

to: Science Direct, Engineering Village, Scopus, Google Scholar, ResearchGate, and Ethos. Two key aspects were searched for:

Firstly, when considering Construction the keywords used for the literature search included '*lean principles*', '*lean enablers*', '*sustainable development*', '*lean methods and techniques*', and '*construction projects*'.

Secondly, when considering Waste the keywords used for the literature search included '*waste*', '*waste minimisation*', and '*waste minimisation techniques and practices*'.

The large list of papers first identified was subsequently filtered down to those key seminal papers included in the thesis, which were reviewed in detail.

2.3 Waste minimisation techniques and practices

2.3.1 Global context

Construction projects are amongst the largest contributors of waste around the world (Oyedele et al., 2013). Each year construction and demolition works produce over 60 million tonnes of waste (WRAP, 2020). Waste in construction is a major global issue and one the industry is still struggling with. For example, in many countries some 15% to 20% of virgin materials end up as waste materials, conflating these problems (WRAP, 2020).

The literature illustrates the current scale of the issue. For example, Lu and Yuan (2011) found that construction and demolition (C&D) waste needs to focus on three major areas, namely: generation, reduction, and recycling, to ensure adequate construction waste management. A better approach demonstrated in Japan was to consider C&D waste as a construction by-product rather than waste, and therefore encourage much more effort to reuse or recycle waste horizons (Nitivattananon and Borongan, 2007).

However, it is important to define waste more carefully as waste in construction comes from three key areas, general construction, renovation activities, and demolition (Kofoworola and

Gheewala, 2009). These waste sources therefore require an inclusive approach across all types of construction without confining them to the particular stage such waste arises from, and this requires several factors to be considered. Thus, any waste management strategy should be considered in the framework of administrative, financial, legal, planning, and engineering functions. This aligns overall with C&D waste management becoming an important issue of sustainable development, which concerns environmental, social, and economic development (Doan and Chinda, 2016).

2.3.2 The UK context

The largest user of natural resources in the UK context is the construction industry, which uses over 400 million tonnes of material per annum, with additionally each year over 60 million tonnes of waste sent to landfill or related disposal sites (WRAP, 2020). Thus, more than one-third of the UK's waste arises from the construction industry, and worryingly only half of this is recycled or reused, with metals and aggregates representing the vast majority of this (WRAP, 2020).

According to the Government Statistical Service and the Department of Environment Food & Rural Affairs (DEFRA), the key points (taken directly from UK Statistics on Waste 2020) are:

- "The UK recycling rate for Waste from Households (WfH; including incinerator bottom ash metal (IBAm) was 45.0% in 2018, decreasing from 45.5% in 2017. There is a European Union (EU) target for the UK to recycle at least 50% of household waste by 2020.
- The recycling rate for WfH decreased in all UK countries except Northern Ireland in 2018. The recycling rate for England was 44.7%, compared with 47.7% in Northern Ireland, 42.8% in Scotland, and 54.1% in Wales. The reduction for England was driven primarily by a reduction in 'other organics' such as green garden waste sent for recycling, linked to adverse weather conditions for plant growth.
- UK biodegradable municipal waste (BMW) sent to landfill has fallen from approximately 7.4 million tonnes in 2017 (21% of the baseline 1995 value) to around 7.2 million tonnes in 2018 (20% of the baseline 1995 value). The UK is therefore still

on track to meet the EU target to restrict BMW landfilled to 35% of the 1995 baseline by 2020.

- Figures for 2017 show that 70.0% of UK packaging waste was either recycled or recovered compared to 71.4% in 2016. This exceeds the EU target to recycle or recover at least 60% of packaging waste.
- It is estimated that the UK generated 41.1 million tonnes of commercial and industrial (C&I) waste in 2016, of which 33.1 million tonnes (80%) was generated in England. The latest estimates for England only indicate that C&I waste generation was around 36.1 million tonnes in 2017 and 37.2 million tonnes in 2018.
- The UK generated 221.0 million tonnes of total waste in 2016, with England responsible for 85% of the UK total."

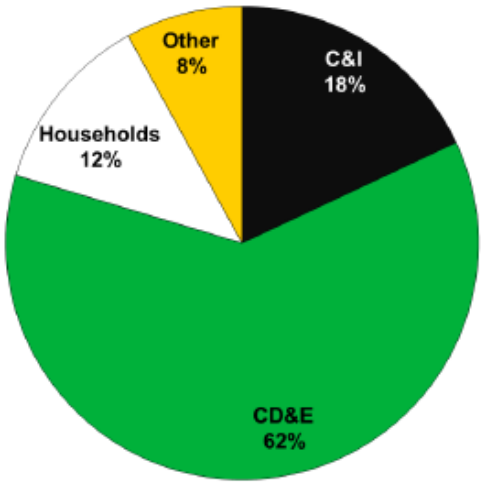


Figure 2.1: Waste generation split by source, UK (UK Statistics, 2020)

2.3.3 Waste management – key definitions

According to the 2008 Waste Framework Directive (Directive 2008/98/EC - Article 3(1)) waste is defined as: "any substance or object which the holder discards or intends or is required to discard"; the process by which this waste is managed is thereby referred to as waste management.

More efficient use of materials is a key feature of waste management. This will provide the key influence on the reduction in use of finite natural resources and thereby reduce the negative environmental effects of construction, including by decreasing requests for landfill.

In addition, waste management contributes to the economic efficiency of the sector and of the UK (and other economies) as a whole (WRAP, 2020).

2.4 Waste minimisation techniques

Esa et al. (2017), in their study of strategies for minimising construction and demolition waste, prioritised the importance of managing C&D waste to mitigate environmental impacts. They used this approach to mention that a more modern construction method would reduce waste generation at the planning and designing stages.

They also suggested that key principles and strategies in developing an integrated management of C&D waste should be identified at the earliest stages. Suitable strategies include:

- A waste management plan and construction methods in the planning and designing stages;
- Enhancement awareness, awards, and regulations during the procurement phase; and
- Effective waste minimisation and management (WMM) during the stages of both construction and demolition.

Therefore, elimination of any perceived and real cost premiums associated with achievement of best practice will come through economies of scale and learning, and ultimately feed through into added value overall.

There is an array of different techniques currently being used to manage waste. Table 2.1 summarises a number of these and highlights key methods, techniques and principles, barriers, benefits, and constraints. Focus has been given to managing the construction and demolition waste (CDW) generated rather than trying to control it at the initial stage of the construction cycle. A broader discussion of these then follows.

Table 2.1 Waste management methods, techniques and principles

Waste Management Methods, Techniques and Principles	Summarised details of method	References
3Rs and 5Rs (see Section 2.4.1)	**Reduction, reduce, and reuse:** Reduction of waste via reduction, reuse, and recycling.	Lu and Yuan (2011)
Waste & Resources Action Programme (WRAP) (see Section 2.4.2)	**Consists of the following:** o Suggests three levels of performance (Standard, Good, and Best Practice) o Adopts a waste hierarchy o Range of benefits (see Section 2.2.3.2) o Range of barriers (see Section 2.2.3.2)	WRAP (2020)
Waste Minimisation and Management (WMM) (see Section 2.4.3)	**Key aspects of waste minimisation:** o Integrates design solutions, demolition, and logistics to develop a logistic plan o Adopts 'Just-in-time' delivery o Requires construction consolidation centres o Adopts Modern Methods of Construction (MMC): off-site manufacturing – utilise prefabrication, factory assembly, pre-assembly, off-site assembly/manufacture, panelised or modular volumetric construction where possible o Requires materials procurement: supply chain manager o Requires Site Waste Management Plan (SWMP) **Benefits of the method:** o To minimise the total quantity of waste produced through a project o To use materials more efficiently and to reduce the amount of waste o Should follow the waste hierarchy o Adopts re-use or recycling as the norm o Requires the formulation and implementation of an SWMP at an early stage of a project o The common principles used in the reduction of C&D waste are reduce, reuse, and recycle (3Rs) – see Section 2.2.3.1 **Barriers include:** o Embedded culture; o Language barriers; o Management initiative o Corporate attitudes	Mohd (2017); Gálvez-Martos et al. (2018); Lu, W. (2011)
Waste Generation	**Methodologies adopted for obtaining estimates of**	Lu, W. (2011),

Rate (WGR) (see Section 2.4.4)	**WGRs are diverse:** o These typically include direct observation, comparing contractors' records, questionnaires and telephone surveys, sorting and weighing the waste materials on site, collecting data through consultation with construction company employees, and tape measurement and truck load records o Normally, two approaches are prevailing: classifying wasted materials into different categories or treating them as a whole	
C&D Waste Minimisation Strategies (identified from the previous studies) (see Section 2.4.5)	**Applied at both construction and demolition stages and consists of:** • Monitoring labourer's attitudes • Applying and ensuring the compliance of the waste management plan • Development and adoption of a written contract among subcontractors stating their obligation in adhering to the on-site waste management plan • Collaboration and communication among project team members • On-site wastes sorting technique • Off-site wastes sorting technique • Increase the availability of recycling facilities in hot-spot areas • Site management (e.g. proper storage facilities) • Appropriate plants for demolition works • Prioritising selective disassembly or dismantling or disassembly, in favour of massive demolition • Making precise prediction of the quantity of materials required to conduct the job to prevent long periods of on-site material storage • Ensuring the availability of on-site mobile crushers so that inert waste can be recycled and reused on-site	Martosa et al. (2018); Esa et al. (2017); Lu and Yuan (2010); Wang et al. (2010); Saez et al. (2013); Wang et al. (2014); Marrero et al. (2017); Lu and Yuan (2011); Wu et al. (2019); Nitivattananon and Borongan (2007); Lu, w. (2011); Poon et al. (2004); Hao et al. (2008); Cheng and Ma (2013); Lu et al. (2016); Chen et al. (2019) ICE have their C&D demolition protocols, etc. (ICE, 2020)
Best environmental management practices for construction and demolition waste (CDW) (see Section 2.4.6)	**Include the following key aspects:** o Waste management strategies • CDW management plans • Economic instruments • SWMPs o Prevention and collection • Designing out waste • Site waste management and prevention • Material use efficiency o Re-use • Building de-construction • Re-use of materials o Waste treatment and material recovery • Waste sorting and processing addressing	Gálvez-Martos et al. (2018)

	the acceptability of recycled aggregates • Quality assurance schemes • Recovery of plasterboard	
Lean Thinking (see Section 2.4.7)	**Key aspects include:** o Total Productive Maintenance (TPM) o Employee involvement, continuous improvement o Benchmarking, o Time-based competition, o Concurrent engineering (CE) o Product, Cost, and Waste Breakdown Structure (PBS, CBS, and WBS) as part of a cost Control Cube o Value-based strategy (or management), o Visual management o Re-engineering o Lean manufacturing. o Business Process Re-Engineering (BPR) o Last Planner® System (LPS)*; o Quality Management Systems (QMS) o Teamwork o Value-based management (VBM) o First run studies o JIT (Just in Time) o Productive meetings, o Increased visualisation o Off-site prefabrication o 5Ss/5Cs, o Mistake-proofing/poka-yoke o Root cause analysis/five 'whys' o Six Sigma o The transformation–flow–value (TFV) generation model o Location-based scheduling (LBS) tools **Frameworks include:** o Lean construction wheel o Lean Assessment Framework o Lean Construction Framework with Six Sigma rating	Abdelhamid (2003); AlSehaimi et al. (2014); Al-Aomar (2012); Alinaitwe (2009); Alshehri (2016); Ahaotu (2019); Adamu and Hamid (2012); Ballard (2000); Bassioni (2004); Biotto (2019); Chamberlin et al. (2017); Diekmann et al. (2004); Gülyaz et al. (2019); Harris and McCaffer (1997); Ismawi (2019); Koskela (1992); Linderman et al. (2003); Low (2012); Pepper and Spedding (2010); Sacks R. (2009); Sacks et al. (2010b); Salem et al. (2005, 2006); Sarhan and Fox (2013); Suresh et al. (2011); Winch (2010); Xiong (2014); Lari et al. (2013)

* Last Planner® is a holistic system, meaning that each of its parts is necessary to support lean project planning and execution.

According to Wu et al. (2019), it is commonly perceived that CDW is mainly generated during construction and demolition stages. Significant efforts have been made to reduce CDW on construction sites (Poon et al., 2004; Hao et al., 2008; Wang et al., 2010). In particular, on-site sorting is recognised as an effective way to reduce waste and increase reuse and recycling (Poon et al., 2001; Wang et al., 2010). More recently, renovation and maintenance of buildings have been identified as essential sources of CDW, although this waste is generated on a smaller scale compared with that in construction and demolition

(Cheng and Ma, 2013; Lu et al., 2016). Many recommendations have been proposed to reduce CDW in prior studies; however, one remaining problem is the lack of meaningful methods to assess the effectiveness of waste management activities. Only if they are proven useful can the proposed waste reduction methods in prior studies be applied in practice.

2.4.1 3Rs and 5Rs

To control the volume of waste produced and the way in which it is disposed, measures are needed. The common principles used in the reduction of waste are reduce, reuse, and recycle (Lu and Yuan, 2011). The principles are adopted from the well-known waste minimisation hierarchy to make sure that waste is managed effectively (Peng et al., 1997; Udawatta et al., 2015). Additionally, the idea of, "*turning waste into wealth*" needs to be implemented during the initial planning stage of construction works.

According to Lu and Yuan (2010), it is also necessary to consider the contextual differences of the study area to successfully apply the management of any waste plan developed (Esa et al., 2017).

Research and practice in CDW management have been guided by the '3Rs' principle, also known as the hierarchy of management of CDW. The principle refers to the 3Rs of reduce, reuse, and recycle, which classify WM strategies according to their desirability (Peng et al., 1997). The 3Rs is meant to be a hierarchy, arranged in ascending order of the adverse impacts of each to the environment, from low to high. Studies have developed various solutions for waste reduction, which can be generally summarised into five categories (Seydel et al., 2002; Begum et al., 2007b), encompassing:

(1) reducing waste through government legislation;
(2) reducing waste by design;
(3) developing an effective waste management system (WMS);
(4) use of low-waste technologies; and
(5) improving practitioners' attitudes toward waste reduction.

Reuse employs the same material in construction more than once, including for the same function (e.g. formwork in construction) (Ling and Leo, 2000) and new-life reuse for a new function (e.g. using a cut-corner steel bar for shelves; using the stony fraction for road base material) (Duran et al., 2006). It is the most desirable option after reduction because minimum processing and energy use is achieved (Peng et al., 1997). Reuse, as a best practice for management of CDW, refers to all harvested materials, construction elements, and building components that can be used in a specific site (Gálvez-Martos et al., 2018).

When reduction and reuse become difficult, recycling is desired. Tam (2008) summarised that recycling can offer three benefits: (a) reducing the demand for new resources; (b) cutting down transport and production energy costs; and (c) utilising waste which would otherwise be lost to landfill sites. Two major concerns on recycling are the economic viability and acceptability of recycled materials.

The benefits of recycling and reusing CDW have been illustrated by numerous studies (e.g., Li, 2008; Marzouk and Azab, 2014; Vieira and Pereira, 2015) which recognised several benefits of recycling and reusing CDW. These benefits are summarised below:

- Reusing materials on site and saving natural resources (Poon and Chan, 2007; Rao et al., 2007; Tam, 2008a; Zhao et al., 2010; Duan et al., 2013; Huang et al., 2013; Sabai et al., 2013; Vieira and Pereira, 2015).
- Decreasing the need for landfill spaces (Hsiao et al., 2002; Poon and Chan, 2007; Marzouk and Azab, 2014).
- Saving energy and reducing greenhouse gas emissions (Huang et al., 2013; Marzouk and Azab, 2014).
- Reducing health-related risks associated with landfilled CDW (Marzouk and Azab, 2014).
- Coping with governmental strategy or industry standards to achieve environmental sustainability (Fatta et al., 2003; Li, 2008).

Both recycling and reuse of CDW generate environmental, social, and economic benefits. For example, recycling programmes can save landfill charges and build a social sustainability

image (Doan and Chinda, 2016), and construction companies could benefit from reducing waste by lowering the cost of purchasing virgin materials (Bossink and Brouwers, 1996).

Despite the widely recognised benefits of recycling and reusing, the sustainable management of CDW is facing some difficulties and challenges, including:

- Lack of waste-processing facilities or companies (Melo et al., 2011; Domingo and Luo, 2017; Jia et al., 2017).
- Insufficient relevant policies, regulations, and acts (Chung and Lo, 2003; Fatta et al., 2003; Rao et al., 2007; Domingo and Luo, 2017).
- Poor communication and coordination among parties involved (Domingo and Luo, 2017).
- Lack of economic feasibility and viability in recycling and reusing CDW, for example, when the cost of recycling and reuse exceeds the recycled waste value, or when the landfilling tipping charge is lower for direct disposal (Zhao et al., 2008; Zhao et al., 2010).
- Poor quality of recycled products and their limited applications (Rao et al., 2007; Li, 2009; Zhao et al., 2010; Sabai et al., 2013; Duan and Poon, 2014).
- Reluctance or cultural resistance to implement CDW diversion (Saez et al., 2013; Esa et al., 2016), for example, illegal dumping still occurring worldwide (Poon et al., 2001; Conceicão Leite et al., 2011; Melo et al., 2011).

Recommendations on improving recycling and reuse of CDW through innovations in construction technology and management include fewer design modifications, modular design, on-site sorting of waste categories, and technical regulations for using recycled materials in construction (Lu and Yuan, 2010; Wang et al., 2010; Saez et al., 2013; Wang et al., 2014; Esa et al., 2017; Marrero et al., 2017). More recently a 5Rs waste management approach has been advocated to either: refuse, reduce, reuse, reproduce, or recycle; or refuse, reduce, reuse, recycle, or rot (Johnson, 2013). This extends the scope of waste management and, through this, potential gains are made.

2.4.2 WRAP

WRAP is a waste management method and the name of a UK-registered charity that works with businesses, individuals, and communities to achieve a circular economy, by helping them reduce waste, develop sustainable products, and use resources in an efficient way. WRAP was founded in 2000, as the delivery body for UK waste strategies; see http://www.wrap.org.uk/construction.

Although WRAP no longer deals with the built environment, aspects of the original "WRAP built environment recommendation" are recommended in this research. WRAP closed its construction programme in 2015 and removed its legacy construction tools in 2021.

WRAP enables and encourages construction clients, contractors, design teams, consumers, and businesses to recycle things and use materials efficiently. This will improve the environment, minimise landfill, and reduce carbon emissions, and also achieve good practice in waste management and minimisation (WRAP, 2020).

"*WRAP's vision is a world in which resources are used sustainably. WRAP works with governments, businesses and communities to deliver practical solutions to improve resource efficiency.*" WRAP's mission is to accelerate the move to a sustainable, resource-efficient economy by (WRAP, 2020):

- "Re-inventing how to design, produce and sell products,
- Re-thinking how to use and consume products, and
- Re-defining what is possible through re-use and recycling."

According to WRAP (2020) the sequence of actions to deliver good practice (see Figure 2.2) should be prioritised in accordance with the traditional waste hierarchy (see Figure 2.3).



Figure 2.2: Sequence of actions to deliver good practice in resource efficiency in construction (WRAP, 2020)

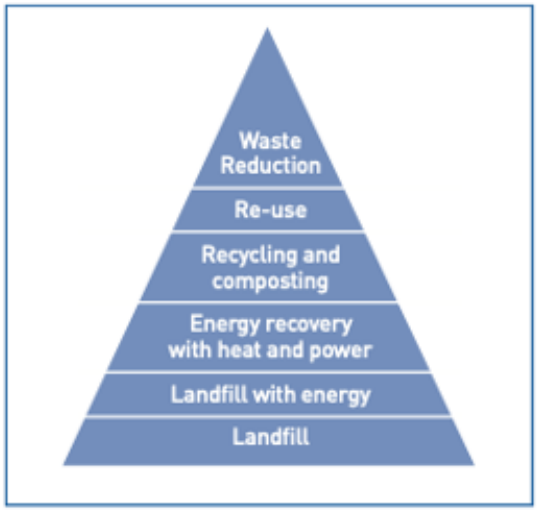


Figure 2.3: Waste hierarchy (WRAP, 2020)

2.4.3 Waste minimisation and management (WMM)

To make a substantial contribution to sustainable development and to help reduce the significant quantities of construction waste sent to landfill, good practice in WMM should be implemented on construction projects (WRAP, 2020). WRAP (2020) has demonstrated how, by implementing WMM, an increased number of different construction stakeholders, i.e., clients, developers, design teams, and contractors, have been able to gain a range of key benefits for their projects. These benefits include (WARP, 2020):

- Project benefits of implementing good practice in WMM;
- Reduced material and disposal costs through a reduction in the materials ordered and waste taken to landfill;
- Increased competitive advantage through differentiation;

- Improved performance against Corporate Social Responsibility (CSR) objectives;
- Lower carbon dioxide (CO_2) emissions;
- Meeting planning requirements.

By using the concepts of standard, good, and best practice, it is possible to explain the extent to which the construction industry has been implementing methods of WMM (WRAP, 2020). These three concepts are illustrated in Figure 2.4.

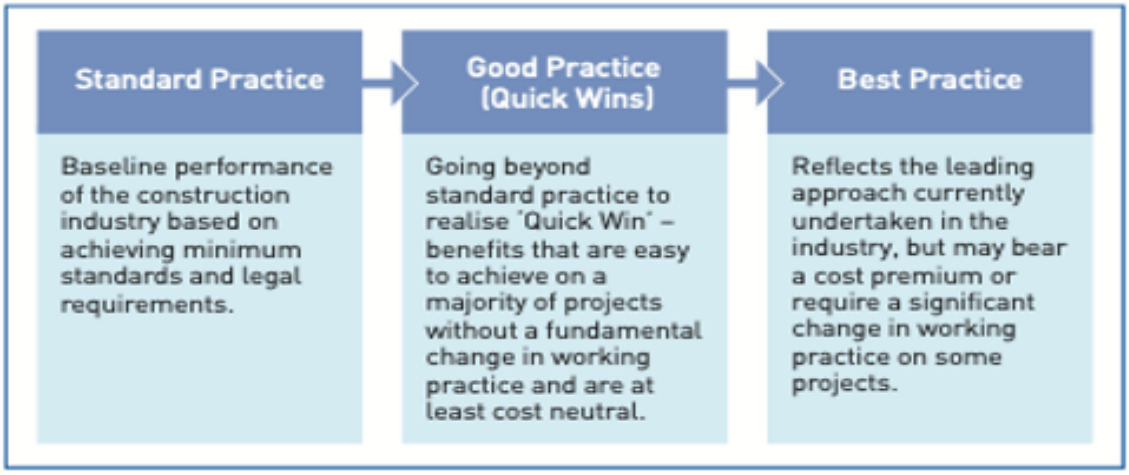


Figure 2.4: Standard, good, and best practice in waste minimisation and management (WRAP, 2020)

To attain a good practice, WMM should be the aim of all contractors, designers, and clients. The important benefits, which include cost savings, lower environmental impact, and more efficient processes, can be realised through a minor change in present working practices. Unfortunately, there are several barriers which must be overcome, as shown in Table 2.2.

Before construction starts, planning and developing an SWMP is critical to achieving good practice in WMM. In the UK, regulations now specify that an SWMP is required for any construction project exceeding £300,000 in cost (at tender) (WRAP, 2020). The DTI originally published a voluntary Code of Practice for SWMPs in 2004. They are now a mandatory requirement across the UK and consist of (taken from WRAP 2020):

Phase 1: SWMP design. In this phase, the scope of the plan is developed and procedures for removal, separation, storage, transportation, and handling of any waste will be developed. A communication strategy should also be defined in a best practice SWMP. Waste prevention

techniques and re-use and recycling opportunities will be identified per waste stream and their potential on-site application will be evaluated.

Table 2.2 Barriers and enablers to achieving good practice (WRAP, 2020)

Key Constraint	Implication	Achieving Good Practice
(1) Lack of client requirements for good practice	The lack of contractual obligations may not induce a contractor to implement good practice in WMM	Client and design teams to make contractor aware that undertaking more than standard practice is likely to realise financial savings and more efficient site operations
(2) Site location	Difficult to find local recycling markets in rural areas	Ensure the waste management contractor can provide a cost-effective recycling service
(3) Project type	Our projects offer fewer opportunities for waste recovery than new build or refurbishment projects	Identity and focus on those material streams that offer Quick Wins
(4) Space on site	Small sites and high-density sites can limit the space available for segregation of waste	Target the key waste streams in each project phase Place a requirement on the waste management contractor to segregate off-site. Adopt other segregation approaches such as smaller containers at each floor level for high-rise city centre projects (for example)
(5) Project timescales	Projects with short lead-in periods, tight programmes, and quick construction rates may overlook good practice	Identify and plan the key material streams offering Quick Wins Implement the areas of good practice that have been shown to be most effective on previous projects Establish partnerships with waste management contractors to undertake a greater role to remove effort from the contractor and subcontractors
(6) Contract variations	Procurement methods that do not significantly penalise clients for making design changes can increase levels of unplanned wastage	Set up a dialogue with the client and designers at an early stage so that waste arising from design changes can be adequately planned Identify areas in the design that are not sufficiently developed and suggest possible waste implications

Phase 2: SWMP implementation. Once the main procedures and strategies are defined, the waste manager responsible for the site should communicate and explain the plan to all the relevant actors within the site and external stakeholders affected by the site activity. The areas for waste storage and the available resources should be well identified within the site, and waste containers should be placed as close as possible to the generation point. According

to Gálvez-Martos et al. (2018), “Training and promotion of the plan should be regularly performed, especially with new contractors or subcontractors, and a documentation file shall be kept updated”.

The benefits of implementing an SWMP in accordance with DTI guidance have been found to be: 15% less waste on site; 43% less waste to landfill; 50% savings in waste handling charges; and 40% saving on waste management costs compared to landfill disposal (WRAP, 2020). According to WRAP (2020, p.9), “There are three key areas where the development and construction industry needs to increase its efficiency: energy, water and materials usage. Figure 2.5 highlights the various ways in which efficient use of materials directly contributes to greater sustainability in construction.”

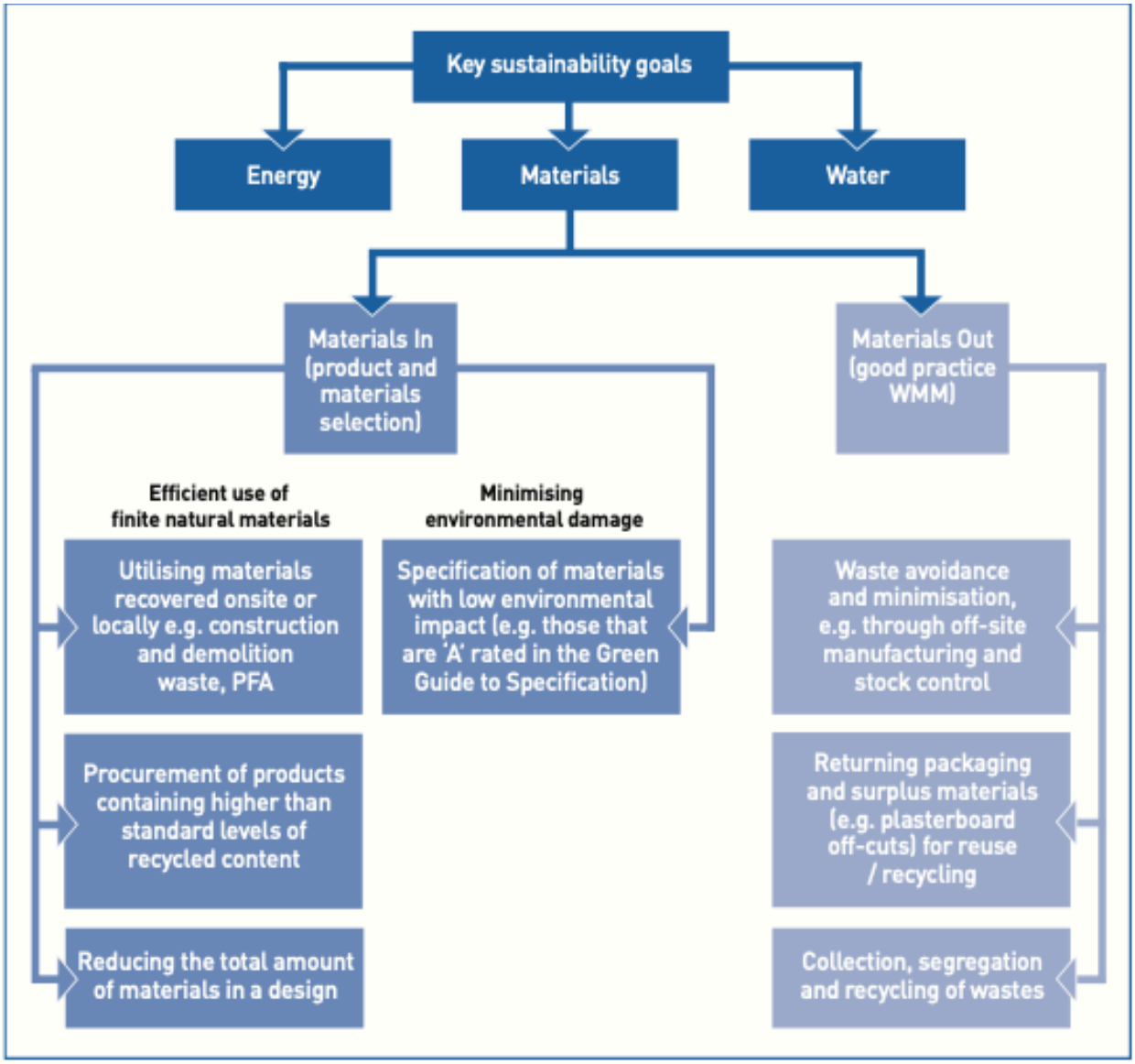


Figure 2.5: Good practice in waste minimisation and management (Sustainability Goals) (Wrap, 2020)

2.4.4 Waste generation rate (WGR)

According to Lu and Yuan (2011), in the construction sector, WGR is a variable that helps in understanding waste management and has been introduced by researchers as a more comparable indicator in different economics. As CDW management is becoming an emerging and prevailing discipline, there are various methodologies for estimating WGRs: direct observation (Poon et al., 2001), comparing contractors' records (Skoyles, 1976), questionnaires and telephone surveys (McGregor et al., 1993), sorting and weighing the

waste materials on site (Bossink and Brouwers, 1996), collecting data through consultation with construction company employees (Treloar et al., 2003; Tam et al., 2007), and tape measurement and truck load records (Poon et al., 2001, 2004a). Normally, two approaches are prevailing: classifying wasted materials into different categories or treating them as a whole.

Lu and Yuan (2011) provided details of a framework for understanding waste management studies in construction. Their work demonstrated that more research is needed to devise effective management of CDW in developing countries and suggested that WGR is a useful comparator tool to achieve this. Here, a clear definition of WGR is required to make such comparisons and, importantly, allow benchmarking across different economies to take place. Further, according to Gálvez-Martos et al. (2018), systematic implementation of these best practices could dramatically improve resource efficiency and reduce environmental impact: by reducing waste generation, minimising transport impacts, maximising re-use and recycling, improving the quality of secondary materials, and optimising the environmental performance of treatment methods. This requires the use of novel solutions, instruments, and approaches to make the management of CDW effective.

2.4.5 CDW minimisation strategies (identified from previous studies)

Table 2.1 shows CDW minimisation strategies applied at both construction and demolition stages.

2.4.6 Best environmental management practices for CDW

According to Gálvez-Martos (2018), Systematic implementation of these best practices could dramatically improve resource efficiency and reduce environmental impact by: reducing waste generation, minimising transport impacts, maximising re-use and recycling by improving the quality of secondary materials and optimising the environmental performance of treatment methods.

Novel solutions, instruments and approaches are required for the management of CDW.
Table 2.1 shows best environmental management practices for construction and demolition waste.

2.4.7 Lean construction (LC)

LC is an approach to design construction systems to facilitate material and information flow, thereby minimising waste of materials, time and effort, and improving productivity (see Koskela 1992 and 2000; Womack and Jones, 2003; Gonzalez et al., 2008; Court et al., 2009; Gonzalez et al., 2009; Sacks et al., 2009; Raid Al-Aomar, 2012; Aziz and Hafez, 2013; Issa, 2013; Ismawi, 2019).

'Lean' or 'lean thinking' refers to an improvement philosophy which focuses on the fulfilment of customer value and the reduction of waste. This philosophy is credited with the rise of Toyota, one of the largest and most profitable automotive companies in the world (Abdelhamid, 2003; Khan, 2012; Aziz and Hafez, 2013; Marhani, 2013; AlSehaimi et al., 2014; Yusof, 2019; Gülyaz et al., 2019).

Lean production, as a key component of LC, can solve many of the problems highlighted in Table 2.3. To reduce waste, the improvement focuses on eliminating non-value-adding or flow activities and making conversion (or value-adding) activities more efficient (Koskela, 2000, 2017).

The concept of lean construction (LC) has been introduced into the construction industry to maximise value of the projects for customers (Gülyaz et al., 2019). Allied to this is the necessity to eliminate construction wastes to achieve project targets (of cost, time and quality), while reducing damage to environment – a key thread of sustainable development (Howell, 1999, Lim, 2008, and Lean Construction Institute 2012, Sarhan et al., 2019).

Table 2.3 Methods of lean production (Heidar Barghi, 2014)

Methods of lean production	Aim
Just in time (JIT)	Removal of wait times
Time based competition	Decrease cycle periods
Value based management	Raising the production value
Total Quality Management (TQM)	Removing errors
Employee participation	Workers with higher abilities ask for superior position
Total productive maintenance (TPM)	Increase influence of supplies
Process redesign (or reengineering)	Arrange through process view and focus on the method
Concurrent engineering (simultaneous engineering)	To work on the projects concurrently
Visual management	Managing and standardization of visual workplace

In LC, production is observed as a value-generation process (Production as Generation of Value). That is, a company produces exactly (and only) what and when the customer requires it. The customer determines value, and the manufacturer only finds the best way to reach the aim (Lean Construction Institute, 2012).

LC consists of eleven basic principles; these were set out by (Koskela, 1992; Aziz and Hafez (2013) as follows:

(1) Reduce the share of non-value-adding activities (waste);

(2) Increase output value through systematic consideration of customer requirements;

(3) Reduce variability;

(4) Reduce cycle times;

(5) Simplify by minimising the number of steps, parts and linkages;

(6) Increase output flexibility;

(7) Increase process transparency;

(8) Focus control on the complete process;

(9) Build continuous improvement into the process;

(10) Balance flow improvement with conversion improvement; and

(11) Benchmark.

Womack and Jones (1996) shortened these eleven principles into five LC principles (Table 2.4) that could be implemented for the total flow process and its sub-processes (Lim, 2008; Lean Enterprise Institute, 2009; Bashir et al., 2011; Muhammad et al., 2013).

Table 2.4 Lean production principles (adapted from Womack and Jones, 1996)

Principle 1 - Recognise value: Value is the first pace of lean thinking, which is decided through the customer's requirements and will be worked on by the makers. Therefore, lean thinking must be used to describe the value in terms of exact goods and products for specific clients, relating to the work of Womack and Jones (1996). Recognise requisites of internal and external customers, which are of value to the client, and present goods that fulfil these requisites. Reduce non-value-adding activities.
Principle 2 - Indicate the value stream: A value stream can be split into three tasks, problem-solving, physical conversion, and data control. This procedure guarantees the results of the entire production will obey the client's primary thoughts.
Principle 3 - Flow: The flow of value helps to reengineer the procedure through eliminating the limits between departments in construction to provide an uninterrupted value stream to the client. There is a common way of separating works into working, departmental, and manufacturing entities, which are in nearly all circumstances going against the production flow.
Principle 4 - Pull: The manufacture plan will greatly rely on the customer as merchandise is created as it is essential and when just needed. As reported by Womack (1996) the word 'pull' relates to a production method which permits the customer to take full advantage of modification. This differs from the conventional method of a 'push' plan where companies prearrange their production in regard to their capacity, after that attempting to sell the manufactured goods using expensive advertisements and paying little attention to what their client really needs.
Principle 5 - Perfection: An important thing to ensure success is to increase trust between companies included at every stage of production, where people can combine hard work in approaching the similar aim of completing the work with an improved method. Lean production pursues perfection with continuous and uninterrupted improvement.

Koskela (1992) proposed three principles of production philosophy to be used in early project phases:

- Tools (i.e. 'kanban' and quality circles);
- A manufacturing method, and
- A management philosophy (i.e. Just-In-Time (JIT) and Total Quality Control (TQC)).

Whilst each method shown in Table 2.5 (see further details in Appendix A) has subtle differences there is no need to use all these key concepts in a construction project. The literature search highlighted that there is a demand for more holistic approaches to be integrated in the existing LC key concepts applied with other concepts. For example, Bashir et al. (2011) introduced a health and safety approach (i.e. OHSAS 18001) in the implementation of lean principles.

According to Dulaimi and Tanamas (2005), the benefits of LC can only be achieved through the full implementation of these principle (this is a view upheld by a number of other authors, e.g. Cullen et al., 2005; Hook and Stehn, 2008; Suresh et al., 2012; Fewings 2013). Since this time Green (2001) and Bertelsen (2004) have discussed that due to the differences across sectors, not all the principles are applicable to construction. Building on this, Salem and Zimmer (2005) observed that most of the principles have been proven to be applicable to the construction industry. Koskela (2004) noted that they do not thoroughly cover the value generation aspects of a production process. Hook and Stehn (2008) also opined that the principles lack focus on cultural aspects of the workforce, which is an inevitable part of lean practice. Additionally, Forbes and Ahmed (2011) suggested that the five principles are applicable to all organisations and should include:

- Customer focus;
- Culture and people;
- Workplace organisation and standardisation;
- Elimination of waste; and
- Continuous improvement and built-in quality.

Table 2.5 Key concepts or tools of lean construction

Key concepts or tools of LC	Relevant aspects	References
• Just-In-Time (JIT) material/ component flow	JIT aims at maintaining a construction material and component flow	Bajjou et al. (2017a), Tezel et al. (2018), Koskela (1992), Tommelein (1998), Pheng and Chuan (2001)
• Total Quality Control (TQC)	Quality control	Koskela (1992)
• Total Productive Maintenance (TPM)	TPM	Marhani et al. (2013)
• Employee involvement	Employee involvement	Abdelhamid et al. (2008)
• Continuous improvement cells	A small-group work improvement activity that is based on Quality Circles (QC); this technique supports the idea that every process can and should be continually measured, analysed, and improved in terms of the resources used, time required, quality demanded by customers, and other performance criteria relevant to the construction process	Nahmens and Ikuma (2009), Miron et al. (2016), Sarhan et al. (2017), Caldera et al. (2018)
• Benchmarking	What makes benchmarking different from other management techniques is the element of comparison, particularly with the external environment. However, benchmarking is more than simple comparison	McGeorge and Palmer (2002)
• Time-based competition	Time-based competition	Koskela (1993)
• Concurrent engineering (CE); concurrent (simultaneous) engineering and fast-track engineering	Lean construction practices and tools that promote its implementation in the construction process	Koskela (1992)
• Value-based strategy (or management)	What the customer wants from the process Value Management (VM) can be used as a means of deciding if the project is really needed. The highest level of function analysis is used. The British/European System: A European Standard for VM was introduced in 2000, namely EN12973:2000. The Japanese System: Unlike the American and British Systems, Japanese VM is not a one-off exercise but a continuous process carried out under the umbrella of the construction project. The Japanese view VM more as a philosophy than a system, one that operates at all stages of the construction cycle, including planning, maintenance and environmental protection	Bertelsen (2004), Koskela (1992) McGeorge and Palmer (2002)
• Visual management	A management strategy that is based on using easy-to-understand sensory systems (i.e. visual performance boards) in close-range communication to increase process transparency, and to facilitate work control and information flow	Formoso, Santos, and Powell (2002), Tezel et al. (2015), Tjell and Bosch-Sijtsema (2015)
• Reengineering/Business Process Re-Engineering (BPR) and lean manufacturing	Reengineering is an important management concept which has achieved quite dramatic and tangible improvements for large business corporations and, as such, merits serious consideration. For many years the construction industry has focused on delivering buildings on time, within budget, and to a specified quality. These goals are quite compatible with the goals of reengineering, which are to achieve dramatic improvements in critical contemporary measures of performance, such as cost, quality, service, and speed, an area that the construction industry is only recently coming to grips with.	McGeorge and Palmer (2002) Small et al. (2011), George and Jones (2008)
• Total Quality Management (TQM)	TQM is a management approach that seeks to integrate all organisational functions (customer service, construction, engineering, and design) to meet performance targets and customer requirements. Lean thinking techniques as applied in the construction industry	Ciarnienė and Vienažindienė (2015), Ullah et al. (2017), Small et al. (2011), George and Jones (2008), Summers (2005)

• The Last Planner® System (LPS) of production control	LPS can more realistically integrate construction process flows and value capturing into the planning and control process than the commonly used Critical Path Method (CPM)	Ballard (2000), Ballard and Howell (1998), Kim and Ballard (2010), Seppänen, Ballard, and Pesonen (2010), Viana, Formoso, and Isatto (2017), Zegarra and Alarcón (2017), Habchi et al. (2016), AlSehaimi et al. (2014); Seppanen et al. (2010), Salem et al. (2006)
• Teamwork and Value-Based Management (VBM)	What the customer wants from the process	Constructing Excellence (2004), Bertelsen (2004), Koskela (1992)
• Increased visualisation	Also called Visual Management; to increase visualisation, promote communication between the coordinators of construction projects, and facilitate information flows	Bajjou et al. (2017b), Tezel and Aziz (2017b)
• Daily huddle meetings	Daily huddle meetings	Salem et al. (2005)
• First-run studies (plan, do, check, act) Problem-solving process (PDCA Cycle)	A work improvement cycle that is based on identifying and analysing process problems (plan), developing and testing potential solutions (do), measuring the effectiveness of the test solution(check), and implementing and standardising the solution (act) An alternative approach to work improvement through process observation and photo/video recording. It is often executed on critical construction tasks at the beginning of their execution to understand productivity rates for better work planning and work improvement opportunities, fine tuning the task design Stands for Plan-Do-Check-Act. The cycle introduced by Walter A. Shewhart and popularised by Dr. W. E. Demings is a method of continuous improvement	Salem et al. (2006), Yu et al. (2011), Bajjou et al. (2017a), Tezel et al. (2018) Ballard (1999), Hamzeh, Ballard, and Tommelein (2009)
• 5S (housekeeping)/5C process and fail safe for quality and safety	A systematic housekeeping process/methodology which is represented by its five distinctive steps all starting with S: Seiri (Sort), Seiton (Set in order or Straighten), Seiso (Shine), Seiketsu (Standardise), and Shitsuke (Sustain)	Johansen and Walter (2007), Stehn and Höök (2008), Ansah and Sorooshian (2017), Caldera et al. (2018)
• Productive meetings	Productive meetings	Salem et al. (2005)
• Off-site prefabrication	It consists of using modularised and prefabricated construction components with the aim to overcome the common production problems encountered during on-site construction (i.e. low output quality, low productivity, high variability, and poor safety)	Thaís da et al. (2012), Bajjou et al. (2017b)
• Error/mistake-proofing (poka-yoke) systems	Poka-yoke, a Japanese word, is a mechatronic device that works as an error proofing mechanism, avoiding mistakes and defects from flowing through the process. It allows increased quality of the construction process and improves safety conditions for the workers	Dos Santos and Powell (1999), Tommelein (2008), Ansah and Sorooshian (2017), Bajjou et al. (2017c)
• Root cause analysis/Five Whys	It is a problem-solving technique used to identify the root causes of a targeted problem. The questions are usually specific to the project and are not limited to five questions. The Five Whys are generally dependent on each project separately and are not restricted to five questions It is a method of qualitative analysis of the reliability which makes it possible to assess the risks of the appearance of failures, to evaluate their consequences and to identify their root causes	Bajjou et al. (2017b), Sarhan (2017)
• Health and safety approach; OHSAS 18001	Health and Safety (H&S) compliance in the UK is governed by EU legislation largely through the Health & Safety at Work Act 1974 and Construction (Design and Management) Regulations CDM (2007), pending replacement of CDM (1994), CHSW (1996), and ACoP (1994)	Harris and McCaffer, 2006 Mohd Yunus (2006)
• Six Sigma	Six Sigma is an organised and efficient process for strategic process improvement and new	Pepper and Spedding (2009), Abdelhamid (2003)

	product and service development that relies on statistical methods and the scientific method to make significant reductions in customer defined defect rates (Linderman et al., 2003). The existence of Six Sigma as a continuous improvement technique in a project would provide a combined, coherent, and holistic approach to continuous improvement of the project (Pepper and Spedding, 2010)	
• Kanban system and quality circle tools	The term 'kanban', a Japanese word, refers to signs or cards used in controlling the amount of material/ components in stock. This technique is adopted in the construction industry as a mechanism to pull materials and components throughout the value stream on a JIT approach	Sarhan et al. (2017), Tezel and Aziz (2017a)
• Last Planner	The person or group that makes assignments to direct workers. Project Architect and 'discipline lead' are common names for last planners in design processes. 'Superintendent' and 'foreman' are common names for last planners in construction processes.	Lean Construction Institute (2014)
• The Lean Project Delivery System (LPDS) of the LCI	The LPDS is divided into four interconnected phases: project definition, lean design, lean supply, and lean assembly	Howell and Ballard (1997)
• Environmental management system (EMS)	EMS	Puvanasvaran et al. (2011)
• Standardisation	Standardisation can be described as a set of methods, components, or processes in which there is repetition and regularity leading to successful practices, also called Standard Operating Procedures (SOP). This technique allows building in the shortest possible time and with the minimum of effort	Fitchett and Hartmann (2017), Tezel et al. (2018)
• Prefabrication	It consists of using modularised and prefabricated construction components with the aim to overcome the common production problems encountered during on-site construction (i.e. low output quality, low productivity, high variability, and poor safety)	Thaís da et al. (2012), Bajjou et al. (2017b)
• Waste elimination	This technique is the core of the LC concept. It aims at spreading a culture among the employees to eliminate the various sources of waste (overproduction, quality defects, unnecessary transportation, over-processing, waiting, inventory, displacements, and unused employee creativity)	Khanh and Kim (2015), Zhang et al. (2017)
• Value Stream Mapping (VSM)	A material and information flow mapping technique which is used to analyse the current state and to design the future one of a production or service delivery from its beginning through to the customer; an information and material flow mapping tool, which is used to graphically visualise the current value stream and design the future state of the construction process while reducing all sources of waste (overproduction, waiting, inventory, displacements, etc.)	Yu et al. (2009), Rosenbaum, Toledo, and González (2013), Yu et al. (2009), Bajjou et al. (2017c)
• FMECA (Failure mode effects and criticality analysis)	Risk analysis is an essential step in the construction project management, and AMDEC or Analysis of failure modes, their effects and their criticality is the English translation of the FMECA, is one of the most used tools in this field. It is a method of qualitative analysis of reliability which makes it possible to assess the risks of the appearance of failures, to evaluate their consequences, and to identify their root causes	Ansah and Sorooshian (2017), Ferng and Price (2005)
• Pareto analysis	A Pareto chart is a graph highlighting the most important causes having an effect on the analysed system and thus allows the development of	Aziz and Abdel-Hakam (2016), Mandujano et al.

	innovative actions to improve the current situation	(2016)
• Ishikawa diagram	This is an effective quality tool used to identify the causes of an inherent problem. It is considered a powerful tool for the root causes analysis (RCA) approach	Dakhli et al. (2016), Bajjou et al. (2017a)
• Lean construction wheel	To assess the extent to which an organisation conforms to lean ideas	Diekmann et al. (2004)
• Three views of construction production	To build theoretical foundation for LC	Koskela (1992, 2000)
• Lean assessment framework	To evaluate the implementation of each lean tool within the proposed framework	Salem, Solomon, Genaidy, and Minkarah (2006)
• Lean construction as socio-technical design	To reveal that both lean manufacturing and LC are rooted in common human and technical elements	Paez et al. (2005)
• Application of flow model in construction industry	To develop the heuristic implementation approaches of the flow model	Santos (1999)
• Line of balance method (location-based planning)	A graphical work scheduling, control, and balancing method which is based on planning/work balancing with respect to location and often used in linear construction projects (i.e. highways, high-rise buildings, etc.)	Mendes and Heineck (1998), Soini, Leskelä, and Seppänen (2004)
• Takt time planning	Work planning based on the time set for the supply of a certain process (takt) that is derived from the customer demand. It forms the basis for single-piece flow in lean thinking	Yu et al. (2009), Frandson, Berghede, and Tommelein (2013)
• Work structuring	A term used to describe the effort of integrating product and process design throughout the project development process to optimise production on site	Tsao et al. (2004), Frandson, Seppänen, and Tommelein (2015)
• Set-up preparation and improvement	Systematic study of a work set-up to optimise each task involved in terms of efficiency and safety, which is also explained under the term Single-Minute Exchange of Dies (SMED)	Filho et al. (2005), Paez et al. (2005)
• Supply chain integration	A close alignment and coordination within supply chains through partnering, long-term contracts, training support for service providers, transparency in information flow, shared risk/benefits, and so on	Dainty, Millett, and Briscoe (2001), Briscoe and Dainty (2005)
• In-station quality – Jidoka	Providing machines and operators the ability to detect when an abnormal condition has occurred and immediately stop work. Together with SOPs, Visual Management, Statistical Process Control (SPC), and mistake-proofing systems, it enables in-station quality or quality at source	Kemmer et al. (2006), Heineck et al. (2009)
• Standard Operating Sheets (SOPs)	Visual documentation of a work process displaying the required material components, process steps, and production rates. SOPs form one of the bases for work standardisation Also called Standard Operating Procedures (SOP), this technique allows building in the shortest possible time and with the minimum of effort	Arbulu and Tommelein (2002), Nahmens and Ikuma (2011)
• Pull production system using kanbans	Controlling and harmonising production between work units based on the number of specific cards, tokens or signals called kanbans	Tommelein (1998), Arbulu, Ballard, and Harper (2003), Ko and Kuo (2015)
• Pre-fabrication and modularisation	Extensively using prefabricated and modularised construction components to overcome the inherent production problems of on-site construction (i.e. low productivity, low output quality, high variability, health and safety hazards)	Gosling and Naim (2009), Gosling et al. (2016)
• Cell production units (multi-functional construction work units)	Forming teams of different construction trades (i.e. plasterer. electrician, carpenter) to work together as a work unit in a particular construction site location to minimise work-in-progress and to maintain a continuous production flow	Moser and Dos Santos (2003), Mariz et al. (2013)
• Information technologies to support lean construction deployments	Extensive use of digital technologies (i.e. mobile systems, distributed databases and cloud computing, sensor networks, etc.), particularly Building Information Modelling (BIM) technology, an object-based, parametric, virtual prototype of a construction asset that can be used from the asset's design to demolition to facilitate the information flow in lean construction deployments	Sacks et al. (2010), Becerik-Gerber et al. (2011)

One key feature of LC appears to be LPS, also known as 'Pull Schedule' or 'Reverse Phase Scheduling' (RPS), which has been developed by Ballard since 1992. Over the years it has been applied by a number of authors and within a range of countries (e.g. in Saudia Arabia by AlSehaimi (2011) and AlSehaimi et al. (2014), in Nigeria by Ahiakwo (2015), Ochao (2014), Solis et al. (2013), and Adamu and Hamid (2012), in Ecuador by Fiallo and Revelo (2002), in Chile by Alarcon et al. (2015), and finally in Malaysia by Marhani et al. (Issa, 2013)).

According to Koskela (1992, 2000) lean thinking is a philosophy based on the concepts of lean production. To differentiate this theoretical foundation from pure production activities, they called it 'lean thinking' (see also Sarhan and Fox, 2013; Tezel et al., 2018).

Moreover, improving flows of production is an important aspect in LC (Court et al., 2009; Gonzalez et al., 2008, 2009; Aziz and Hafez, 2013; Issa, 2013). Sacks et al. (2009) stated further that achieving smooth and stable flow in production processes is a central tenet of lean thinking. Lean construction itself presents a new well-organised method for construction projects (Alarcon, 1997). Lean is a philosophy of managing human organisations and so it involves techniques but between the philosophy. For example, Last Planner is a tool for production control at site level (Ballard, 2013; Aziz and Hafez, 2013; Court et al., 2009; Gonzalez et al., 2009; Gonzalez et al., 2008; Issa, 2013).

Al-Aomar (2012) emphasised that lean thinking at all project stages is imperative for the development of any LC framework. According to Yusof (2019), an approach of integrating lean thinking into the design process of a construction project can achieve substantial benefit at the design stage, from which significant gain can be embedded at a key stage of the construction cycle. However, the construction sector lags behind other sectors as highlighted in the Egan Report (1998) and more recently in Sir John Egan's speech to the House of Commons in 2008 (Ward, 2015).

Paul Morrell's report of 2011 further set out how to improve the efficiency, cost-effectiveness, and sustainability of construction work for the UK government. He led the UK Government, Innovation and Growth Team, that produced an influential report, *Low Carbon Construction*, published in November 2010 (Morrell, 2011a). He was also the instigator of

the *Government Construction Strategy* (published in May 2011; see Morrell, 2011b) which, echoing the earlier Latham and Egan Reports, stressed how the construction sector needed to work more collaboratively and to use information technology, notably BIM, to support the design, construction, and long-term operation and maintenance of its built assets. Morrell was a strong advocate of BIM, having publicly backed its use in 2010, and BIM was made mandatory for all centrally procured public sector construction projects from 2016 (see Morrell, 2011c, 2011d; Architects' Journal, 2012).

A key factor that affects the use of lean production within construction (LC) is complexity. Construction is a complex production of a one-of-a-kind product for a customer. Within this intimate relationship, clients, external factors, and site conditions, to name a few aspects, are all sources of inherent complexity. Thus, these complex interchanges need to be fully appreciated if the benefits of LC are to be realised.

2.4.7.1 Key concepts of (and related tools for) LC

Other management philosophies exist for LC and include total productive maintenance (TPM), employee involvement, continuous improvement, benchmarking, time-based competition, concurrent engineering (CE), value-based strategy (or management), visual management, reengineering, and lean manufacturing. Alinaitwe (2009) further added business process re-engineering (BPR), CE, and LPS; Harris and McCaffer, 1997) added teamwork and value-based management (VBM).

Kaizen; DFSS; Theory of constraints; Lean project delivery system (LPDS); BIM; KanBIM: is a BIM-enabled pull flow construction management software system based on the LPS (Sacks et al., 2010); Integration/link between lean construction (tools) and BIM; Value management/engineering; Designing a pull system; Sustainability (sustainable construction and development); Environmental sustainability are also key concepts of lean construction.

Salem et al.'s (2005) study evaluated the effectiveness of six key LC concepts in the University of Cincinnati's garage project. The data collection methods included observations on sites, interviews, questionnaires, and documentary analysis. The key concepts involved were:

- LPS;
- Increased visualisation;
- Daily huddle meetings;
- First run studies;
- 5S (housekeeping) process;
- Fail safe for quality and safety.

Based on Salem et al.'s findings, implementation of the 5S process and fail safe for quality and safety were found not to meet the expectations due to an increase of the budget. There was a need for behavioural changes and training for effective use of the key concepts here. The rest of the key concepts selected for the project were either ready to use or were recommended with some modifications.

Similarly, Adamu and Hamid (2012) investigated LPS using four key concepts and tested them in the construction of housing units in Yobe State Government, Nigeria. Due to some constraints, 5S was not tested. However, the data collection methods did include direct involvement in the production management, interviews, and questionnaires. Based on the findings, effective training, full implementation of LPS, and partial implementation of the other key concepts have reduced and eliminated waste on site. It was also found that there was a need for cooperation of top management to improve the interest in LC amongst the stakeholders.

Suresh et al. (2011) introduced nine primary key concepts of LC that could be implemented in LC practice. These key concepts essential to the implementation of LC are:

- LPS;
- Productive meetings;
- Increased visualisation ;
- Off-site prefabrication;
- 5Ss/5Cs;
- Mistake-proofing/poka-yoke;
- Root cause analysis/five "whys";
- First run studies and JIT.

Whilst each method has subtle differences, there is no need to use all these key concepts in a construction project. The literature search found that there is a demand for more holistic approaches to be integrated in the existing LC key concepts application with other concepts. For example. Bashir et al. (2011), introduced health and safety approach in the implementation of lean principles. Bashir et al. (2011) suggested that OHSAS 18001 could be incorporated with the key concepts of LC. This is a fair assumption given that OHSAS 18001 has been rigorously tested and is an internationally recognised approach to improving the health and safety performance of a construction company. As a result, by having a safer and more conducive workplace at sites, it increases the productivity of the project and provides improved job satisfaction for the client.

Moreover, by using LPS as the basis of the LC approach, Abdelhamid (2003) suggested using of Six Sigma application opportunities in construction projects. In general, Six Sigma is an organised and efficient process for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make significant reductions in customer-defined defect rates (Linderman et al., 2003). The existence of Six Sigma as a continuous improvement technique in a project would provide a combined, coherent, and holistic approach to continuous improvement of the project (Pepper and Spedding, 2010).

2.4.7.2 Lean construction theories

The TFV model of production formulated by Koskela (1992) is reported to be able to improve performance once applied to construction. Also known as the TFV theory of production, it utilises three major theoretical models of production (Sacks, 2009; Sarhan and Fox, 2013):

- Production as Transformation;
- Production as Flow; and
- Production as Generation of Value.

The Production as Transformation view analyses identifies distinct steps that each add value to the product (Ohno and Shingo, 1998). According to Womack et al. (1996), lean production

is considered a sequence of activities which switch between value-adding and 'inspecting, waiting, and moving', which are non-value-adding. The focus is on optimisation of value-adding activities. That said, non-value-adding activities are not ignored. recognising that waste can be detected and removed for the total improvement of the production process. This is called Production as Flow.

In LC, production is observed as a value generation process (Production as Generation of Value). That is, a company produces exactly (and only) what and when the customer requires it. The customer determines value, and the manufacturer only finds the best way to reach the aim. Implementation of lean thinking will be explained in the following sections.

2.4.7.2.1 A review of the Last Planner production control system

Last Planner® is a holistic system, meaning that each of its parts is necessary to support lean project planning and execution. The Last Planner® System of production control is necessary on projects to support working toward planned accomplishments, doing what can be done to move along a planned path, and when that becomes impossible, determine alternative paths that accomplish desired goals.

"LPS is known to be the most developed practical use of Lean Construction. It focuses on minimising the negative impacts of variability, uncertainties, buffers, making projects more predictable, creating reliable work plans and convalescing collaborative planning" (Ahiakwo, 2015).

Last Planner is a perfect method for controlling real production at the workface, that is, it is not ideal for the strategic development and progress of a master schedule for the project, as the Critical Chain Method (CCP) is. The Last Planner, that is the first line supervisor (manager) of labour, thinks, analyses, and evaluates what activities 'should' and 'can' be carried out at the present or at a particular moment, for example in the next week, and decides which 'will' be done, that is the Last Planner 'shields' production. This replaces the need for buffers (Ballard, 2000, 2013).

2.4.7.2.2 Reducing task duration variability – Last Planner

Percentage Plan Complete (PPC) considers the activities planned to be carry out on a weekly work plan; it can be calculated using Equation 2.1:

$$PPC = \frac{\text{(Number of completed activities on plan)}}{\text{Total Number of Activities on Plan}} \quad (2.1)$$

Master Schedules show the feasibility and possibility of finishing the work within the time available. In addition, they build up and show strategies for execution. This allows a decision to be made and, from this, a user can specify when long-lead items will be required or wanted. This requires recognition of milestones that are essential and important to stakeholders or clients by utilising:

(1) *Look-ahead process:* By utilising First Run Studies and the Activity Definition Model; there are several key components:

- **Explode** scheduled activities into detailed assignment level within the lookahead window.
- **Screen** the limitations on every task that is assigned by eliminating limitations or constraints.
- **Make** the assigned tasks ready.
- **Balance** capacity and load by bringing forward/delaying scheduled work, increasing/decreasing capacity, or making a decision, choosing or determining how to invest excess capacity as wanted or required.
- **Adjust** the Master Schedule or Phase.
- **Learn** to evaluate, determine, and advance/develop the performance.

(2) *First run studies:* A clear and unambiguous detailed plan for a process built up previously or before starting the work. Comprises application and review, health and safety considerations, process design comprising workflow, tools, timing and location of activities, release of work downstream, crew balance, etc. A plan is built up with the individuals engaged in carrying out the work, and then tested and improved. The real/definite procedure is recorded and examined to recognise developments.

(3) *Screening and constraints:* Through eliminating constraints, activities and tasks are made ready to be assigned. Screening is the procedure of examining the tasks for constraints and assessing if they can be removed in time for the planned beginning.

(4) *Purpose of weekly work plans (WWPs):* The last step of planning prior to publishing and announcing assignments for implementation. This utilises the 'Five Criteria' to make sure assignments can be finished while achieving a decrease in variation. This gives information to support improvement and learning. Definition, soundness, sequence, size, and learning are quality characteristics of WWPs (Ballard, 2000, 2013). Figure 2.6 shows the LPS and critical chain combined (Winch, 2010).

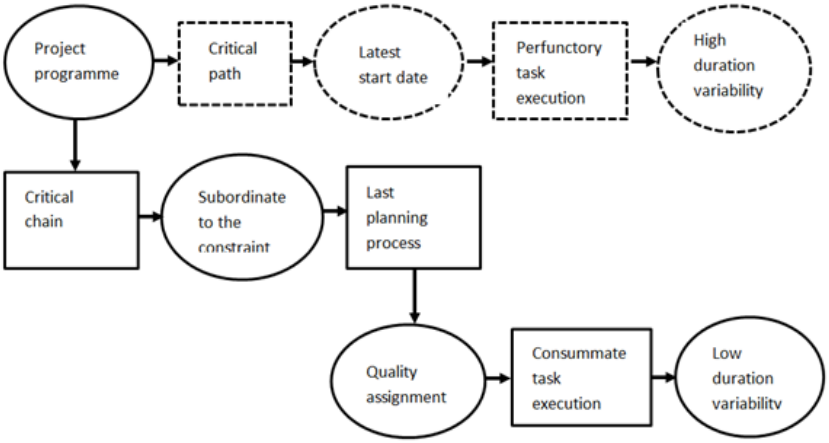


Figure 2.6: Last Planner system and critical chain combined (Winch, 2010)

2.4.7.2.3 Previous applications/implementations of LPS to construction projects

The LPS (also known as Pull Schedule or RPS) has been continually developed by Ballard since 1992. According to him, future research areas have been proposed, including root cause analysis of plan failures and quantification of the benefits of increased plan reliability for both design and construction processes (Ballard, 2000). Over the last 20 years, Ballard and other authors have sought to fill this gap.

Before the research reported in this thesis (see Chapter 5) was conducted, the LPS had been applied in full to the construction phase of projects. For example, a research study based on action research by Al-Sehaimi (2011) examined the effectiveness of implementing LPS to

improve the construction planning and control process, aiming to minimise related causes of delay by bringing together empirical data showing the implementation of LC techniques in construction projects in Saudi Arabia.

The findings of Al-Sehaimi (2011) “reinforce those of LPS studies in other countries, with some differences. In other words, in the light of the benefits achieved, it can be stated that LPS is a universal technique applicable to different contexts and local conditions. Major benefits are demonstrated in terms of improving management practice, while various causes of delay can be identified and dealt with regularly”.

Research undertaken by Brady (2014), “provides a new model and associated method for applying Visual Management for production planning and control in construction”. Furthermore, research investigations into the implementation of the LPS in Nigeria, “to improve construction processes within the Nigerian construction industry” were carried out by Ahiakwo (2015). A framework was developed to mitigate the barriers to implementing LPS in construction projects in Nigeria. It was revealed from a focus group that the framework has the potential to facilitate the implementation process as proposed.

In research aimed at improving construction management practice with LPS, AlSehaimi et al. (2014), Chamberlin et al. (2017), and Sacks et al. (2010) have tested LPS in combination with visualisation.
Research undertaken by Biotto (2019) set out to “devise a model to design, plan and control the stages of design and construction in the context of projects with overlap between these stages, using location-based scheduling (LBS) tools and other lean practices to pull and align the project production regarding location, sequence and takt-time”. Her findings indicated that “the use of LBS tools applied in construction to pull production in design and supply. The production control is conducted by an adapted last planner system to confirm and align deliverables with construction. The final model of this research can be used in the project management of construction projects with overlapping of design and construction phases, for example fast-track construction, flash-track construction, and complex projects with concurrent development of design and construction”.

2.4.7.2.4 The influence of cost on LC – current LC approaches for implementing cost

Controlling the budget using the product breakdown structure (PBS) is at the centre of cost management and planning. The cost planning hierarchy is shown in Figure 2.7. The benchmark of cost per unit is used in the earliest phase of the project. As the design is developed, more precise figures per m^2 or other appropriate measures can be developed. As more design detail becomes available, the information can be broken down into the elemental cost plan. The lowest level of detail available in PBS terms is provided by the bill of quantities.

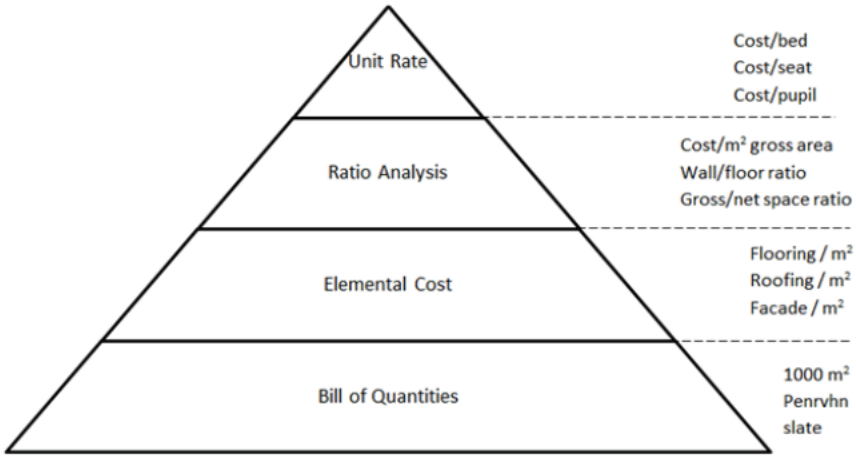


Figure 2.7: The cost planning hierarchy (Winch, 2010)

Three key aspects exist here:

(1) **Value engineering and cost management:** To recognise 'unnecessary cost' and so bring the facility back on estimated budget, therefore guaranteeing the feasibility of the project is the aim of the value engineering process (Winch, 2010).

(2) **Constructability:** Improving conformance quality, reducing the schedule, or removing safety hazards, reducing waste, and increasing productivity is the aim of constructability.

(3) **Controlling the budget:** The work breakdown structure (WBS) tends to be developed iteratively as the project progresses. The first level of the WBS is the trade package level. The next level might be whole trade tasks such as formwork. Below this level, the WBS might be broken down into elements. The finest level of detail – which is often left to the subcontractor – is the weekly one. This level is required because operatives tend to be paid on a weekly cycle, and this is the planning cycle

recommended by advocates of the last planner technique. Every element in the WBS will be broken into the three typical elements, which are the labour, plant, and materials costs needed for execution of the task; this is known as the cost breakdown structure (CBS). The matrix of the CBS and the WBS generates the database categories for the project at their highest level of detail. Combined with the organization breakdown structure (OBS), this matrix provides the Cost Control Cube (Winch, 2010; Zhang, 2014).

2.4.7.2.5 The influence of cost on LC – current LC approaches for implementing quality

This section reviews various concepts associated with quality and then considers the contributions of quality control, quality assurance, and TQM to the quality of construction. It also addresses the growing use of quality management systems for achieving superior performance in construction. It highlights the fact that quality in construction can be achieved only through the direct effort of all stakeholders of the project.

Gene Miller of Mosher Steel (cited in Sabbagh (1989)) identifies both the cost of non-conformance and the problems generated by the culture of broad tolerances; stating therein that troubleshooters do not add value, and their resolutions of misfits can have knock-on effects elsewhere on conformance, budget, and schedule.

Quality of specification; quality of conformance; quality of conception; and quality of realisation are the four different meanings of quality in construction which are related to each other (Low, 2012).

The principles of quality management systems (QMS): The four main components of QMS are illustrated in Figure 2.8. The four basic approaches identified are: (1) inspection; (2) quality control (QC); (3) quality assurance (QA); and (4) TQM (Bassioni, 2004; Winch, 2010; Low, 2012; Lari et al., 2013; Alshehri, 2016; Ahato, 2019).

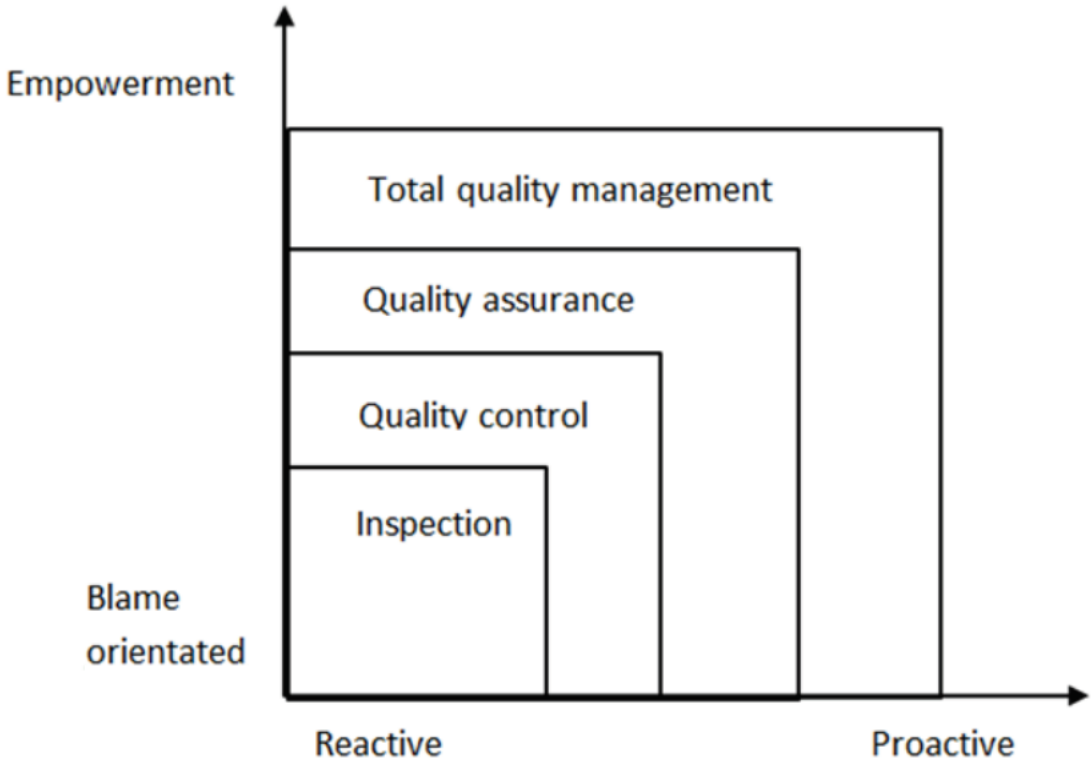


Figure 2.8: Approaches to conformance quality management (Winch, 2010)

According to Winch (2010) the following concepts are component parts of quality management:

- An Acceptable quality level (AQL).
- Corby's argument.
- Quality loss function (QLF).
- NPV.
- Failure mode and effect analysis (FMEA): There are three elements to FMEA: occurrence, detection, impact; risk priority number (RPN).

The role of inspection in QC is to identify when there is a problem to be tackled. Higher levels of process capability will reduce inspection requirements for a given tolerance band. Inspection is the least sophisticated level since "Quality control is the part of quality management focused on fulfilling quality requirements. There are a number of operational techniques available" (Winch, 2010).

Reference is often made to Ishikawa's seven QC tools (1990). However, other researchers have identified seven new QC tools, for example Oakland (1993). These tools are often the basis of process improvement projects (PIPs). QC focuses on: cause-and-effect diagrams; performance measurement; statistical process control; and value-stream mapping. QA is the 'part of quality management focused on providing confidence that quality requirements will be fulfilled' (Winch, 2010).

QA systems are of three basic types (Winch, 2010):

(1) first-party systems, which are the responsibility of the company concerned alone;
(2) second-party systems, where suppliers are accredited by buyers using proprietary standards – common in defence procurement and the volume manufacturing sectors; and
(3) third-party systems, where the QA system is certified by an independent third party.

In addition, there are several key elements required when creating a culture of improvement:

(1) Empowering those doing the work;
(2) Training – which is crucial for success;
(3) Organisational learning;
(4) Aligning incentives with desired performance;
(5) Senior management commitment is essential; and
(6) Using formal PIPs.

Management practice in conformance is increasingly focused on the role of formal PIPs. These combine the control loop thinking behind kaizen-type PDCA cycles with types of process improvement tools. Moreover, kaizen is a well-established quality improvement approach, and both ISO 14001 and OHSAS 18001 have PDCA 'front ends' which emphasise the dynamic nature of achieving high environmental and safety performance. One of the most widely diffused PIP routines is Six Sigma with the DMAIC cycle (Define; Measure; Analyse; Improve; Control) at its core (Winch, 2010).

Quality awards and self-assessment: To give greater focus to TQM efforts, several countries have developed quality awards such as the EFQM Excellence Model. The model is divided into enablers and results (Winch, 2010).

Conformance management in construction still relies largely on the least sophisticated level – inspection: "*The conventional approach to defining project success is in relation to the Time/Cost/Quality project performance Model - a successful project is on time, below cost and conforms to specification. However, this is a rather limited notion; it is an execution-based approach not a total project life cycle approach. We need to develop a more sophisticated definition*" (Winch, 2010).

The presence of a conceptual framework for product integrity in construction, as summarised in Figure 2.9, is the starting point for assessing project success.

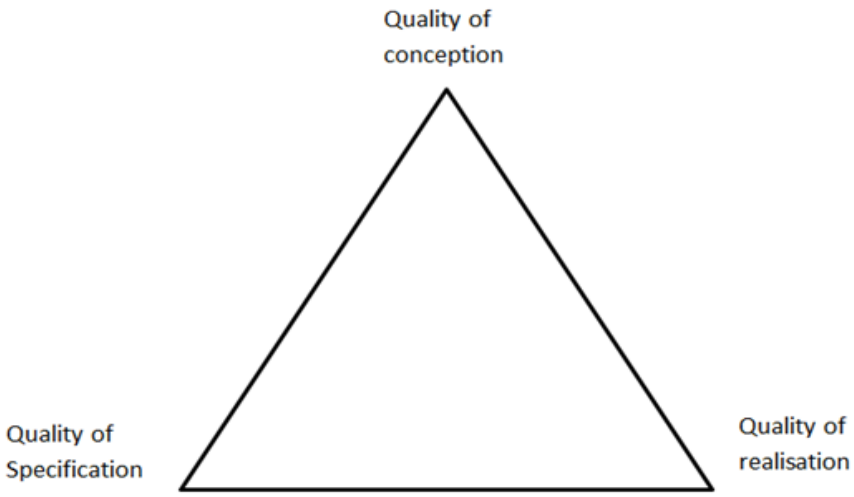


Figure 2.9: Product integrity in construction: the quality of intention (Winch, 2010)

Figure 2.10 demonstrates how product and process integrity in construction stem from Figure 2.9.

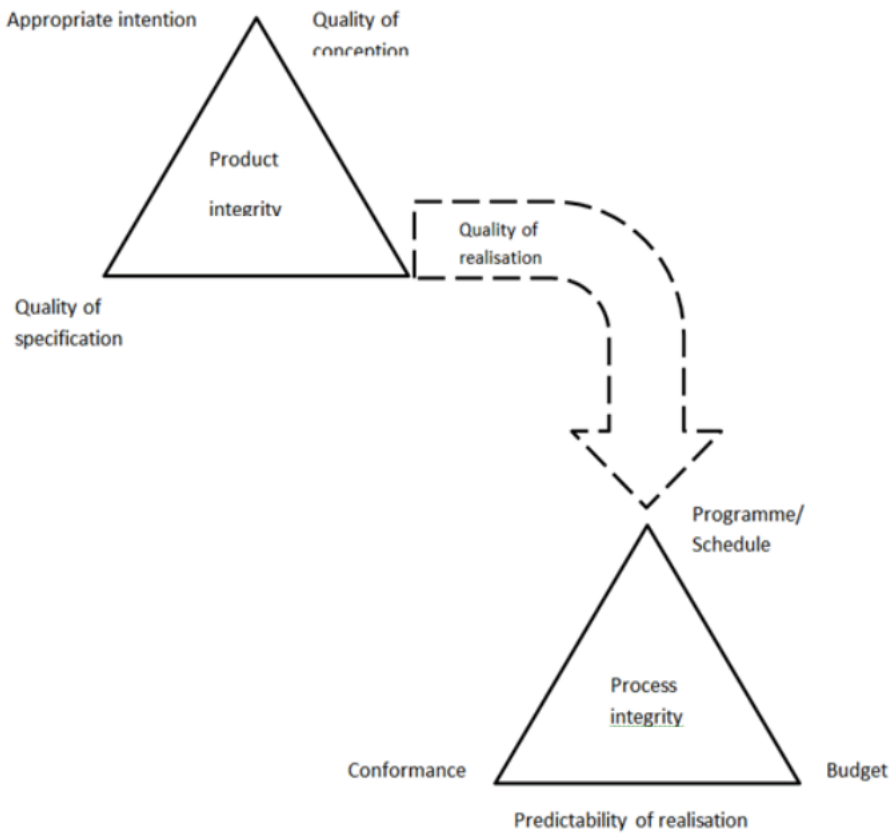


Figure 2.10: Product and process integrity in construction (Winch, 2010)

2.4.7.3 Implementation and experience of LC framework

Several LC frameworks have been developed which can be utilised for implementation if they can be fully understood and are practical and feasible. To be specific, several proposed LC models are reviewed here, namely:

- Application of flow model in the construction industry (Santos, 1999);
- Three views of construction production (Koskela, 1992, 2000);
- LPS (Ballard, 2000);
- LC wheel (Diekmann et al., 2004);
- Green and May's (2005) model;
- LC as socio-technical design (Paez et al. 2005);
- Lean assessment framework (Salem, Solomon, Genaidy, and Minkarah, 2006); and
- Johansen and Walter's (2007) model.

The main advantage of LC implementation in projects is that construction companies could cut down the construction cost due to use of correct materials and less waste at sites (Suresh et al., 2011) due to proper project planning.

According to Marhani et al. (2013), based on the literature review, it can be summarised that there are seven main barriers to implementing LC. Aspects such as managerial, technical, human attitude, the process of LC, educational, government and financial are among the other main barriers. According to Abdullah et al. (2009) and Mossman (2009), a lack of commitment from top management of a company is one of the main barriers to implementing LC. This barrier refers to various aspects that are related to the support shown by the top management in an organisation. Kim and Park (2006) found that many construction projects face a lack of support from the top management. In addition, a lack of communication among stakeholders also occurs in construction projects (Abdullah et al., 2009). This will lead to disruption and ineffectiveness of the delivery and coordination system.

Without continuous support from the top management, the stakeholders involved in the construction industry may face numerous difficulties in adopting the LC concept. Besides that, the top management of a construction company should overcome this breakdown in communication so that it will not contribute to low productivity and quality of the projects.

Alinaitwe (2009) highlighted that a lack of buildable designs is one of the main barriers under technical aspects. In addition, certainty in the production process and provision of benchmarks also contribute as the main barriers during implementation of LC. Meanwhile, Tindiwensi (2006) found that most architectural designs lack constructability elements due to limited knowledge about construction practices and the separation of design from construction contributing to a breakdown of the production process during construction. This will have an impact on the implementation of LC, specifically on the workers' productivity. Therefore, all stakeholders should be involved from the pre-construction stage and take into consideration the buildability and constructability of the design and process. By doing so, changes to designs during the construction stage that could disturb the production process can be avoided.

Howell (1999) added that human attitude is one of the main aspects that slows down the

execution of LC in the industry, especially during the physical implementation phase. According to Kim and Park (2006), the attitude of the stakeholders in a construction project to the LC concept is a sensitive factor that in fact influences the success of implementing the LC concept. Abdullah et al. (2009) further explained that attitude here refers to the tendency regarding intent, commitment, and co-operation that needs to be presented by the stakeholders if they want to implement LC successfully. This kind of thinking will thus determine their performance of work and will affect the productivity of a construction project.

In addition, the lengthy implementation period of the LC process is regarded as a barrier to implementing LC. Based on the work of Kim and Park (2006), it was discovered that the implementation of LC in construction projects had resulted in too many meetings and information needed for discussions. Moreover, these meetings had to be held regularly and took up too much time when poorly managed. This occurs especially during the pre-construction stage, but if this situation is well managed it will generate profit and have positive effects on the construction company itself, especially on boosting their reputation.

The stakeholders involved in a construction project need to be given ample training to enable them to possess the necessary knowledge and expertise in implementing the LC concept (Abdullah et al., 2009; Alinaitwe, 2009; Mossman, 2009). Inadequate exposure to the requirements for LC implementation is also regarded as a barrier (Abdullah et al., 2009; Alinaitwe, 2009) to LC implementation. The training given must be balanced with understanding the concept and principles of lean as well as comprehending the key concepts required to undertake the LC concept. Furthermore, training and educating the employees may take time and effort. Hence, top management should play an important role to expand training and education, to improve understanding of the LC concept.

Finally, inflation due to unsafe market conditions for construction, additional construction costs, and poor salaries of professionals (Olatunji, 2008) are barriers to financial aspects. A lack of incentives or reward systems in a construction project can also prevent wide implementation of LC (Alinaitwe, 2009). A sufficient source of funding is a must to ensure a construction project runs smoothly. The provision of contingency cost will protect the

construction project from inflation or additional construction cost due to instability of the construction markets.

Regarding construction management barriers, according to Adnan et al. (2019), there are barriers to the application of LC techniques concerning safety improvement in construction projects (Lim, 2008; Lean Enterprise Institute, 2009; Bashir et al., 2011).

According to Bajjou, and Chafi (2018b), there are barriers to the implementation of lean construction in the construction industry. Bayhan et al. (2019), studied the Enablers and barriers of lean implementation in construction project. Thoumy et al. (2018), explored barriers in the implementation of lean construction management.

According to Ahiakwo (2015), the Nigerian construction industry is associated with several challenges which impair its performance. These challenges were grouped into six major barriers: resistance to change, cultural issues, supervision and QC, fluctuation and variations, subcontractor involvement, and lengthy approvals, the first two revealed as the most important.

These aspects will all be considered in the development of the final modelling framework produced.

2.4.7.4 Set-based concurrent engineering (SBCE) approaches

In the construction industry, SBCE approaches have been applied to the construction phase such as in site layout, construction engineering, engineering design, and construction technology. SBCE has attracted a fair amount of attention in recent years. Ballard (2000) hypothesised that the application of SBCE in combination with several additional lean product development enablers would reduce negative iteration in design. He suggested several strategies for reducing negative iteration in design.

The "study on the use of 'set-based design' in the Toyota production development provides the procedures on how the Toyota designers produce sets of design alternatives and gradually narrow the set until they come to a final solution. However, in some perspectives, this system

of product development process is an inefficient system. Apparently, Ward et al. (1995) does not present a detailed process or methodology for the system" (Yusof et al., 2015). The value, knowledge (or learning) and improvement elements presented enabled Toyota to achieve customer needs through optimising designs, minimising design rework, and achieving high profit levels; the process was named SBCE (Khan et al., 2011; Khan, 2012). The traditional method can be called a point-based method, while the proposed method can be called a set-based method. The advantage of using a set-based method is that the waste in the construction process is eliminated by every activity embedded in the construction phases; and by eliminating waste, the value can be maximised.

Whilst providing detailing on every single method is beyond the scope of this thesis, references are provided such as in Table 2.1 and Table 2.5. Additionally, the literature search also highlighted that there is a demand for more holistic approaches to be integrated within LC. For example, Bashir et al. (2011) introduced a health and safety approach (i.e. OHSAS 18001) in the implementation of lean principles.

2.5 Building Research Establishment and Environmental Assessment Method (BREEAM)

The BREEAM tool, the longest serving tool of its kind in the world, evolved in the United Kingdom (UK) in 1990 to address critical environmental issues such as climate change, the fossil fuel crisis, and rapid urbanisation. The English planning system encourages new building and major refurbishment projects to adopt this tool to promote Sustainable Building Development (SBD). Recently, landscape practitioners in the UK have raised concern that the tool focuses on energy, transport, materials, and ecological aspects (such as native species), while other fundamental landscape values are not considered. Landscape is fundamental in terms of building and infrastructure, as it is a combination of different components such as land use, nature, and wildlife and is a key aspect of culture. The SBD context is often characterised as comprising three pillars – environment, society, and economy. However, to fully integrate landscape, this research incorporates a fourth pillar, that of culture. BREEAM focuses on waste reduction in both aspects of construction and operation of buildings and as such very much advocates implementation of such aspects as SWMPs (See Section 2.6) and Resource Management Plans – RMPs.

According to Gayathiri (2021), an evaluation exercise identified that the BREEAM tool has a significant gap, which is in addressing the landscape. Further, Chen et al. (2019) considered that these management measures have limited effects in real operations (see also Yuan and Wang, 2014). The different objectives between construction contractors and government administrations are the primary reasons for the limited effectiveness in CDW management (Yuan and Shen, 2011). The first group is more concerned about profits, while the other group pays more attention to the benefits of the whole of society.

In the UK, government departments launched tougher penalties against illegal dumping (Fullerton and Kinnaman, 1995). In Europe, Gálvez-Martos et al. (2018) discussed the best management practice in CDW management. In addition, the major factors influencing the decision behaviours of management departments and contractors are supervision intensity, supervision costs, penalties, waste disposal costs, and revenues from illegal dumping. Further, raising fines is insufficient for controlling illegal dumping and achieving better CDW management (See Section 2.6).

2.6 Waste minimisation and management (WMM)

2.6.1 Good practice in WMM

According to WRAP (2020), to reduce the amount of waste needing final disposal and to use materials in a more professional and well-organised way is the principal objective of good practice in WMM. To make good business sense for the construction sector and clients, it is useful to adopt the waste hierarchy to reduce, reuse, recycle, recover, and dispose.

Good practice in WMM should follow the waste hierarchy. To minimise the total quantity of waste produced in a project should be the primary aim. Next, in order to limit the quantity sent to landfill, effective management of the waste that is produced is needed. This will include recovering the material in several waste streams for either reuse or recycling.

During the project, the potential for minimising and managing waste should be considered. To attain this, a requirement for good practice in WMM needs to be presented at the beginning of a project when there is greatest possibility of influencing its outcomes. The objective should be addressed in the following project phases (design and construction) by all parties, with the lessons learnt from the project implemented in future projects.

For delivering good practice in WMM, the formulation and implementation of an SWMP at an early stage of a project is a critical component (WRAP, 2020, p. 11). Figure 2.11 shows the procedure for this.

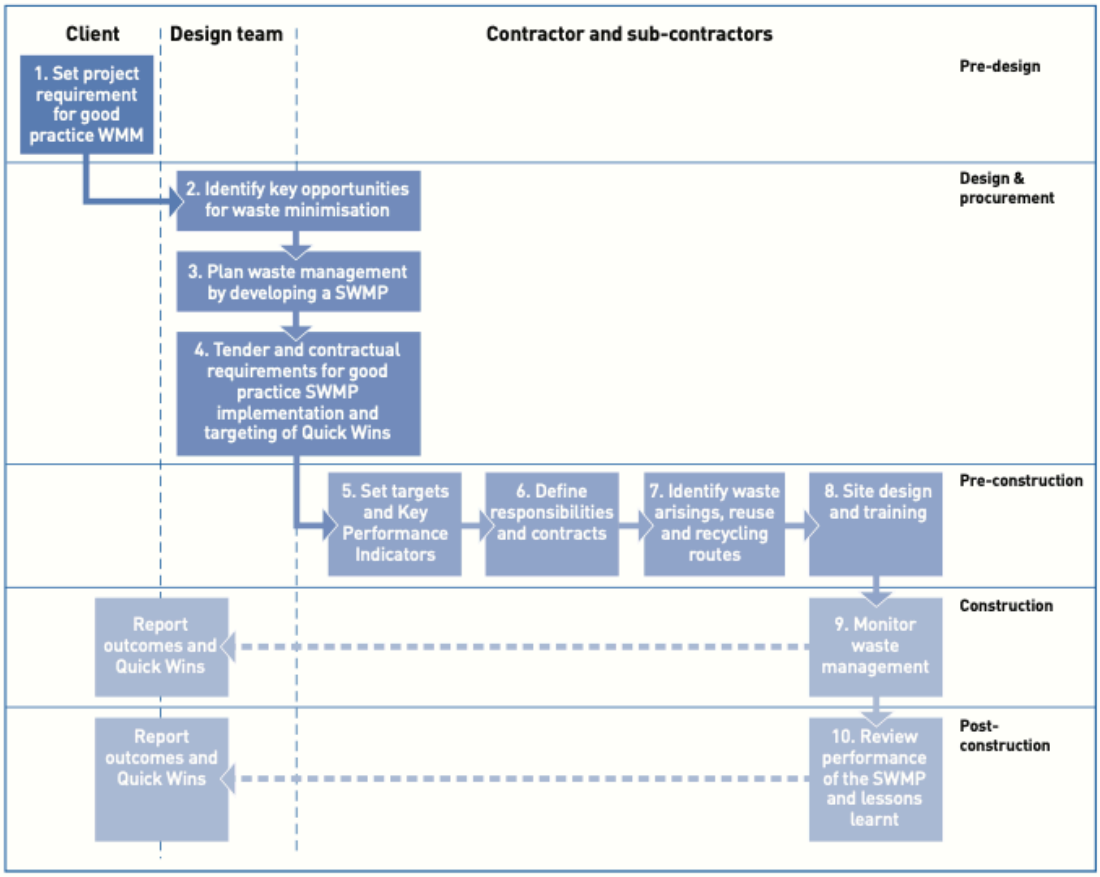


Figure 2.11: Achieving good practice in waste minimisation and management (WRAP, 2020)

According to Lu and Yuan (2011), although the term CDW considers tangible wasted materials, there is also research saying that it should be regarded as non-value-adding work (Serpell and Alarcon, 1998; Hosseini et al., 2012).

Therefore, it is advisable to give this area more attention in future studies, not least by considering how this can be integrated under the umbrella of CDW management.

2.6.2 Life cycle assessment (LCA)

Life cycle thinking (LCT) has been highly promoted in the industry as a solution to its many problems such as low trust, discontinuity, fragmentation, risks, and (most importantly) lack of sustainability. After a long period of education, LCT has now become more welcoming, evidenced by many LCA or Life Cycle Cost (LCC) methods. Thus, through this approach the thinking on CDW management should be extended to include the whole lifecycle (Lu and Yuan, 2011). However, LCT still has a long way to go as CDW management depends on the fate of LCT in the construction industry as a whole. As examples of LCT for CDW management, Craighill and Powell (1999) developed a lifecycle assessment methodology to measure the environmental, social, and economic impacts of alternative methods for managing CDW. Hao et al. (2007) suggested that the overall efficiency of CDW management will largely depend on how to integrate the information and processes involved in managing CDW throughout a project's lifecycle. Hao et al.'s (2007) study adopted this concept and through this showed the construction project lifecycle as a commonly understood process, from conception, design, construction, operation, and maintenance, to demolition. For example, Teng et al. (2018) illustrated that using prefabrication for building has many benefits, including improved construction process efficiency and reduced waste and environmental effects over a building's life cycle.

2.6.2.1 LCA of CDW

According to Wu et al. (2019), the primary purpose of studying the LCA of CDW is to promote the sustainability of the construction industry. This is because the generation of CDW takes place during two crucial life cycle stages (i.e., construction and demolition) and other stages (e.g., design and operation) of buildings and infrastructure (Blengini, 2009), and therefore the management of waste will affect the whole life cycle performance of the project. Thus, the LCA approach is applied in CDW studies (Mercante et al., 2012; Wu et al., 2015; Kucukvar et al., 2016), whose main focuses include:

- Developing models to assess the life cycle impacts of processing CDW.
- Assessing the life cycle energy and resource efficiency of processing CDW.

Thus, the LCT for CDW research provides a more comprehensive understanding of the impacts of CDW management, particularly the methods used to address the waste (i.e., reuse, recycling, energy recovery, and landfilling). However, the development of a life cycle

database for CDW is still lacking even in developing and, to some extent, in developed countries, and so limits the adoption of LCA in CDW.

2.6.2.2 ISO 14001 approach to waste management

According to Balasubramanian and Sreejith (2017), the important/relevant processes facilitating green practices (or activities/initiatives undertaken to build internal environmental resources and capabilities) identified for greening the construction sector include environmental management systems (EMS) and ISO 14001 certification, cross-functional integration, environmental auditing, environmental training and green-related research and development.

2.7 Construction management frameworks for buildings

2.7.1 RIBA Plan of Work

First developed in 1963, the RIBA Plan of Work (PoW) is the definitive UK model for the building design and construction process, also exercising significant influence on an international stage. The RIBA PoW provides "*a shared framework for the organisation and management of building projects that is widely used as both a process map and a management tool and providing important work stage reference points used in a multitude of contractual and appointment documents and best practice guidance*" for the construction industry. "*It has been amended and updated over time to reflect developments in design team organisation, changes in regulatory regimes and innovations in procurement arrangements, although these changes have generally been incremental and reactive to changing circumstances rather than strategically driven.*"

The RIBA PoW 2020 represents the most up-to-date development since its inception. It reflects the "*very best principles in contemporary architectural project and design management, and demonstrates the commitment of the RIBA to undertaking continuous improvement of its core guidance and to providing strategic leadership at a time of rapid change in the construction industry*". It organises the process of briefing, designing,

constructing, and operating building projects into eight stages and explains the stage outcomes, core tasks, and information exchanges required at each stage (RICS, 2020). These stages are:

- Stage 0 - Strategic Definition
- Stage 1 - Preparation and Briefing
- Stage 2 - Concept Design
- Stage 3 - Spatial Coordination
- Stage 4 - Technical Design
- Stage 5 - Manufacturing and Construction
- Stage 6 - Handover
- Stage 7 - Use

Setting out these eight stages (see RIBA, 2020) "*details the tasks and outputs required at each stage which may vary or overlap to suit specific project requirements*". By acting, "*across the full range of sectors and project sizes*", the RIBA PoW (see RIBA, 2020), "*provides straightforward mapping for all forms of procurement; integrates sustainable design processes*" *and* "*maps Building Information Modelling (BIM) processes*", in so doing it "*provides flexibility in relation to (town) planning procedures*".

The RIBA PoW is not a contractual document. However, it does direct readers to various tools and supplementary core documents used by a project team, including documents relating to professional services contracts, **Schedules of Services**, and project protocols, which may or may not be contractual, and to the various forms of commonly used **Building Contracts**.

The RIBA PoW 2020 (available at www.ribaplanofwork.com) "*enables the creation of a bespoke practice or project Plan of Work containing the relevant procurement (tendering), programme and (town) planning activities*". As such, it "can be tailored to accommodate" specific, "project and client requirements".

The RIBA PoW considers buildings that are refurbished and reused or demolished and recycled in a continuous cycle. If building outcomes are to improve, better briefing processes will be required. More importantly, feedback from completed projects must be available to inform subsequent projects. The RIBA PoW recognises the stages that a building project goes through and promotes the importance of recording and disseminating information about completed projects. Table 2.6 outlines several key benefits of the RIBA PoW; whilst it was written for the earlier version, it still very much applies to the latest i.e., 2020, iteration.

Table 2.6 Benefits and advantages of using the RIBA PoW (after Bailey, 2015)

Benefits of using the RIBA PoW	Comments
Explain the process to clients	It is logical and simple to follow the work stages and the task bars format helps illustrate what is to come and where the project is up to and outlines the scope of service that is being offered.
Organise your own output	It is very sensible to organise filing, electronic folders, documentation referencing, and drawing numbers into the PoW stages.
Provides clarity on fee structure	The PoW is used to illustrate what you will be doing in each stage, attribute fees to that activity, and a time allowance; as a result, fee costs seem appropriate for the work provided and the client can see with absolute clarity what they are being charged for. This also helps when trimming a fee component; it can easily be attributed to a part of the service so when the fee reduces the service and time reduces too.
Exert control of design processes	Architects can use the PoW to demonstrate the value of sequential and iterative design processes. The control of the design component of the project through the process wins time and opportunity to improve on design standards for the whole design team.
Reinforce the utilisation of project strategies	Work stage task lists produced to encourage the formulation, review, and updating of many project strategies that provide a good-quality management tool and robust discipline for the framework to complete successful projects effectively.
PoW illustrates programme	The effect of delays shows not just as a calendar event but also the impact on the time available for tasks within subsequent stages. This supports claims for additional resource or accelerated working.
Use the information exchanges	To force a complete and timely record of progress through the project. An excellent way of illustrating to the client the value architects are bringing to the process.
Encourage whole-process mentality	Using the PoW to visualise the journey taken and ahead helps contextualise the job in hand today for the project architect, their team, and the whole design team too.

Through these benefits, several key aspects are established:

- Bring greater clarity to the different stages of a project – the guidelines set out are easy to follow and to understand (Freire and Alarcon, 2000);

- Makes business sense through providing an industry wide tool, as presented by Bailey (2015);
- Global professional membership body established, providing a community and more disciplined approach through accountability;
- Deliver better buildings and places, stronger communities, and a sustainable environment;
- More inclusive in nature;
- Provide a framework for greater ethical behaviour;
- Engender and promote greater collaborative working; and
- Encourage greater environmental awareness.

According to Orihuela et al. (2011), although a standard construction process has been established in countries such as the USA, UK, Australia, and Canada, there is still a lack of detail on how these phases should be carried out. However, from a practical perspective, it is also very complicated (Freire and Alarcon, 2000).

According to Yusof et al. (2015), it has been suggested by institutions that the RIBA PoW (2020) only provides guidelines for practitioners, and as such these approaches still lack details of the activities that need to take place. However, all the guidelines still provide valid and practised aspects, regardless of the problems encountered by the practitioners. As such it can provide a useful framework for operations and process management. For example, in a study of the framework for the effective implementation of building regulations and policies in the case of Sub-Sahara African countries by Nengou (2019), the framework for effective implementation leaning on the RIBA 2013 PoW was developed and assessed. In addition, Chen et al. (2019) outlined a key gap in the knowledge to develop a LC overlay to the RIBA PoW. This current research builds upon this idea, fully integrating the two.

2.7.2 BIM Task Group

The BIM Task Group brought together expertise from industry, government, institutes, and academia to strengthen the public sector's BIM capability and provide the information the

industry needed to meet the government's BIM requirements. It was supported by the Department for Business Innovation & Skills and the Construction Industry Council.

There were six main working parties associated with the BIM Task Group, covering areas such as Training and Education, COBie data set requirements, Plan of Works, BIM Technologies Alliance, UK Contractors Group, and Construction Products Association.

2.7.3 The Construction Industry Council

The Construction Industry Council (CIC) Plan of Works group communicated a collective understanding of BIM amongst the professional institutions. In addition, the CIC was tasked with establishing a network of regional hubs to ensure up-to-date and consistent information was disseminated across the UK and allowing for local feedback to the BIM Task Group (see www.cic.org.uk; www.ribabooks.com; RIBA Publishing, 2007).

2.7.4 The Construction Playbook

The Construction Playbook sets out key policies and guidance for how public work projects and programmes are assessed, procured, and delivered (Government Guidance, 2020; gov.uk). The Construction Playbook captures commercial best practices and specific sector reforms outlining the government's expectations of how contracting authorities and suppliers, including the supply chain, should engage with each other. These are set out in 14 key policies for how the government should assess, procure, and deliver public works projects and programmes which all central government departments and their associated bodies are expected to follow on a 'comply or explain' basis.

2.7.5 ISP 19650 – 2:2018

Organisation and digitisation of information about buildings and civil engineering works, including building information modelling (BIM)-Information management using building information modelling-Part 2: Delivery phase of the assets.

2.7.6 2018 Soft Landings Framework

The Soft Landings Framework 2018 is a six-phase approach to help a project team focus more on the client's needs throughout the project, to smooth the transition into use and to address issues that post-occupancy evaluation (POE) has shown to be widespread.

Dr Agha Hossein, Soft Landings Operational Lead at BSRIA (see Hossein, 2020) suggested that Soft Landings is "not just about better commissioning, fine-tuning and handover. Soft Landings can be used for new construction, refurbishment and alteration." The next section summarises the key stages for each framework.

2.7.7 Summary of the key stages for each framework

Table 2.7 sets out for comparison the key stages of each of the construction frameworks previously discussed in Sections 2.7.1 to 2.7.6, above.

Table 2.7 Summary of construction management frameworks for buildings

Framework	Key stages
RIBA Plan of Work (2020)	0 - Strategic definition. 1 - Preparation and briefing. 2 - Concept design. 3 - Spatial coordination. 4 - Technical design. 5 - Manufacturing and construction. 6 - Handover. 7 - Use.
BIM Task Group	0 - Strategy 1 - Brief 2 - Concept 3 - Definition 4 - Design 5 - Build and commission 6 - Handover and close-out 7 - Operation and end-of-life
Construction Industry Council (CIC)	1 - Preparation 2 - Concept 3 - Design Development 4 - Production Information 5 - Manufacture, Installation & Construction Information 6 - Post Practical Completion
The Construction Playbook	1 - Preparation and planning. 2 - Publication. 3 - Selection. 4 - Evaluation and award. 5 - Contract implementation.

ISO 19650-2	1 - Assessment of need. 2 - Invitation to tender. 3 - Tender response. 4 - Appointment. 5 - Mobilization. 6 - Collaborative production of information. 7 - Information model delivery. 8 - Project close out.
2018 Soft Landings Framework	1 - Inception and briefing. 2 - Design. 3 - Construction. 4 - Pre-handover. 5 - Initial aftercare. 6 - Extended aftercare and post occupancy evaluation.

2.8 Construction processes and construction management

Considering that any waste reduction method (of which LC is identified as the most appropriate; see Section 2.4), an understanding of how a construction process can be managed to ensure transparency needs to be identified. Hence, this section looks at the various forms these can take – with an aim toward identifying a suitable construct. This sub-section firstly outlines what makes a basic construction process. This paves the way for highlighting the shortfalls with the way things are currently (or traditionally) done.

2.8.1 The construction process

The construction phase in the construction project life cycle is considered as a significant contributor to the project performance. Many researchers (e.g. Howell and Koskela, 2000, 2002) have considered this phenomenon as being dependent on the project success which comprises time, cost, quality, and sustainability.

The construction process can be usually divided into three phases from project conception, through to project design, and finally project construction (Chan and Kumaraswamy, 1997). This can be described as linear project delivery as modelled by Emmitt (2002). The project construction is identified as an assembly process whereby multiple contractors (including engineers and builders) ultimately materialise the client's requirements based on architectural

and engineering drawings. This construction process is also referred to as the design and production process, which has been widely practised around the globe.

Although the construction process has been established in many countries, there is a lack of detail on how each of the phases should be carried out (Orihuela et al., 2011). It has been suggested by various institutions (e.g. Institution of Civil Engineers (ICE), LCI, International Group for Lean Construction (IGLC), Royal Institute of British Architects (RIBA)) that the various stages are a guide for practitioners. However, the number of phases used changes considerably depending on which text you read (e.g. RIBA versus NEC) and for the most part these lack details of the activities which need to take place and when. Therefore, it is necessary to develop a bespoke construction process framework for every project, whereby the details of each of these activities can be considered. At the same time, such a construction process framework is required to eliminate waste and enhance building project performance.

2.8.2 Construction management

Construction management is the overall planning, coordination, and control of a development from inception to completion (Al-Jibouri, 2003; Harris and McCaffer, 2006; He and Yin, 2010). Construction management is aimed at meeting a client's requirements in order to produce a functionally and financially viable project in the engineering and architectural environment.

Construction management (CM) is the design, programming, and construction of the building. Therein, construction covers building and civil engineering works. The difference between management contracting and CM is that in the CM form of procurement, the client has direct contracts with trades' contractors, the specialists. In CM, management of the technical people involved in the project is more important than the design.

To gain insight into the controllable managerial factors related to poor project planning and management, causes of delay in projects are examined through the identification of problems related to management of projects (AlSehaimi, 2011).

2.8.2.1 CM tools, techniques, and methods

There are many CM tools, techniques, and methods out there for managing construction projects. Table 2.8 identifies a number of these. Those that are relevant to this work have been highlighted.

According to Winch (2010), while Last Planner and Critical Chain do address the problem of variability, they do it by buffering task execution instead of directly addressing the process capability problem; because of this, they cannot be considered complete LC tools.

Table 2.8 Construction management tools, techniques, and methods

Tools that are available in construction management

1. Critical Path technique
2. Critical Chain technique
3. Program Evaluation and Review Technique
4. Classic technique
5. Waterfall technique
6. Agile project management
7. Rational Unified Process
8. Extreme project management

New approaches to project scheduling

A. The Critical Chain method (CCM)
B. Critical space analysis (CSA)
C. Last Planner – reducing task duration variability (LPS): Lean Project Delivery System (LPDS)
D. Dependency structure matrix (DSM)
E. Scheduling reciprocal processes
F. Visualising the schedule

Lean Project Delivery System (LPDS): Founded in 1997 by Gregory Howell and Glenn Ballard, the LCI developed LPDS and LPS of production control, applying principles

pioneered in manufacturing to construction (Ballard, 2000). LPDS is divided into four interconnected phases: project definition, lean design, lean supply, and lean assembly (Sarhan and Fox, 2013).

The Critical Path method (CPM): was developed in the 1950s by James Kelley and Morgan Walker of Remington and DuPont, respectively, to improve efficiency and reduce the costs associated with plant shutdowns and restarts. The method considers that the shortest probable time and duration for the project is given by the longest sequence of tasks, that is the sequence with the minimum slack or float, while the activities or tasks are arranged in order and aligned in accordance with dependencies. To make sure the work/project is finished in the shortest likely time, the attention of management should focus on the activities of the critical path. Limitations of CPM are that considerable computational resources are required to assess and examine the network and to keep it updated. Managers have little time to plan on most construction projects.

The problem which LPS can help address is that there may be a reluctance to rely upon (or trust) deterministic programming. This may be because probabilistic techniques (PERT) are typically more optimistic than the worst-case scenario and this is not always helpful when timescales for construction projects shift (Jannarkar, 2013).

Furthermore, the problems and complexities of updating, because of technical troubles on site and the organisational limits of CPM, have tended to make CPM a historically orientated control tool instead of a future-orientated management tool (Jannarkar, 2013).

The duration of an activity is often estimated, frequently determined by asking those who are in charge and accountable for executing the work. As these individuals may be held accountable for meeting the estimates, they may act opportunistically. Padding of times and intervals happens, which is completely different from the float in the programme. A culture of '*no blame*' is necessary, and a therefore a pre-requisite, to overcome this problem, hence the reason for encouraging a move from CPM to CCP (see, for example, Jeong et al., 1999).

Based on the LCI's LPDS, the stages of the traditional project management process (define, design, supply, assemble, and deliver) are enhanced to become lean (faster and more

effective with less waste) (Al-Aomar, 2012). This is a view shared by Marhani et al. (2013), Abdullah et al. (2009), Jorgensen and Emmitt (2008), Lim (2008), and Koskela (1992) who have all confirmed that LC offers many benefits when implemented in construction projects, the main advantage being a reduction in construction costs due to the use of correct materials and a reduction of waste on site (Suresh et al., 2011) due to adoption of proper project planning (and lean-centred) techniques (see Section 2.4.2). Allied to this is a shortened project and improved quality that embrace sustainability principles.

2.8.2.2 Construction management issues and problems

Although traditional planning methods have been used to manage construction waste, time and cost problems still remain. The various issues and problems with construction management are shown in Table 2.9.

Table 2.9 Construction management issues and problems

Construction Management Issues and Problems	
TIME • Project delay • Time is not being managed efficiently • Traditional planning methods • Too many people in the chain, and the supply chain is massive • The contractual procedures and the interchange between the different parties involved in a construction project • Time management and control issue	Time issue (Time overruns)[1] • Poor labour productivity • Lack of project funding/shortage of materials • Poor contract management • Design changes • Inaccuracy of material estimate • Skilled labour shortage • Financing and payment of completed works • Changes in site conditions • Inclement weather • Inadequate planning • Subcontractors and nominated suppliers • Imported materials and plant items
COST • Cost overruns • Projects are overrunning • Cost management and control issues	Cost issue (Cost overruns)[1] • Inaccurate quantity take-off • Late deliveries • Additional work • Weather • Poor contract management • Mistakes and discrepancies in design documents/materials cost increased by inflation • Materials shortage • Economic conditions • Client requirements • Site conditions • Poor site management and supervision

	• Design changes • Inaccurate estimates • Problems in planning and design as main causes of change orders • Imported materials and plant items • Delays • Subcontractors and nominated suppliers • Price fluctuation • Financing and payment of completed works • Delays in design information • Changes initiated by designers • Lack of experience of project type • Long waiting time for approval of drawings • Changes in site conditions • Lack of experience of project location
WASTE • Non-value-adding work in construction • Direct and indirect C&D waste (material loss and non-value-adding work) • Problems with waste management • There is the amount of waste that is still currently produced, and it goes into landfill • The problem is that there way too much waste being produced • Waste management and control issues	Waste issue[1] • Poor contractor briefing • Transport • Construction defects • Poor specification • Delays • Poor technical knowledge • Construction changes • Insufficient pre-construction meetings • Poor level of commitment to quality improvement • Unnecessary movements • Excess inventory • Poor communication between construction team • Over-production • Insufficient and unrealistic constraints of project cost • Making construction decisions on cost and not value of work • Lack of project definition • Insufficient and unrealistic constraints of project time • Inadequate involvement of other professionals and teamwork during the construction stage • Effect of standards and construction code on quality • Lack of constructability review of construction • Over-processing
QUALITY • Poor performance • Too many people in the chain, and the supply chain is massive • The contractual procedures and the interchange between the different parties involved in a	Quality issue[1] • Ineffective and poor planning and control • Site congestion/poor site management • Changes in site conditions • Excessive stress • Poor labour productivity • Skilled labour shortage (project environment

construction project • Quality management and control issues	factor) • Lack of knowledge to read work statements • Mistakes in design documents • Non-compliance with procedures • Human/judgement error • Poor supervision and team effort • Subcontractors and nominated suppliers • Physical and mental inability • Untidy site • Site hazard (e.g. dust, noise) • Inclement weather • Organisational pressure • Client requirements • Tripping • High risk activities • Procedural issues
SUSTAINABILITY • There are systems available currently, but they have problems • Sustainability management and control issues	Sustainability issue[1] • Environmental • Social • Economical

Reference: [1]Olawale and Sun (2010)

Modern building and civil engineering projects are highly complex, both in conception and implementation. Moreover, the construction industry is a combination of distinct groups of participatants, with the links between these groups being unique to each project. This uniqueness comes from the individual demands of the project joined with the continuing development of specific roles (Al-Jibouri, 2003; Harris and McCaffer, 2006; He and Yin, 2010). There should be a good working relationship between the main contractor and the contract manager who are not contractually linked, and between those who have working relationships based on a contract (Aziz and Hafez, 2013), thus:

- 'Design and Build' contracts are commonly known as package deal contracts. Design and build is a term describing a procurement route in which the main contractor is appointed to design and construct the works, as opposed to a traditional contract, where the client appoints consultants to design the development and then a contractor is appointed to construct the works. The aim of Design and Build projects is to reduce cost and increase quality by improving the constructability of the building design. However, the new technologies cannot yet effectively support the implementation of Design and Build projects (Aziz and Hafez, 2013).

- Management contracting, on the other hand, is presented as an alternative to Design and Build packages where separation and independence of the designer from the builder is not guaranteed.

The contractual procedures and the interchange between the different parties involved in a construction project can be a problem. For example, within the construction industry, the biggest problem resides in the fact there are so many people involved within the supply chain. This causes a logistical nightmare for materials coming into a project and just as importantly waste coming out (Al-Jibouri, 2003; Harris and McCaffer, 2006; He and Yin, 2010).

In Europe, CDW forms a large section of all generated waste (Gálvez-Martos et al., 2018). Given the rather varied waste management practices, there is a need for new approaches in the construction sector. The study by Gálvez-Martos et al. (2018) related best practices and combines main principles for the management of CDW (see Section 2.5).

Standard forms of contract have been drafted on the theory that the contractor will make several decisions for design all the time, even if it is minor. A 'fitness for purpose' condition is usually a pre-requisite from the contractor (ICE, UK; NEC Contract, 2017).

Within the current process, the following have been found (Heidar Barghi, 2015):

- Customer value is not maximised
- Waste is not sufficiently minimised
- Too many resources are used

In order to support reduction of waste in the project life cycle, further work is now required to integrate a number of the tools identified here (i.e. Last Planner, DSM, systems dynamics, Critical Chain, critical space, and 4D planning) into a single information system. In order to do this, a compatible 'host' framework is required to help with the organisation and management of building projects. Chapters 3 and 5 consider one such host framework (i.e. RIBA PoW) in more detail.

2.9 Summary

This section identifies and critically evaluates management tools that allow for a shared framework of briefing, designing, delivering, maintaining, and operating using buildings (also the aim of my research), and to show the various frameworks that are out there which enable this to happen and convince the reader why the RIBA PoW 2020 is the most appropriate. For example, this should include frameworks such as those in Sections 2.3.1–2.3.6. Several journal and conference papers have been reviewed, to evaluate the problems, challenges, and implementation challenges in construction projects and, through this, ascertain the gap in the current state of knowledge. This is summarised in Sections 2.9.1 and 2.9.2 below.

2.9.1 Identification of knowledge gap and innovative features of the research

Analysis of the literature suggests that the conversion, flow, and value models should be used in an integrated manner to offer the best results (Santos, 1999; Koskela, 1992). After the prevalent success of lean production, a number of lean construction models have arisen, which look at the feasible implementation of lean principles in the construction industry. lean production has its basis in the TPS (see Figure 2.12).

Womack and Jones (1996) describe the pull principle as the mechanism that prevents any good or service being supplied which a customer has not requested. The result is a reduction in work in progress. Production control theorists working in manufacturing distinguish two primary ways of regulating workflow in manufacturing systems: push and pull. In construction, pull is ultimately derived from target completion dates, but specifically applies to the internal customer of each process. Applicability of these concepts to production control has been explored (see Ballard, 1999, 2000 and Tommelein, 1998).

Push systems release materials or information into a system based on preassigned due dates (from a master production schedule, for example) for the products of which they are parts. Pull systems release materials or information into a system based on the state of the system (for example, the amount of work in process and the quality of available assignments) in

addition to due dates (Hopp and Spearman, 1996). In factory systems, pull may be derived ultimately from customer orders.

According to Sacks et al. (2009), "*Pull flow is a method of controlling product flow through a series of processing steps in which the quantity of work in progress inventory between process stages is minimized, and only products demanded ("pulled") by the ultimate 'client' process are produced*".

The literature shows that there is a lack of HRM (human resource management), and that existing LC models are the missing human part and dimensions (Green, 2002; Liker, 2004; Gao and Low, 2014). The knowledge gap will be fulfilled if there is a focus on the human resources issues.

Therefore, further research is needed to test and validate the framework using empirical data.

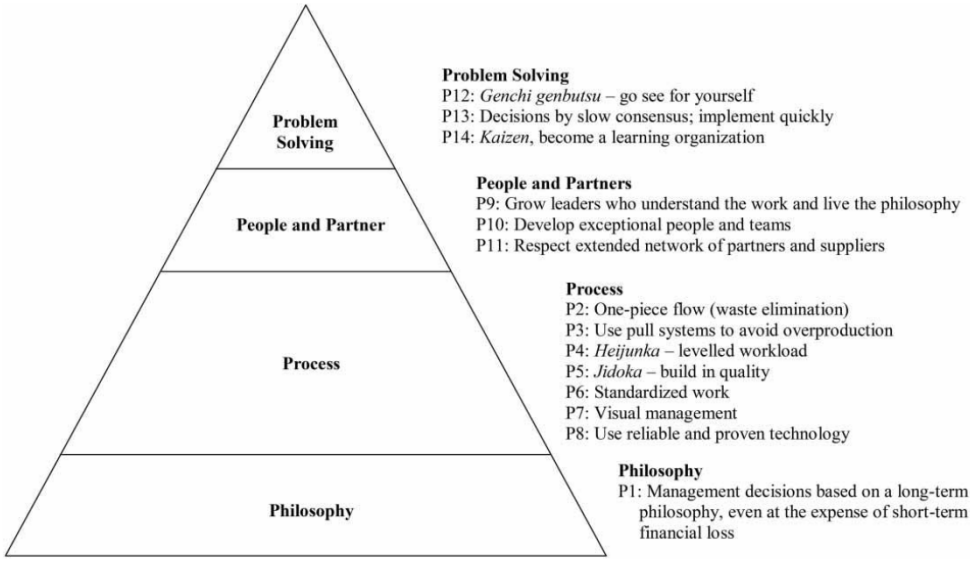


Figure 2.12: The Toyota Way model (Liker, 2004)

Research carried out by AlSehaimi (2011), regarding improving construction planning practice in Saudi Arabia by means of LC principles and techniques, tested the applicability of the best-known technique, LPS. Further, he suggested that "*the management process can be enhanced through continuous improvement and assessment, thus improving project delivery*

in terms of cost, time and quality". According to Lu and Yuan (2011), more studies might be needed in the future to examine the non-value-adding work in construction.

According to Gao et al. (2014), most of the frameworks they examined lacked a high degree of comprehensiveness. Their findings also showed that features of abstractness, fit to an organisation, and human and technological aspects were not equally considered because of an improper understanding of lean. As described in Section 2.8, the development of the workforce was considered in this research.

According to Daniel (2017), the application of this system in the UK construction industry has not been fully explored among industry practitioners. In addition, a systematic "understanding of how Collaborative Planning (CP) practice in the UK aligns with the LPS is still lacking. The absence of authoritative research and empirical data makes it difficult for an appropriate approach to be developed to improve current practice".

LPS can reduce task duration variability (Alarcón, 1997; Bicheno, 2004; Dennis, 2007; Ballard, 2013; Heidar Barghi, 2013; Lean Construction Institute, 2014).

According to Esa et al. (2017), the "construction actors agreed that a more modern construction method would reduce the waste generation at the planning and designing stage. Selecting an appropriate material also could help reducing the waste generation at this stage. They also considered the importance of implementing a modular design that will promote standardization of building components".

"The findings reveal that it was important to create awareness among the construction actors on having a proper management of C&D wastes and at the same time provide sufficient training related to the management of wastes" at the procurement stage (Esa et al., 2017). Site management is critical in controlling waste generation in the construction and demolition stages. Labourers' attitudes also need to be monitored due to their significant impact on waste generation.

The findings disclosed two groups of factors for the planning and designing stage: a "Waste Management Plan" and "Construction Methods". For the procurement stage, two groups of

factors have also been defined: “Awareness and Awards” and “Regulations Enhancement”. Meanwhile, only one factor has been concluded for the construction and demolition stages: “Effective Management”.

Gálvez-Martos et al. (2018) stated that “*It is obvious that the technology and the potential for high performing waste management systems is already in the market and available to those regions, municipalities, waste authorities or waste contractors willing to improve their performance. However, the construction sector shows a traditional behaviour, which heavily relies on standards, while being completely economically driven. In addition, the high variety of actors involved in the CDW value chain creates a complex mesh of responsibilities, with very different decision-making chains. Of course, the low impact of any waste-related decisions on construction project budgets does not encourage improvement beyond current standard practices. Therefore, most of the observed efforts focus on the creation of drivers addressing the whole landscape of construction stakeholders across the construction value chain. Systematic documentation of current best practices observed across Europe provides an evidence base to develop policies and management strategies that deliver circular economy solutions to the construction sector*”.

According to Huanyu Wu et al. (2019), “*several future research opportunities are identified*” which are “*developing the advanced performance evaluation criteria for wasted materials and recycled products; extending the research boundary of waste flows; developing advanced methods to assess the waste management performance*”; reducing “*waste from early project stages; and reducing waste during the building operation. These findings are not only valuable to better understand the waste research, but also useful to assist practitioners to further improve waste management performance*”.

Martin Crow, Head of Sustainability at Hanson UK (Hanson, 2020; see agg-net.com; hanson-sustainability.co.uk), said, “*Hanson is firmly behind the WRAP commitment to halve construction waste to landfill. Waste reduction is one of the 14 key performance indicators we measure in our sustainability report. There is also wide-scale support from sector bodies such as the ICE, RIBA, UKCG, EECA and many of their body members*” (see WRAP, 2020). Apparently, most of the causes of waste can be removed by means of implementing LC techniques (Polat and Ballard, 2004). In addition, there is a gap in the literature and on

what has been missed at a strategic level. The comparisons revealed various shortcomings and limitations of LC frameworks that are currently available; a more comprehensive framework is needed to bridge such gaps.

The gap in knowledge stems from the different techniques used for construction management, and the associated different techniques for waste management. However, there is no idealised system that combines those for both waste management and construction management into a logical process that can be used currently.

The purpose of this research work is to outline the way too much waste is being produced, and through research how a solution needs to be derived to be minimise future waste generation.

Time, cost, and quality aspects have also been considered and developed in this research project as have issues with and challenges to implementing LPS and the proposed method.

Importantly, how to deal with top management executives is the hardest and most difficult issue. It would be easy to communicate with working staff but sometimes it would be very hard to clear confusion about directives and information which are given by managers. For successful implementation of LPS, there is a need for effectual communication among different levels in organisations; and because this is often lacking, implementation of LPS fails. Moreover, this is one of the most common reasons that leads to the failure of implementing LPS so that it does not fully achieve pull flow (Heidar Barghi, 2014).

2.9.2 The contribution to knowledge and novelty of this research project

2.9.2.1 The contribution to knowledge of this research project

The key contribution of the research presented in this thesis includes the development of a pull flow system, that is pull flow control in LC management.

2.9.2.2 The novelty of this research project

The key novelty of the research presented in this thesis includes: improvement of construction process and performance through development and implementation of an integrated lean-enabled pull flow construction process framework model, followed by measurement and control methods.

This would result in increasing the efficiency of transformation activities known as value-adding activities (processing). The innovative construction process models presented in this research have been developed based on the core enablers that can be used to identify and eliminate waste. There are 21 types of wastes identified and SBCE integrated with LPS is considered in the core enabler of the construction process model. The proposed construction process model integrates LT into the traditional construction process with activities which can eliminate waste in the construction process. As it is not always possible to eliminate flow activities, there is a need for a pull flow system, which will remove waste and can control flow activities with the help of pull flow in the construction process; therefore, value will be achieved through that process.

The RIBA PoW is used to integrate and incorporate the principles to develop a standard model, where construction stages and activities of the construction process in construction projects are described, as this has proved to be the most effective way to implement changes associated with the proposed LC model.

One of the proposed improvement steps includes the development of elements of LPS. In addition, the production and process flow play an important role in construction project success. However, visualisation of workflow and its progress is very difficult at construction sites. To address this issue, a pull flow construction management system based on LPS has been proposed to provide smooth flow and control of construction planning and building, which has been implemented and evaluated in the form of case studies, after being improved by means of a questionnaire and interview surveys.

This study will help to improve the successful implementation of LC in the construction industry. Using this method will add better intelligibility and transparency to LC. This will

result in reduction of plan variations. The extensiveness of the proposed model means that it can bring about several approaches from which to look at the LC model for the construction industry.

As proposed in the research presented herein, foreman empowerment by means of the proposed pull system called the Implementation and Control System in LPS is key. Integration of all models together, resulting in a pull system which is flexible based on the kind of construction project, will enable this to take place. Individuals do not know how to adopt LC. The goal of this research is to propose, define, develop, and test a lean-enabled system to support planning and control, value generation, and waste reduction daily on construction sites.

An extensive review of indicators (KPIs, key performance indicators) and enablers and comparison of RIBA and WRAP tools was carried out in this research project. In RIBA, "*Task bar 5, Suggested Key Support Tasks task bar: clarifies the activities required to achieve the Sustainability Aspirations, reducing the carbon emissions related to the building, and those required to embed BIM into the process*". As can be seen in this project, the research presented will embed lean into the process to fulfil the gap in knowledge.

The *Guide to using the RIBA Plan of Work 2013*, and associated updates in 2020, demonstrates how the RIBA PoW assists the implementation of sustainability measures. To fill the gap in knowledge, in this project, the RIBA PoW will be used to assist the implementation of LC measures with the help of lean enablers and indicators and developed frameworks/systems.

Thus, the aim of this thesis was to create a tool, relying on the LC principles of flow management.

Thus outlines the fact that the construction management processes discussed in this chapter, demonstrated that that most appropriate approached to meet the requirements and help fill key gaps (see Section 2.9.1) is the RIBA PoWs combined with the key aspects of waste management from LC methods. This pulls together the key benefits of both systems to produce one overarching approach.

In conjunction with the RIBA PoW, this research will establish KPIs in order to benchmark the performance of the construction industry in the UK and Iran, helping to reduce and prevent waste being sent to landfill.

To fill the gap, waste management methods have been critically evaluated as well as construction management processes that are like the RIBA PoW. This critical evaluation has showed that there are problems with the current construction and waste management processes.

The framework for measuring the performance of the proposed construction process is shown in Figure 2.13.

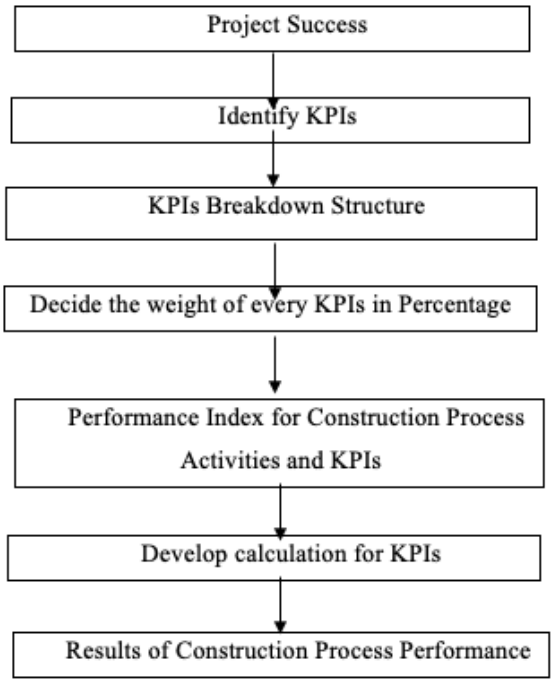


Figure 2.13: Framework for measuring the performance of the proposed construction process

The hierarchy for the KPIs of construction process performance is shown in Figure 2.14.

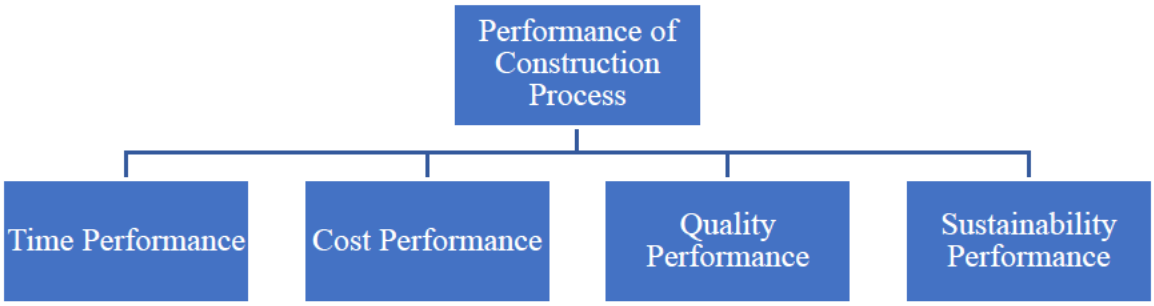


Figure 2.14: Hierarchy for the KPIs of construction process performance

2.9.3 Final summary statement

The gap in knowledge is associated with the different techniques used for construction management; many different techniques are used for waste management, but there is no system that combines both waste management and construction management into a logical process that can be used concurrently and in partnership. As such there is currently no system that coherently maps the benefits of LC with the RIBA PoW; therefore, such an approach needs to be developed so that joint benefits can be garnered together in one usable framework. Chapter 3 will now set out the methodology used to develop the research and, through this, address these gaps in the current state of knowledge.

3 METHODOLOGY

3.1 Introduction

This chapter presents the methodology employed to develop ways to improve the construction process and, through this, manage construction waste, time, and cost to improve the quality and sustainability of construction projects. The adaptation of lean principles was found to be the best way forward, with key enablers identified. Through this it was found that a combination of these were key to developing a framework for the construction process (see Chapter 2). The RIBA PoW has been used to integrate and incorporate the principles to develop a standard approach that incorporates all key stages and activities employed during the construction process, as set out in Chapter 2. This current chapter sets out the stages used to develop the final framework, details of which are presented in Chapters 4 and 5. This framework builds on the RIBA PoW, implementing several LC principles and techniques, and was developed using the 10 steps set out in Figure 3.1 (see stages S1–S10). By applying LC principles to the RIBA PoW for measuring and controlling Time, Cost, Quality, and Sustainability, a new framework was produced. Through this integrated approach, a more effective and efficient way to manage construction can be achieved.

The methodology employed in the research presented in this thesis is broken down into four main stages:

M1 - Critical literature review

M2 - Develop conceptual framework

M3 - Develop quantitative and qualitative questionnaire and analyse results (to help refine framework)

M4 - Apply framework (to case study) to test and validate the final framework produced.

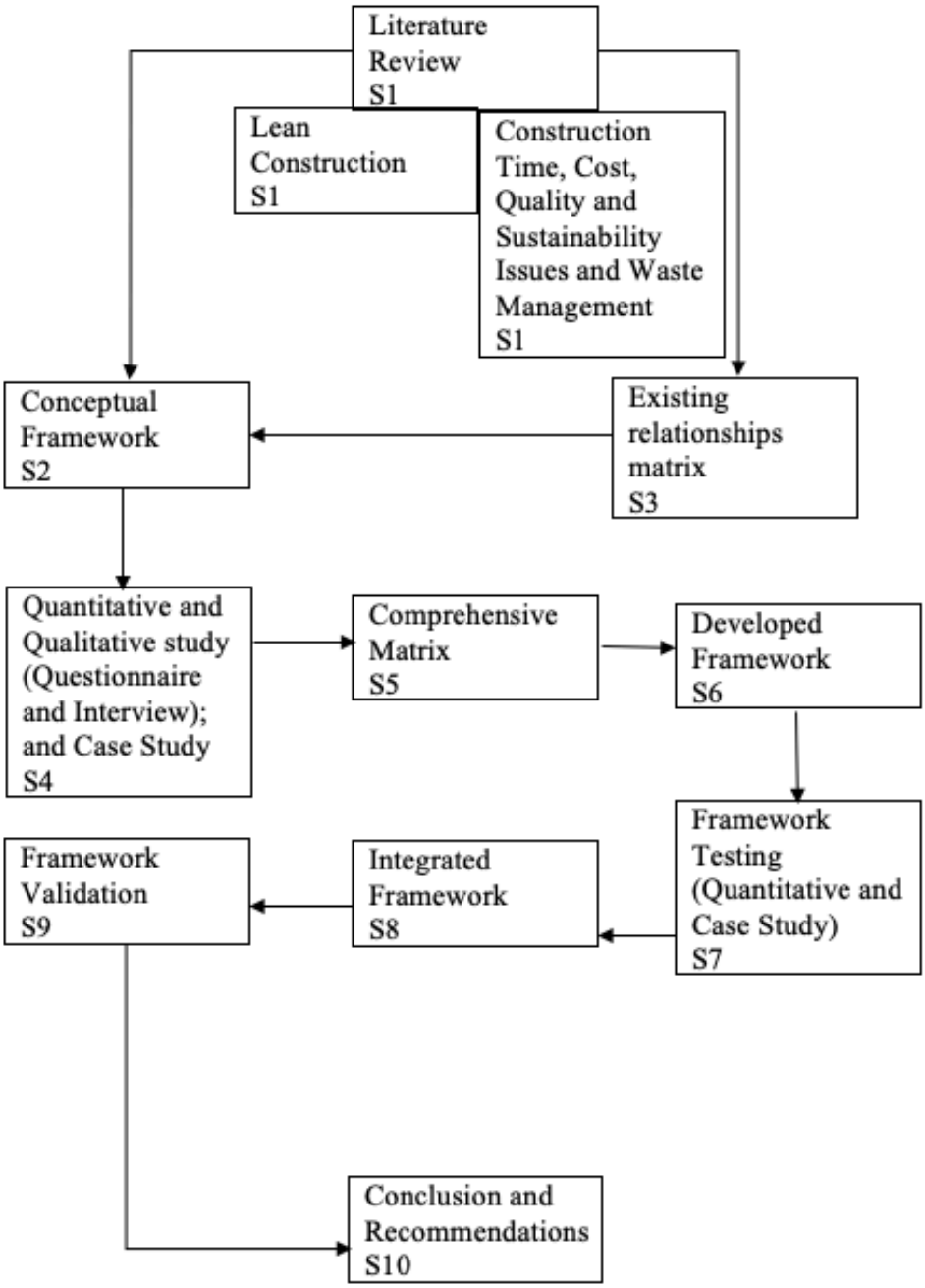


Figure 3.1: Research methodology (note steps S1–S10 define key steps used in the methodology adopted in this research)

The first stage of the work employed a literature review to critically assess the most relevant existing frameworks (see Chapter 2). From this, the key requirements for improving existing frameworks were assessed, providing the key areas of uncertainty found in the literature. Once completed, key definitions were established, in particular how waste in the construction process is defined; from this, a baseline was found. By applying the principle of LT, it was

then possible to establish where waste can be eliminated. This then establishes the identification of waste (Yusof and Heidar Barghi, 2015).

After the definition and identification of wastes were established, the lean enablers were studied and identified, using the lean implementation tools and methods available. Evaluation of the core enablers was the main focus of this study, as these core enablers are used to drive the process and to support innovation in the construction process. Subsequently, a construction process framework model adopting LT was proposed, which includes waste identification, lean enablers, waste elimination, and recommended construction process activities.

From this, an integrated framework was established that could serve as a guide to contracting organisations in using LC techniques, to achieve an improvement on construction sites. This embedded:

- The impacts of LC techniques;
- Drivers of LC practice in organisations;
- Challenges to the implementation of LC techniques; and
- The outcome of implementing LC practice.

These aspects were ranked to demonstrate how the variables compare with one another. This ranking enables organisations to allocate priorities in making decisions. Further detail of each of these methodological stages M1 to M3 and steps S1 to S10 is provided in Section 3.2.

Figure 3.2 summarises the overall approach adopted in this research by way of a flow diagram, highlighting the key stages undertaken and how they all feed into each other.

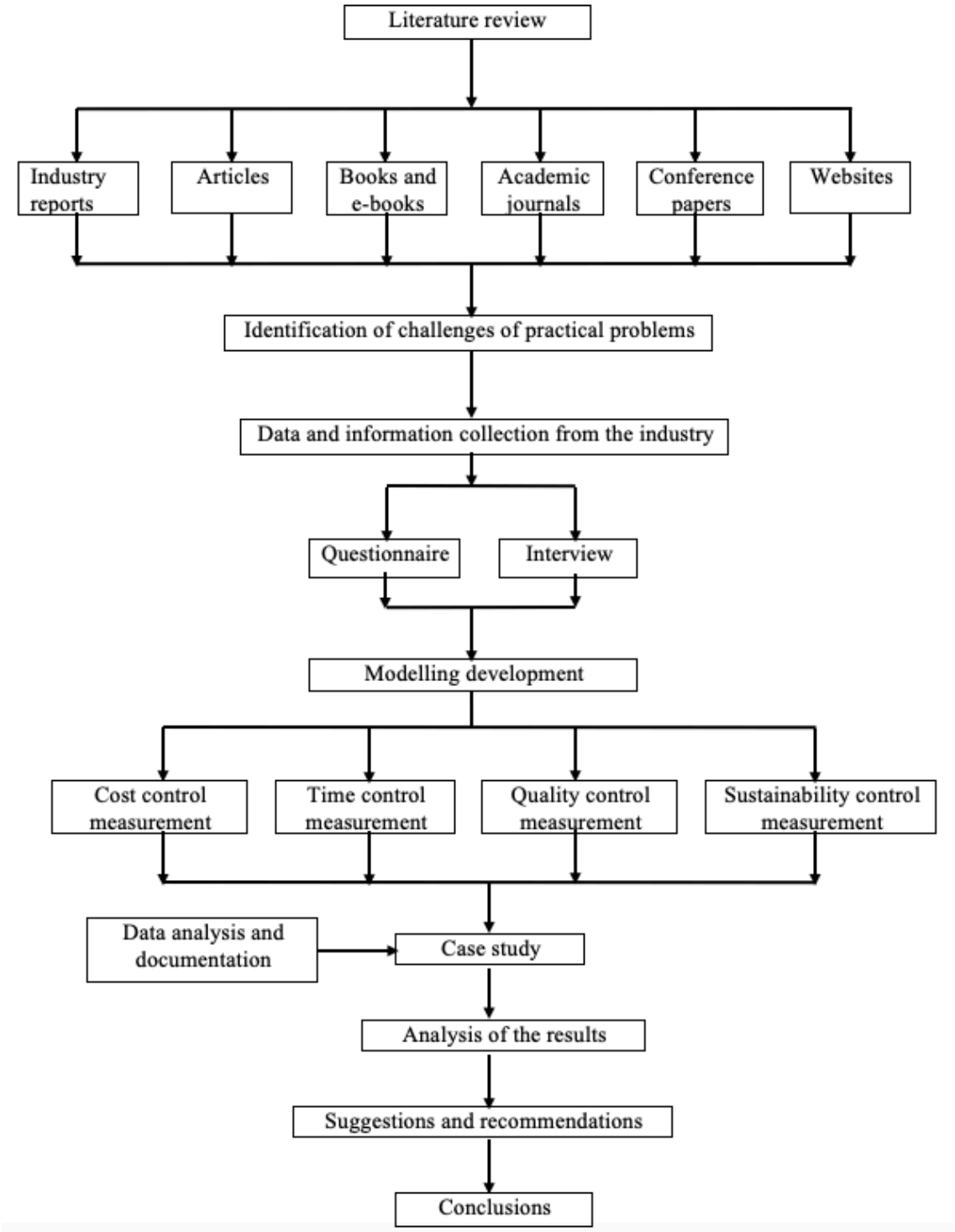


Figure 3.2: Flow diagram of methodology

The expected outcomes of the research are as follows:

- A framework that provides effective implementation of LC in the RIBA PoW;
- Increased knowledge of the awareness of construction practitioners through the questionnaire and interview survey on LC;

- Development of a performance improvement based on the case studies; and
- Documentation of suitability of LC in the developing and developed construction industry market.

Figure 3.3 shows a process flowchart for the quantitative data analysis undertaken in S4. Figure 3.4 shows the development of the conceptual framework for implementation of LC in the construction process.

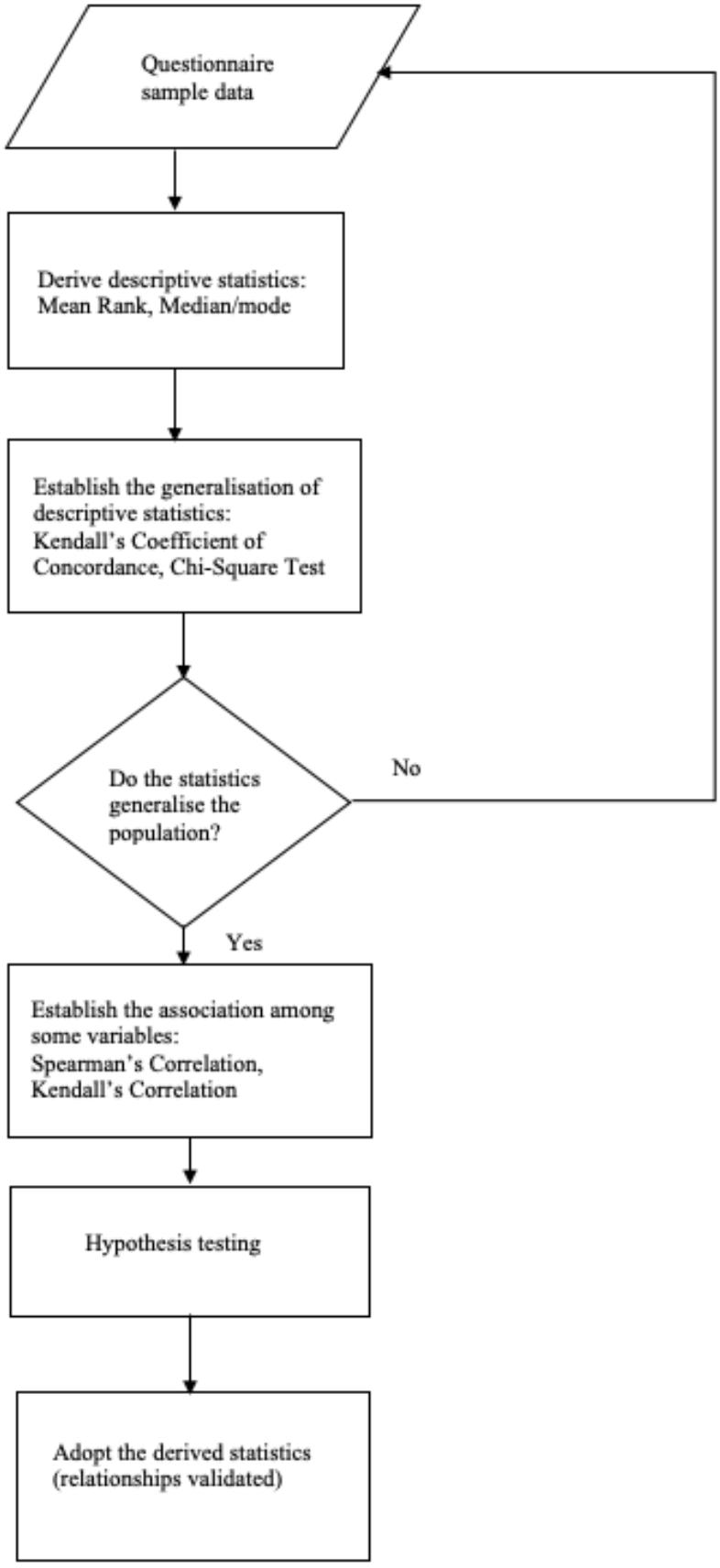


Figure 3.3: Process flowchart for quantitative data analysis

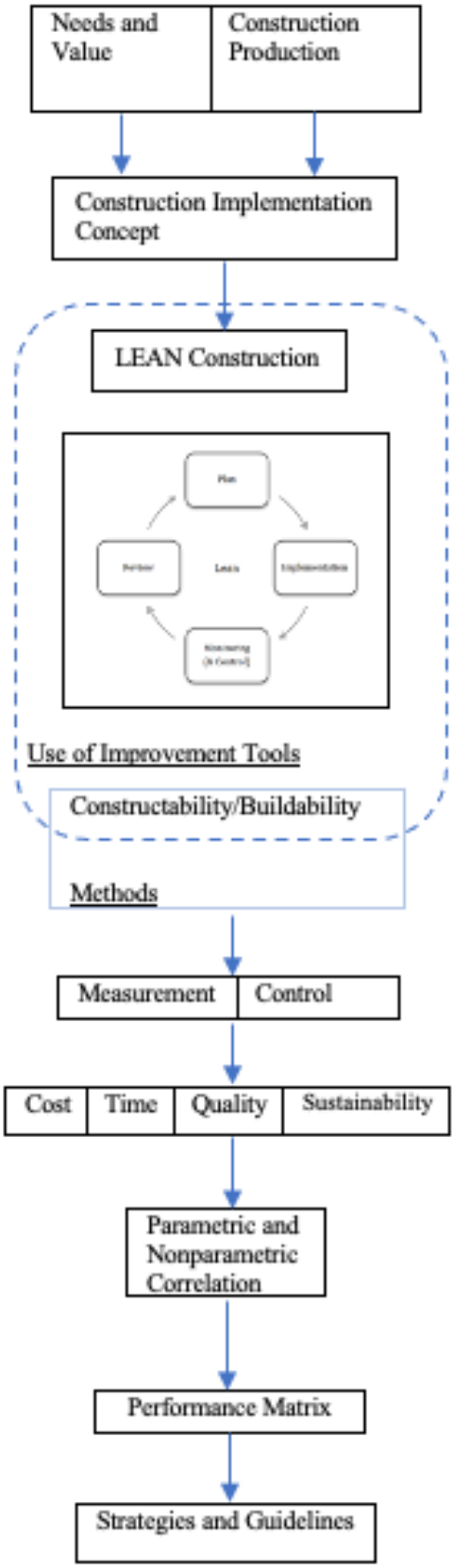


Figure 3.4: Conceptual framework developed for implementation of lean construction in the construction process

The general flow of the research process is shown in Figure 3.5.

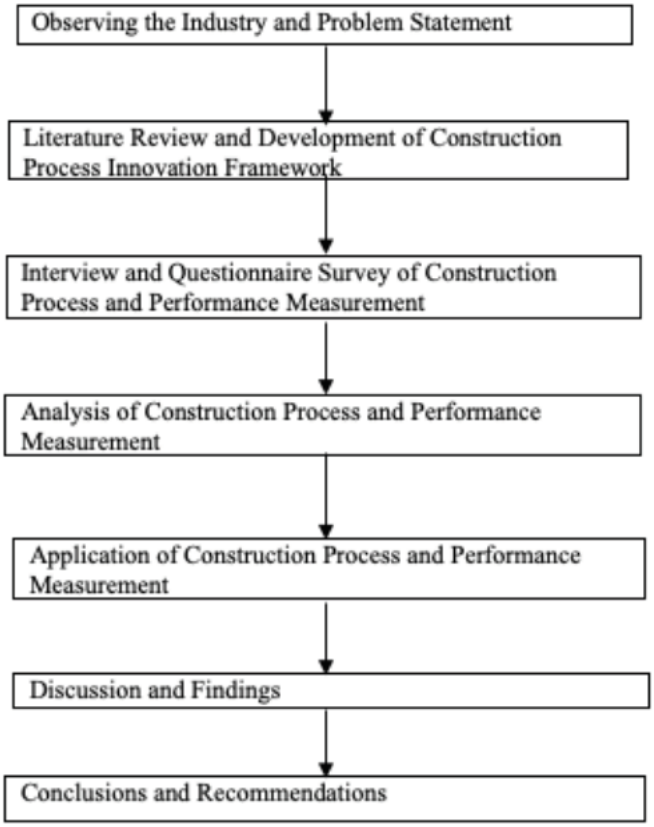


Figure 3.5: General flow of research process

3.2 Research methodology

3.2.1 Introduction

Control and measurement of Time, Cost, Quality, and Sustainability have been reviewed and the development of related control models has been carried out in this research project (see Section 2.9.1). Further details of the four methodological stages (M1–M4), previously set out in Figure 3.1, are described in the sections below.

3.2.2 M1: Literature review

The literature review was carried out during the project using websites, e-books, conference

papers, journals, academic journals, industry reports, and books. The literature review section includes measurement and control, for example, management of Time, Cost, Quality, and sustainable construction. Control and measurement have been reviewed in this project and measurement control models have been developed, for example, cost control and how to control the cost within the budget. To ensure the measurement and control models are taken account of and to make the framework applicable to building and construction projects, decision-making processes to control Time, Cost, Quality, and Sustainability were reviewed.

A systematic literature review was used to identify the key gaps in knowledge. This demonstrated the need for a framework/model to support decision making with controls on Time, Cost, Quality, and Sustainability fully embedded. Further details are described below in Section 3.2.3 (and Chapter 2, see Section 2.9.2).

3.2.3 M2: Framework development

This second methodological stage was used for the development of the framework. Several approaches were used herein to provide the data and evidence base for all the changes proposed. These included questionnaires and interview(s) with expert engineers from both companies and people drawn from a variety of sources; further details are discussed in Chapters 4 and 5.

This section presents a proposed framework that models the construction process and adopts lean principles:

- Sub-Stage M2.1: General model;
- Sub-Stage M2.2: Develop each phase;
- Sub-Stage M2.3: Methods of controlling Time, Cost, Quality, and Sustainability are embedded;
- Sub-Stage M2.4: Case studies to test and validate the proposed models.

LC concepts are presented in Chapter 2 (see Section 2.4.7). This shows how these concepts are interconnected and why it is important to understand all the key concepts of LC, to improve performance while minimising construction waste and, hence, why it is important for all stakeholders to be responsible when it comes to choosing the best approach to be

implemented in their construction sites. This was a key driver for the proposed model developed in the research presented herein.

The framework was developed as part of Methodological Step 2 (M2). In other words, the second objective (O2) was to develop a framework that integrated the different aspects of Sub-Stage M2.1 to Sub-Stage 2.3 within a conceptual model. This required the development of a questionnaire and undertaking interviews with expert panels to assess the applicability and validity of the framework proposed. From this, changes were made to reflect their collective feedback.

3.2.4 M3: Data and information collection

This study employed questionnaire surveys and semi-structured interviews (see Chapter 4 Section 4.7 and Chapter 5 Sections 5.2 and 5.4) to collect quantitative and qualitative data. Case studies were also carried out (see Chapter 5, Sections 5.3, 5.3.3, and 5.3.7–5.3.9). The information collected was analysed and the major findings summarised (see Chapter 5).

Information collection was carried out based on different methods, including questionnaires, interviews, analysis of documents, and observation. Different types of interviews such as telephone interviews or face-to-face interviews were used as the primary method, allowing input from a variety of potential users on different aspects, from which honing of the framework was then undertaken.

The interviews were particularly useful as they are capable of offering rich and extremely clarifying material (see Chapter 5, Sections 5.3.4, 5.3.5 and 5.4–5.7). The interviews were conducted with a broad range of people, which were chosen from engineers who are members of the Iran Construction Engineering Organisation, and included: contractors, designers, subcontractors, consultants, and directors of companies, as well as labourers. Throughout, care was taken to ensure confidentiality; for this purpose, participants are identified using an anonymous numbering system. A variety of interviewees were used to provide a diverse group from which to draw findings. Different opinions potentially offer a better understanding of the image of the actual organisational and managerial matters on site (Robson, 2002).

Before conducting the interview with individuals, the author had prepared a full list of pre-determined questions from which the interviewees were asked to outline the project objectives, to mention and specify their opinions about the methods that are currently used, the results expected from the presently utilised methods, and to recognise and categorise how the construction process on site is controlled and managed.

However, the author believes that this technique of collecting information was not sufficient in responding to the research questions. According to Robson (2002), "*as the actions and behaviour of people are central aspects in virtually any enquiry, a natural and obvious technique is to watch what they do, to record this in some way and then to describe, analyse and interpret what we have observed*". Thus, a direct observation method was used, despite the limited time available to be on site. The main period of these visits (across sites in Iran) took place during the summer of 2017, as there was a chance to be on site during construction operations and while finishing touches were being made. However, during earlier visits to Iran in 2011 and 2012 there had been a chance to observe operations of excavations, retaining walls, foundations, heating and cooling pipework, sewerage pipe installation/plumbing, gas/pipework installation, and electricity pipework, and these data have also been incorporated in the research presented herein and were gathered as part of earlier MSc project work; see data from these visits presented by Heidar Barghi (2013).

The aim of these observations was to recognise in practice the techniques and methods discussed in the interviews. In addition, it was intended to recognise their competence and effectiveness in controlling and managing the process of construction by identifying and recognising waste and value loss. Therefore, the information collected from the observation was utilised to complement the data obtained from the other methods used in the case studied (see Chapter 5, Section 5.3.10). The informality of the method permitted the observer substantial and significant choice in what data were observed and collected, and how they have been recorded (Robson, 2002). Observation is a fundamentally qualitative method.

A direct process of collecting information is called observation; Robson (2002) argues that openness is one of the most important advantages of this technique: "*You do not ask people about their views, feelings or attitudes; you watch what they do and listen to what they say*".

Moreover, observation in the field overcomes the intrinsic artificiality which is extensively presented in other methods. However, observation is not simple and is not a problem-free choice. It is argued that an observer can influence the circumstances under observation and, in some way, get in the way of the information collection. In addition, observation tends to be time-consuming; as an example, "*the classic participant observation study, deriving from social anthropology, demands an immersion in the 'tribe' from two or three years*" (Robson, 2002).

The quantity of written documents produced in a typical construction project is huge. The complexity of construction guides/operation manuals can lead to disputes and arguments between a project's stakeholders, with the possibility of leading ultimately to court action, which must not be underrated. As a solution, people typically document and record everything. Further, contract clauses assist the generation of documents as well; for example, it is not hard to discover a clause in a construction contract which asks for a daily site register. However, these documents are a rich source of data. So, in the case studied, another technique of collecting information was documentary study and analysis. However, the documents on hand were limited, inadequate, or incomplete. This is because they were written for reasons other than research. The analysis of documents was therefore based on the documents on hand. However, these disadvantages and problems do not prevent this approach being used as a useful supplementary technique in a study that used several methods.

A very broad and large range of documents can be analysed, including:

- Minutes of meetings,
- Designs,
- Financial reports,
- Contracts,
- Daily site register, and
- Operation manuals.

Hence, several methods were used for collecting the information. Robson (2002) discovered that case studies normally involve several techniques of collecting information. Although

much of the information and data available were qualitative, the documentary analysis provided quantitative information and data as well.

Qualitative data were utilised in complementing, enhancing, and demonstrating the quantitative data and therefore offered a more reliable analysis of the information. Validation of the framework was achieved using a group of stakeholders who were professionals within the field, to obtain their opinions on the framework developed; feedback loop allowed the framework to be refined accordingly.

This research used two case studies (see Section 3.2.5, below). The framework was applied to the case studies and as part of this, and the questionnaire and the interview process were used in parallel. This approach offered flexibility and was found to be a good way to then refine the framework accordingly – to help the experts in the field to better understand the capabilities and the limitations of the model developed.

The use of findings from the literature review to develop the framework, and then the application of case studies that interlinked with the stakeholder group, allowing them to critique its application to a particular case study, enabled the identification of strengths and weaknesses.

3.2.5 Case study

Case study materials have been collected from industry and used to test the proposed model. Two detailed case studies from Iran were employed in this study. Both represented residential projects; details are provided in Chapter 5 (see Sections 5.3.3.1–5.3.3.1.2 and 5.3.3.2–5.3.3.2.2, respectively). This allowed comparisons across themes/areas/scale of the projects.

Case studies encourage in-depth investigation of instances within the research subject. The nature of the in-depth data collection may limit the number of studies examined when research is subject to resource constraints. Case studies may be selected based on their being representative, with similar conditions to those used in statistical sampling to achieve a representative sample, to demonstrate particular facets of the topic, or to show the spectrum of alternatives. Case study research may combine a variety of data collection methods, and provide a successful way to achieve this, e.g. Yeung et al. (2009) examined three case studies

as part of their work based in Australia.

Commonly, case studies employ interviews of the key ‘actors’ in the subject of study. Data from such interviews may be coupled with documentary data. In fact, interviews have the capability of giving and offering rich and extremely clarifying material. However, a meeting or a session could last more than an hour so interviewing is very time-consuming. Furthermore, interviews need careful preparation in constructing the essential preparations, planning and provision to visit and in assuring all the essential permissions. In the majority of situations, notes and comments have to be written up or tapes transcribed. These activities, to attempt an enquiry in the real world, require additional time and (Robson, 2002).

Scaled questionnaires were used to measure the attitudes and beliefs of the technical personnel using a Likert scale, in which respondents are given choices reflecting varying degrees of intensity. Generally, the level of agreement or disagreement will be measured using five ordered response levels (Likert, 1932). A pilot survey was run on a few questionnaires to remove any unclear statements. Appendix B shows the Questionnaire Surveys that were conducted to ask the industry to give their judgement regarding the proposed model. Therefore, in the questionnaire and interviews, focus will be on the proposed model in the UK and Iran.

With these case studies, for a particular project, data collection was carried out to validate the cost, time, quality, and sustainability aspects associated with each project, reflect the models, see whether the project was successful or not, and to test how the models will work or not, as well as how the project follows the proposed procedures. The expected outcomes were to:

(1) Establish good practice by reviewing and identifying case studies;
(2) Develop LC tool(s); and
(3) Develop the new method/model.

The developed framework was applied to two case studies, as indicated above. The methodological steps that allowed this to take place are presented in Chapter 5 where further discussion about each case study is provided.

The two case studies, construction projects in Iran, were carried out to validate the proposed framework with what happens on site. In studying these projects, several methods for collecting information were used; they are outlined in Section 3.2.6 below.

According to Yin (quoted in Robson, 2002), a "*case study is a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidence*". The interviews were conducted with a broad range of people, from Iranian Engineers who are members of Iran Construction Engineering Organization, contractors, designers, subcontractors, consultants, directors of companies, working labourers, and foremen. The questionnaire was distributed to the contractors chosen among members of the Iranian Institute of Civil Engineers and The Iranian Contractors Association.

It is interesting that despite different site locations, companies, and project management methods and approaches, to some degree, all projects presented similar problematic characteristics, that is time and cost overrun, lack of coordination, lack of safety and quality, conflict and disagreement between the client, subcontractors and contractor, and an unreliable programme, which are certainly an enormous concern. This will be picked up in Chapter 5.

3.2.6 Data analysis and documentation

Framework models, surveys, and case studies have been used in this research (see Figure 3.2). However, a key part of this was to ensure that interpretation of any data gathered was undertaken appropriately, where necessary using suitably robust statistical methods. This section will highlight the details of how this was undertaken for this research.

3.2.6.1 Ranking the variables

A questionnaire survey and a two- and a four-round Delphi method (see Chan et al., 2001; Manoliadis et al., 2006; Yeung et al., 2009) were used for data gathering and finalising the results. A concordance analysis, measuring the consistency of the experts' responses over successive rounds of the Delphi survey, was used. The consistency of the results of Rounds 1 and 2 were analysed and compared using Kendall's coefficient of concordance (Yeung et al., 2009; Khosravi et al., 2011).

In the first round of the KPI Delphi questionnaire, the respondents were asked to rank/to provide ratings in the rank scale questions. In second round, they were requested to re-evaluate their responses. In the third round, they were asked to provide ratings on the top five selected responses based on a five-point Likert scale (see Section 3.2.5). In Round 4, they re-evaluated the corresponding weighting.

Relative Importance Index (RII) analysis allows identification of the most important criteria based on participants' replies and it is also an appropriate tool to prioritise indicators rated on Likert-type scales (Al-Tmeemy et al., 2012). Hence, the data have been analysed using the RII method. Based on the extensive literature review (e.g. see Assaf et al., 2006; Le et al., 2008; Al-Tmeemy et al., 2012), Microsoft Office Excel and the RII technique were used to analyse the data collected from the survey, presented in the form of graphs, bar charts, and tables. The RII technique was used by Holt et al. (1996) in the same context of application using the following formula:

$$RI = \Sigma \frac{1n_1+2n_2+3n_3+4n_4+5n_5}{5[n_1+n_2+n_3+n_4+n_5]} \quad (3.1)$$

where $n_x =$ the number of respondents agreeing with choice *x*.

This formula is also used in relation to the Likert scale. The computation of RI using this formula yields a value of RI ranging from 0.2 to 1, where 0.2 represents the minimum strength and 1 the maximum strength (Holt et al., 1996).

The RI were derived according to the following formula (Fadiya et al., 2012):

$$R.I_j = \sum_{i=1}^{5} W_i X_i; W_i = \frac{i}{5}; X_i = n_i/N \quad (3.2)$$

where *i* represents rating categories; *j* represents the variables; *n* represents the number of respondents that chose category *i*; and *N* represents the total number of respondents.

The results obtained from the surveys were analysed using IBM SPSS Statistics 24 software (Statistical Package for the Social Sciences; see Appendix B). This was used because it is the

world's leading statistical software, offers advanced statistical analysis, and is comprehensive statistical software.

The data analysis methods applied were descriptive statistics, inferential statistics (Spearman's rank correlation test and chi-square test), and hypothesis testing. These are described in Section 3.2.6.2 below.

3.2.6.2 Spearman's rank correlation test, Kendall's coefficient of concordance, and hypothesis testing

Spearman's rank correlation is a non-parametric test that compares medians rather than means and this makes it appropriate for the ordinal data gathered in this research (Jamieson, 2004), according to the following formula:

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \qquad (3.3)$$

Or

$$r_s = 1 - (6\sum d_i^2/(N^3 - N)) \qquad (3.4)$$

where r_s is the Spearman's rank correlation coefficient, d_i represents the difference between the ranks for each case given to the two variables of each driver and outcome, and n or N is the number of subjects or pairs of ranks (Weinberg and Abromowitz, 2008).

The correlation coefficient, a measure of relationship between a pair of variables, varies between +1 and −1 where +1 means a perfect positive relationship between the pair (association) while −1 means a perfect negative relationship between the pair (dissociation). As required of every hypothesis test, the null hypothesis of this test is expressed as follows:
H_0: There is no association between the pair of variables.

The hypotheses were tested using the Kendall's coefficient of concordance (W). The significance value of Kendall's coefficient of concordance is 0.000 (i.e. < 0.05), indicating that there was agreement (at 5% significance level).

Kendall's W is used to determine the degree of agreement between raters when working with ranked data (ordinal level of measurement). Kendall's W ranges from 0 to 1, with 1 representing perfect agreement, so all the ranks would match. For a W of 0, there would be perfect disagreement among the raters: they would not agree on any of the rankings.

The Kendall's coefficient of concordance formula is:

$$W = \frac{12v - 3n(n-1)^2\, m^2}{n(n-1)^2 m^2} \qquad (3.5)$$

Where:

$$v = \sum_{j=1}^{n} \quad (\sum_{i=1}^{m} R_{ij})^2 \qquad (3.6)$$

where n = number of project success criteria; m = number of experts; R_{ij} = significant degree allocated for ith project success criteria by jth expert; and W = Kendall's coefficient of concordance.

A Performance Index (PI) measurement model was developed in this research project.

Next, the inhibiting factors and mitigating measures that in practice affect LC cost and time control were considered. The common factors that inhibit both time and cost controls during a construction project were firstly identified, then mitigating measures were developed for the top leading inhibiting factors.

A Likert scale was used to rank the factors. Using the following formula, the scale was converted to an RII for each factor (Olawale and Sun, 2010).

$$\text{Relative importance index (RII)} = \Sigma w \div (H \times N) \qquad (3.7)$$

where w = the total weight given to each factor, calculated by addition of the various weightings given to a factor, which ranges from 1 to 5.

H = the highest ranking available (i.e. 1 in this case).
N = the total number of respondents that have answered the question.

To calculate weight: w is the total weight given to each factor by the respondents, which ranges from 1 to 5 and is calculated by an addition of the various weightings given to a factor by the entire respondent.

Previous researchers such as Al-Tmeemy et al. (2012), Alwi et al. (2003), Assaf et al. (2006), Le et al. (2008), and Zeng et al. (2005), have successfully used RII in their research, as it allows identifcation the most important criteria based on participants' replies and it is also an appropriate tool to prioritise indicators rated on Likert-type scales.

The development of measures to mitigate the inhibiting factors was the next step used. Responses were simplified to facilitate analysis by assigning numerical values of 1 to 5 to the ratings. This five-point scale was converted to an RII for each individual factor, using the formula (see equation 3.7) adopted by Kumaraswany and Chan (1997, 1998) and Iyer and Jha (2005).

A Time Matrix, Cost Matrix, Waste Matrix, and KPIs for measuring performance and developing a performance index were developed in this research project. A Master Schedule (schedule of executive steps) was available; Primavera software was used to analyse the case study data obtained (see Section 3.2.5). Further details of this are presented and discussed in Chapters 5 (see sections 5.3.3.1.2, 5.3.3.2.2, 5.3.5, and 5.3.7–5.3.9) and 6 (Section 6.2).

A Master Schedule was prepared using Primavera PERT Master software and PPC (Percentage Plan Complete) of the construction process (see background details in Appendix D) which utilised the principles suggested by Ballard (2000).

SPSS software was used for all the analysis undertaken in this research, to select the top project success criteria used for the model. From this, a correlation matrix was created in SPSS, and finally a project measurement model was proposed, based on that proposed model. This then allowed the project success index to be calculated using the proposed equation (see

equation 5.4, Chapter 5). The performance matrix for stages 5, 6 and 7 of the modified RIBA PoW was also proposed for assessing construction projects' success.

In a similar study by Yeung et al. (2009), statistical analysis was performed involving the calculation of Kendall's W for the KPIs to obtain a measure of consistency, and a performance index was developed. In another study by Khosravi et al. (2011), the calculated Kendall's W for the KPIs was used to develop a model for measuring the success of construction projects using a project success index.

The Delphi method (a two-round and a four-round Delphi questionnaire survey) was used to gather data and finalise the results, based on the respondents' answers to the questionnaire and interview questions (Chan et al., 2001). According to Chan et al. (2001), the Delphi methodology is being progressively implemented in many complex areas in which a consensus is to be reached. The Delphi approach, designed to extract the maximum amount of unbiased information from a panel of experts, is an extremely formalised way of communication. As the Delphi method is a rather subjective area of research, it was deemed suitable to use it for this study.

The Delphi method used in this research consisted of two and four rounds. The definition of experts and their selection; the number of rounds; the questionnaire structure; and the number of questions in each round of study were the key issues in preparing the Delphi study (Manoliadis et al., 2006).

The first round of the Delphi questionnaire covered the construction issues and development of the measurement and control methods used. The respondents were asked to identify and rank the following parameters:

- Time planning,
- Control and overrun factors,
- Production control in construction,
- Cost management and control practices
- Cost control techniques and cost overrun factors,
- Techniques and methods utilised for quality management and control,

- Sustainability management and control,
- Waste in the production process, training and continuous learning,
- Inhibiting factors and mitigating measures and earned value method.

In the second round of Delphi questionnaire, respondents were requested to provide ratings on the top five factors based on a five-point Likert scale (the top five factors were selected for further analysis based on those selected by at least 50% of Delphi experts). This allowed the KPIs to be re-evaluated.

Furthermore, in the first round of the Delphi questionnaire regarding the KPIs, the respondents were asked to identify a minimum of five to a maximum of ten KPIs that they believed to be the most vital for assessing the success of relationship-based construction projects in the UK and Iran. In the second round, the selected KPIs were re-evaluated.

In third round of the Delphi questionnaire, respondents were requested to provide ratings on the top five KPIs based on a five-point Likert scale (the top five KPIs were selected for further analysis based on what was selected by at least 50% of Delphi experts).

During the fourth round weighted KPIs were re-evaluated.

While analysing the data, the opinion of the group was the main focus, rather than that of individuals. Therefore, a concordance analysis, measuring the consistency of the experts' responses over successive rounds of the Delphi survey, was used. The consistency of the results of Rounds 1 and 2 were analysed and compared using Kendall's concordance analysis (see Section 3.3.6.2). A group of experts were selected to determine the KPIs of construction relationship-based projects in the UK and Iran.

Round 1 of the UK questionnaire was used to collect information and Round 2 was used for comparison with Iranian data, using case study applications for accurate finalisation of the proposed framework and associated results. Rounds 1 and 2 of the Iran questionnaire were used for collecting information, and application and implementation in the case studies. During Round 2, the Iranian data gathering was based on interviews. Rounds 1 and 2 were used for the UK; Rounds 3 and 4 of the Delphi method were used for Iran. For Iran case

study and application and Implementation there as well as the methods application and Implementation used there (see Chapter 5, Section 5.7).

Yeung et al. (2009) used a similar Delphi study and KPIs in Australia for developing a performance index. A similar research method was applied to develop a partnering performance index, for partnering projects in Hong Kong (see Yueng et al., 2007). This demonstrated an empirical study which applied the Delphi survey methods used to develop a model to assess the success of relationship-based projects based on a conceptual framework.

To obtain the most valuable opinions from the practitioners and academics who have in-depth knowledge about KPIs, only those who met the covering letter criteria were selected. The composition of this group of experts provides a balanced view for the Delphi study. Further details are provided in Chapters 4 and 5.

3.3 Summary

Using the methodology outlined in this chapter, a new adaptation of the RIBA framework has been developed. Chapter 4 builds upon this picture, by presenting the results of each of the key stages set out above. The development of a construction framework and a first set of results are presented therein based upon the derived questionnaire.

4 DEVELOPMENT OF CONSTRUCTION FRAMEWORK AND RESULTS

4.1 Introduction

The application of lean principles in construction projects aims to increase the value of these projects and to eliminate construction waste, to achieve project targets of time, cost, and quality, while reducing damage to the environment (sustainable development). Lessons learned from the construction industry have shown that by adopting lean principles, processes can significantly enhance the overall success of a construction project. Currently, the potential benefits have still not been fully released in a uniform way. This chapter presents a new proposed model that contains a set of lean methods and techniques to support the application of lean principles in construction project practice and, via this a method to more consistently achieve the full benefits that LC approaches can offer.

Many of the construction process models currently used in the industry have several problems. In many circumstances, these models cannot be used efficiently and effectively, particularly when lean methods and techniques are applied. The challenges and problems with applying lean principles in construction projects are discussed below in this section. The adaptations of lean principles with enablers in the proposed model are identified and assessed; a combination of different lean methods and techniques as the major enablers are taken into consideration in the construction process. This proposed model is then integrated and incorporated into the RIBA PoW to implement lean methods and techniques in construction activities, as this has proved to be the most effective way to implement changes associated with the proposed LC model. This is illustrated in Figures 4.1 and 4.3 (see Section 4.1.1 below). The measurement and control methods which have been developed to control and manage cost, time, quality, and sustainability are also presented in this chapter. Recommendations are given to improve the implementation of LC in construction activities.

The construction phase in the life cycle of a construction project contributes significantly to the project's performance. Poor outcomes from the construction phase in the development process are considered as the major contributors to project delay, cost overrun, and poor performance, all of which affect the overall project performance. The aim of this study was to

develop a construction process model to improve the performance of the construction process to make construction projects more effective and efficient.

The adaptation of lean principles, with the identification of waste and enablers in the construction process, is evaluated. The innovative construction process models presented in this research have been developed based on the core enablers that can be used to identify and eliminate waste. Adaptation and consideration of the core enablers of the construction process model are also discussed.

4.1.1 Construction process

As discussed in the Chapter 2, the RIBA PoW, first developed in 1963, is the definitive UK model for the building design and construction process. This chapter aims to show the development of a framework that embeds LC within the construction process. To generate a new framework, the RIBA PoW was used to integrate and incorporate LC principles to develop a standard model where the construction stages and activities of the processes in construction projects are described (see Figure 4.1). The construction flow process illustrating how this maps to the RIBA PoW is shown in Figure 4.1 below. It should be noted that whilst Figure 4.1 illustrates this process for the RIBA PoW 2013, the core principle is still valid following the release of the 2020 PoW. It should be further noted that the latest addition to the RIBA PoW was issued after the substantive work undertaken to support this research had been completed. However, the impact from the update is limited because whilst this research is based on the 2013 version, the updated 2020 version is broadly similar and therefore all the findings and suggestions made using the 2013 version are still applicable for the 2020 version (see Chapter 2).

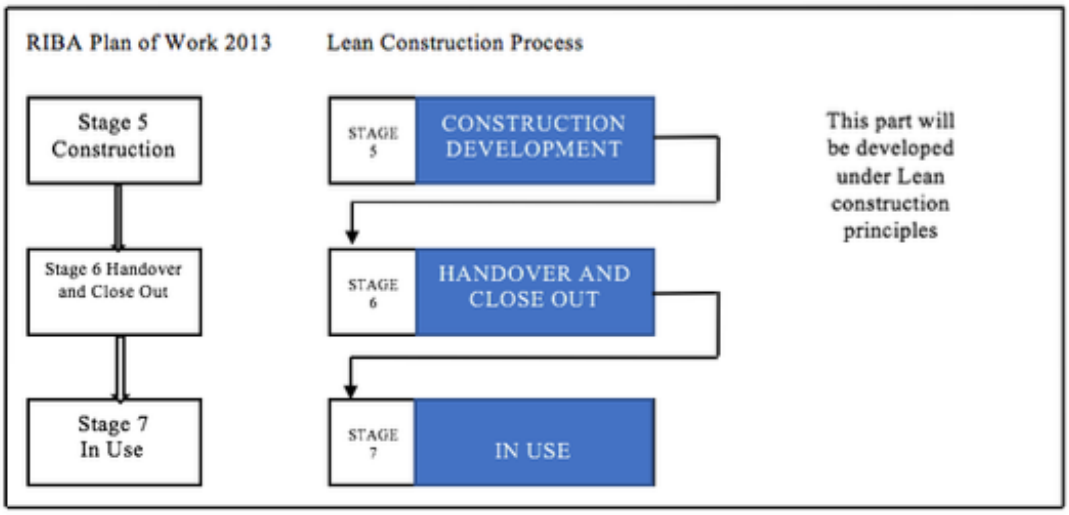


Figure 4.1: Construction flow process illustrating how lean construction process stages map to the RIBA Plan of Work

The earlier stages of the RIBA PoW were considered in another study by Yusof (2019). In addition, the author has a published conference paper (see Yusof et al., 2015). In a study of lean design processes for building construction projects, Yusof (2019) proposed a design process based on the principles of SBCE as the core enabler. The proposed development in the research presented in this thesis uses SBCE in the construction stage. The LC process development model will then be able to significantly reduce construction rework.

The art of managing large projects preceded the management of production processes by more than 4000 years. Yet 'project management' as a recognised intellectual discipline or, more correctly, as a methodology has only been around for a few decades. The formal adoption of project management methods should provide managers, working to very tight schedules, with the means to manage large and complex projects (McGeorge and Palmer, 2002). Construction work, other than maintenance operations, is essentially project work. Expenditure on new construction work in the UK, for example, runs into tens of billions of pounds annually.

The aims of a project manager today are no different from those in previous centuries, namely, to bring together, for a finite period, considerable resources in the form of manpower, machines, and materials to complete the project on time, to specification, and within budget. Today, however, the project manager can use several tools that will keep track of a multitude of different parallel tasks, allowing better-informed decisions to be made

quickly and with confidence. Complex and concurrent engineering processes need clearly defined relationships between the supplier/contractor and purchaser; the project manager must implement policies to this end (Pilcher, 1992; McGeorge and Palmer, 2002; Harris and McCaffer, 2006).

The concepts of concurrent (simultaneous) engineering and fast-track engineering are also recognised lean techniques (Koskela, 1992). To make it possible for all related parties in a product initiation to work on their projects concurrently, concurrent engineering (CE) must be produced. This is also known as simultaneous engineering, which is a recognised lean technique.

Project management is a powerful methodology, one with which all members of a project management team should be familiar. Likewise, a project is a specific, finite task in which the means for its completion must be created for its duration. Each project will be unique. It will be dependent on parent organisations for its resources, especially people. Each project, almost inevitably, will be subject to change, which may mean a departure from the plan, the programme, and the budget. Project management is the overall planning, implementation, control, and coordination of a project from inception to completion, needed to meet the required standards within time and to budget. In other words, project management means the management of the whole process.

In view of the considerable responsibility entrusted to the project manager, selection, training, and authority are of great importance. The Latham Report recommends that the terms of appointment and duties should be clearly defined (Latham, 1994). The project manager should be given the necessary authority to ensure that the work is carried out satisfactorily through to completion without frequent reference to the owner.

Modelling is the process of constructing a model, a representation of a designed or actual object, process, or system, a representation of a reality (McGeorge and Palmer, 2002). A model must capture and represent the reality being modelled as closely as is practical; it must include the essential features of the reality whilst being reasonably cheap to construct and operate and easy to use. Models may be used to investigate and/or to predict by managers, for whom predictive models are more valuable, whilst auditing requires investigative modelling.

The growth of LC led to the establishment of the Lean Construction Institute in 1997 (https://leanconstruction.org/pages/about-us/). The lessons learned therein from the construction industry have proved that adopting LC principles can enhance construction project success, reduce time and cost, and solve construction environmental problems (Howell, 1999; Alarcón, 2005; Green and May, 2005; Aziz et al., 2013; Issa, 2013; Marhani, 2013; Lean Construction Institute, 2017; Sarhan et al., 2019).

This thesis presents a new framework model that contains a set of lean methods and techniques to support the application of lean principles to construction project practice. The innovative feature of the research is the development of a framework that provides effective implementation of LC within the RIBA PoW. Importantly, Phase 1 of the model's development includes Construction Planning, Cost Control, and Time Scheduling.

Project success is assessed in terms of Time, Cost, Quality, and Sustainability issues (Lean Construction Institute, 2017). In other words, a project is considered as being successful if it is completed on time, within the budget, meeting a customer's needs (i.e. quality and customer satisfaction), and if it is deemed sustainable. This is not easy to achieve as construction projects are broadly understood to be unpredictable, which leads to low performance, such as cost and time overruns, low quality, and inconsistent value generation (Bertelsen, 2004).

Several models have been proposed and developed in Phase 1 (see Figures 4.1 to 4.22). These include designing a pull system. The proposed new model will consist of integrating and developing the LPS and SBCE models, amongst others. Also, the problems, gaps, and barriers to implementing the Last Planner production control system in developed and developing countries are discussed in Chapter 2 and are considered in future development, as discussed in Chapter 5.

The framework development in this research project consists of two parts, conceptual frameworks (see Section 4.2) and implementation frameworks (see Section 4.2.2).

4.2 Conceptual construction process model (conceptual framework)

The framework development steps in this section are initiated with how to start the process of integrating 'lean thinking' (LT). LT starts with the customer and the definition of value. The key is to identify waste, and to ensure that the root cause of waste generated is eliminated, not just the symptom.

Flow is probably the hardest lean concept to understand. To understand flow, the concept of value stream needs to be understood. Therein, the identification of value and the definition of value propositions for specific customers are key. Within a process, any activity which does not add 'value' to the customer is called 'waste'. Such aspects include, but are not limited to, those such as financial controls. Sometimes, identified waste cannot be eliminated as it forms a necessary part of the process and adds value to the company. Otherwise, all 'muda', as the Japanese call waste, should be eliminated (Santos, 1999).

Continuous improvement is at the core of LT. The improvement cycle is never ending as lean thinkers are aiming for 'perfection'. This cultural change is the hardest change of all for many in the process industries. Organisations which are truly lean will invest the time and effort in supporting a change in culture for guaranteed sustainability. Some of the ways in which culture can be impacted are highlighted in the case study (see Chapter 5).

According to Melton (2005), "*there is no doubt that the elimination of waste represents a huge potential in terms of improvements – the key is to identify both waste and value; develop our knowledge management base; realize that sustainable improvement requires the buy in of the people operating the process and managing the business, and therefore a culture of continuous improvement*".

This research shows the waste in construction and how it could be minimised, and discusses the principles, methods, and implementation phases of LC. It has been shown that the LPS technique can improve various aspects of construction management practices, is more prevalent, and is an important application of the LC concepts and methodologies (see Chapter 2). Based on lean approach principles, the research presented herein set out to develop a methodology for process evaluation and define areas for improvement.

The LPS technique has been shown to enhance construction management practices and bring numerous advantages. Through this, construction projects will be more stable and less stressful for all stakeholders, by reducing dependencies and variations to identify and eliminate waste (non-value-adding activities) (Aziz and Hafez, 2013).

Lean implementation begins with leadership commitment and is sustained with a culture of continuous improvement and adoption of appropriate tools. These philosophies should therefore be embedded within the development of the new conceptual framework presented here. According to Sarhan and Fox (2012), the use of inappropriate tools is all too often identified as a significant barrier to the successful implementation of LC; this is a view held by other researchers (e.g. Johansen et al., 2002; Bashir et al., 2010). It is important to realise that for these tools and techniques to be optimally used, the lean philosophy must be clearly understood (Bhasin and Burcher, 2006). Whilst focusing on lean tools alone may improve performance, it will not lead to long-term sustainable improvement (Hines et al. 2011) or yield the full benefits of LC (Bashir et al., 2010).

Common et al. (2000) and Johansen et al. (2002), in their work to establish a conceptual framework for LC, identified four areas as being fundamental attributes of a lean approach, namely:

1. Procurement,
2. Planning,
3. Control, and
4. Management concepts.

Within each area, they identified several tools and techniques that were seen as being influential for the realisation of LC. Johansen and Walter (2007) developed this conceptual framework further to include eight areas. Each area was associated with several tools and techniques which have been found to be most effective in improving conformance to lean principles. Building on this work, the importance of establishing a lean culture among the construction industry was further emphasised by Hines et al. (2011), Santorella (2011), and Terry and Smith (2011). In addition, there has been an improved understanding of the importance of using appropriate Performance Measurement Systems (PMSs) to support the

successful implementation of LC (Lantelme and Formoso, 2000; Alarcón et al., 2001; Leong and Tilley, 2008). Other studies have highlighted the value of linking the contribution of lean concepts with the challenges of the triple bottom line of sustainability (e.g. Huovila and Koskela, 1998; CPN, 2009). According to Yeung et al. (2009), an increasing trend of client organisations has been observed over the last decade – to introduce partnering and alliancing, two similar and innovative non-adversarial relationship-based approaches, to manage their building and construction works worldwide (Walker et al., 2000b; Chan et al., 2002). As a result, effort to implement LC have become more comprehensive and are accompanied by several frameworks and models (see for example, Marhani et al., 2013).

Examples of these include the works of:

- Koskela (1992, 2000), who used three views of construction production to build a theoretical foundation and accompanying models for LC; these included (1) transformation model; (2) flow model, and (3) value generation model.
- Diekmann et al. (2004) presented the LC wheel to assess the extent to which an organisation conforms to lean ideals. The wheel covered topics of elimination of waste; standardisation; culture/people; customer focus; and continuous improvement.
- Green and May (2005) evaluated the existing model of LC from policy makers' point of view; topics covered were waste elimination, partnering, and structuring the context. Their findings suggested that both learning and innovation are necessary for more efficient and effective ways of working to enhance LC; this upheld the view of Barlow (2000).
- Salem et al. (2006) developed another lean assessment framework, to evaluate the implementation of each lean tool within the proposed framework. Topics covered six lean tools, identified in four scopes, namely: (1) low variability (i.e. Last Planner); (2) process variability (fail safe for quality); (3) transparency (5Ss), and (4) continuous improvement (huddle meetings).

According to Rahani et al. (2012), one of factors to maintain a quality product is to reduce or eliminate Work in Progress (WIP), covered by process variability in these factors, as listed above in this section.

These LC principles have been adopted/adapted in a number of ways by authors, for example, Gao and Low (2014), who examined the current implementation frameworks for LC in the context of the construction industry and sidelined them in favour of a newly proposed framework based on the Toyota Way model. Muhammad (2013) also developed a framework for utilising LC strategies. However, this was within the context of promoting safety on construction sites. Likewise, several observations on the ease with which LC can be adopted (or not) and the influence of local context have been reported. For example, Brady (2014) highlighted the lack of transparency in the construction process (third bullet point in the list above), which leads to communication issues and inefficient decision-making. This was a key motivation in the research presented in this thesis to develop the Lean Construction Management (LCM) model – a visual management model based on lean concepts, designed to improve transparency in production planning and control in construction.

LC is still in the stages of learning and training in many developing countries, and in some developed countries it is still a work in progress. For example, according to Labib (2017), who studied of a variety of databases, there is no sign of implementation of lean practices or LT in the construction industry in Jordan which is disjointed and not well organised. This shows that applicable construction management is vital to the success of construction projects; it also highlights the need for the development of the framework within this current research. Moreover, the outcomes also show that the awareness and implementation of lean planning tools and practices are still underestimated.

Academics will be able to use the research to identify initial indicators and tools for further in-depth studies related to lean logistics within developed and developing countries.

According to Beale (2008), for successful lean implementation, employee motivation is a critical factor, but there is limited research regarding individual-level influences. In a similar way, Thirkell (2016) explored how employees experience LT. She found that there are several problems in understanding, communicating, and transferring LT in context; and as a consequence, the depth and breadth of lean application in the cases is very limited. Thirkell (2016) went on to suggest that there is "*a shared view among managers and professionals of the difficulties associated with measuring (intangible) contributions and outputs that might otherwise convince professionals to support Lean approaches*." In addition to this, a lack of

empathy with the contextual relevance of lean was demonstrated with the key training programmes. Many of the professionals here fought to maintain frontiers of control, and senior managers and sponsors acknowledged that this was 'inevitable' (Thirkell, 2016). This research suggests that managed participation is a key feature of lean implementation. Allied to this, Al-Sehaimi (2011) advocated adopting lean principles through 'action research', suggesting this would help construction experts to better recognise their problems and in so doing help deliver satisfying solutions, through providing convenient tools for improving construction management.

The review presented in this section of the existing frameworks of LC revealed that frameworks differ considerably in many areas (see Chapter 2). This current research should therefore try to better understand and integrate a large set of existing lean tools as part of this current framework development.

4.2.1 Initial modelling development (first stage model development)

From the literature, it has been shown how current approaches are failing in several ways (see Chapter 2). Developing a framework that embeds LC is part of the solution. However, this should also be accompanied by industry buy-in, whereby (through the process of conducting questionnaires and interview surveys) solutions are sought to the previously mentioned problems and challenges. The research presented herein started with the model development (First Stage).

The transformation–flow–value (TFV) generation model of production, also known as the TFV theory of production (Sarhan and Fox, 2013), was first formulated by Koskela (1992) to improve performance once applied to construction; Production as Transformation, Production as Flow, and Production as Generation of Value (i.e. TFV) are the three main theoretical production models, also known as LC theories.

4.2.1.1 Lean modelling (PIMR) development cycle

In the current research, the proposed lean modelling development cycle, which includes *Planning, Implementation, Monitoring and Control, and Review* (PIMR) functions, has been

proposed (see Figure 4.2) for integration into Construction Stage 5 of the RIBA PoW as shown through the construction flow in Figure 4.3 and through the developed conceptual framework in Figure 4.4. Therein, 'Validate feasibility' has been placed within Stage 6 – Hand over and close out, although it is also acceptable within Stage 7 – In Use.

Figure 4.3 shows a more detailed aspect of Figure 4.1.

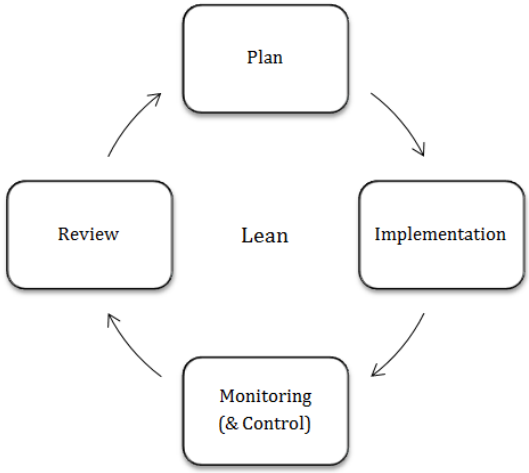


Figure 4.2: Proposed lean modelling development cycle

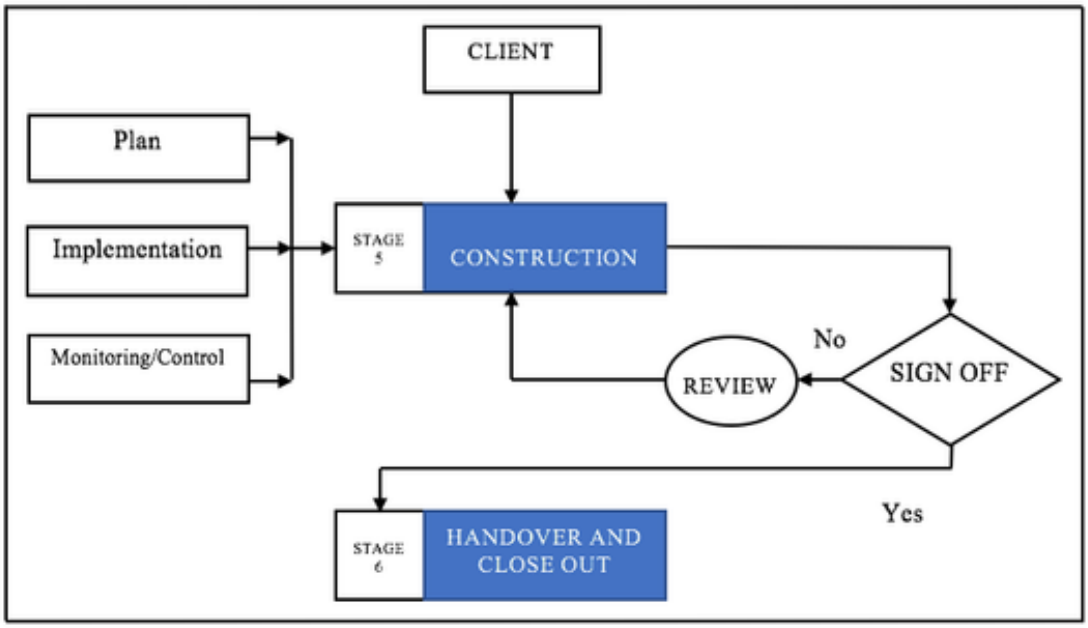


Figure 4.3: Construction flow with lean principles embedded

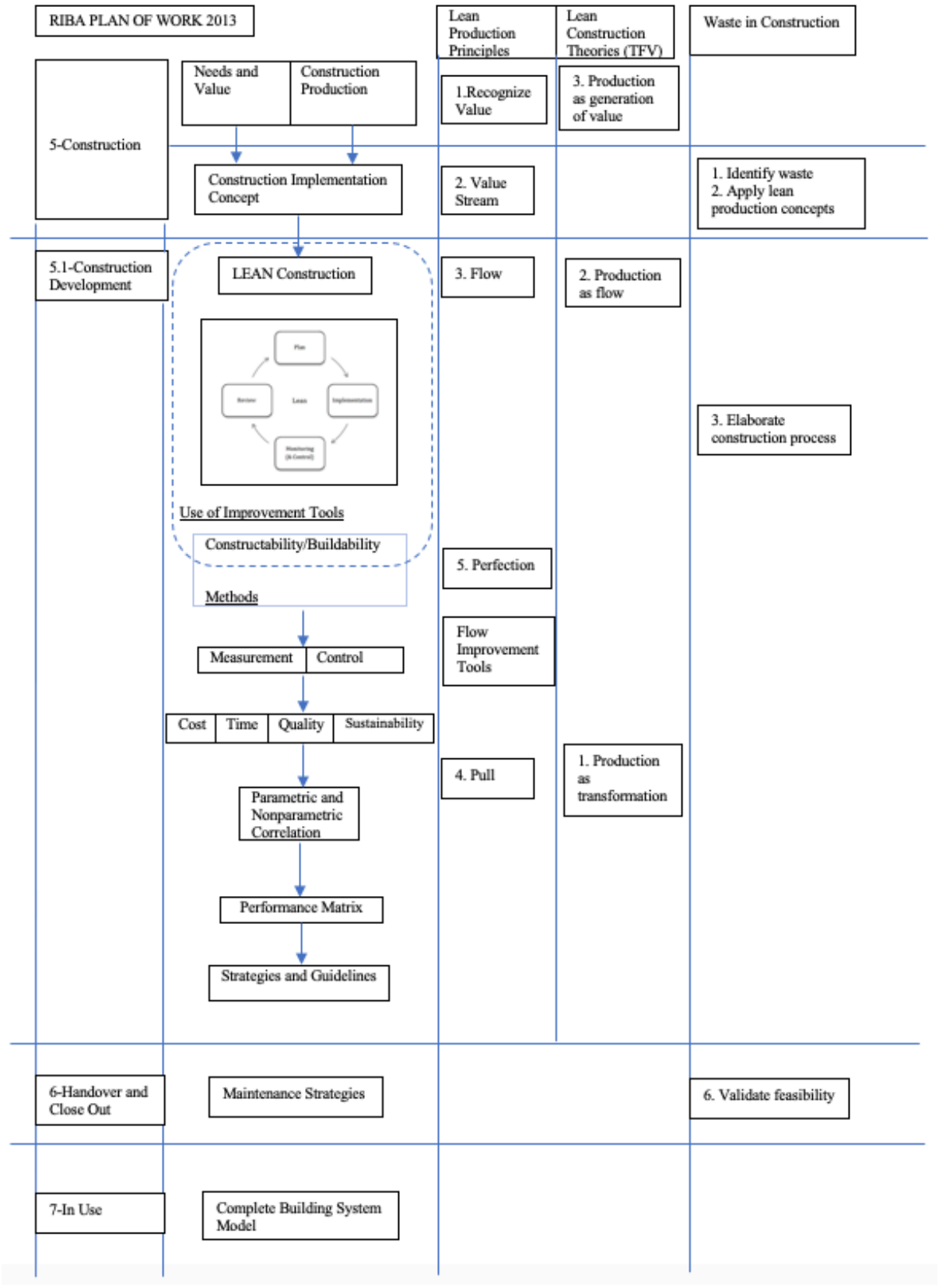


Figure 4.4: Fully developed conceptual framework for implementation of lean construction in the RIBA Plan of Work (after RIBA 2013)

In this research, lean PIMR (Figures 4.2 and 4.3) is proposed for the construction industry. Performance, Waste, Planning and Control, Cost, Time, Quality, and Sustainability management are presented in a single framework; as far as the author is aware, this does not currently exist, a gap this research intends to fill.

In brief, the quadrants of PIMR, shown in Figure 4.2, are:

(1) Planning: A well-developed plan allows all the efforts of monitoring and control to begin against a background of knowing how the costs have been calculated in terms that are readily understood by site planners and construction managers (Ballard, 2000; Harris and McCaffer, 2006). Planning and Control are two sides of the same coin that keep on rotating throughout a project. Planning describes and outlines the criteria for success and produces strategies for reaching objectives. Project planning is often confused with project management, as successful project management requires a well-thought-out plan. Project planning must be followed by project control.

Project planning means:

- Planning methods;
- Choosing between 'in-house' services and external suppliers/contractors;
- Deciding on cash flow (the cost plan or budget); and
- Deciding on the schedule of operations (the timing plan).

Project management software is largely used for planning and monitoring but allows an iterative approach to developing the plan. From an initial draft plan, data on the sequence and duration of operations (activities), on resources, and on costs are inputs into the software. Analysis of the output leads to modification of the plan, for example, to improve resource management, until a satisfactory plan is obtained. Shingo (1988) divided management into functions of planning, control (with implementation), and monitoring (see below in this section).

(2) Implementation: Processes and operations are implemented as planned; implementation is not a managerial function (Koskela, 2001). Monitoring and controlling: as the work proceeds, it must be measured against the plan.

(3) Monitoring and Control: Relates to cause and associate results that occur in events needed to comply with the plan and through this activate learning and replanning. Monitoring is the act of checking actual progress and actual resource usage against planned progress and planned resource usage. Control is the act of taking decisions to alter the likely future outcome and bring the project back on the planned schedule, as well as decisions relating to rescheduling of activities, reordering of activities, and altering of resources to change the duration of activities. Thus, the planner must collect the information on the rate of progress to date and current resource usage to update the computer model and monitor progress. This information can be presented to construction managers together with suggestions for rescheduling. The rescheduling decisions taken by managers may need processing before control decisions are implemented (Ballard, 2000; Harris and McCaffer, 2006).

Considering the progress in LC to date, the current research enhances the conceptual framework established by Sarhan (2011), which includes hard and soft aspects of LC principles. Therein, these two aspects incorporated nine cornerstones, which were recognised as being fundamental attributes of a lean approach.

The soft aspects of lean comprised two cornerstones: 1. Lean culture and 2. Collaborative relationships. The hard aspects of lean include: 1. Performance measurement and evaluation; 2. Procurement; 3. Management concept; 4. Planning and control; 5. Design; 6. Installation of design; and 7. Supply.

Due to its great potential in fulfilling a client's objectives in terms of increasing the value and productivity of a construction project, LC is seen as an alternative approach that can be implemented in the construction industry (Marhani, 2013).

Better management would be possible through the use of improvement tools such as Lean principles; Last Planner System (MBM thinking); Earned Value Method (EVM)/Customer Earned Value (CEV); Environmental Management System (EMS); Concurrent Engineering; Set-Base; Process Engineering; Six sigma; Plan-Do-Check-Act (PDCA); Set-Based Concurrent Engineering (SBCE); Kaizen / Kaizen costing; Lean & Building Information Modelling (BIM); SMART; Lean Project Delivery System (LPDS); Kanban; Poka-yoke (error-proofing); Just-In-Time (JIT); Total Quality Management (TQM); Kaikaku; and

Kanban (Pull flow control in lean production management, and Kanban + BIM = KanBIM) in the framework above Figure 4.4.

According to Melton (2005), key tools and techniques within a lean system should at the very least include all of the following:

- Kanban;
- 5Ss;
- Visual control
- Poke yoke; and
- SMED (Single-Minute Exchange of Dies).

Melton (2005) suggested that 'lean' (and accompanying tools) has significant benefits to offer the process industries, not least performance improvements across the whole supply chain, which directly or indirectly support increased business performance. Within this research and developed framework, better consideration of the following has been facilitated through integration of lean tools and LT:

- Construction/buildability methods such as management and control skills;
- An implementation plan;
- Information management;
- Performance improvement;
- Strategy;
- Visual management;
- Integration;
- Construction knowledge;
- Team skills;
- Corporate objectives;
- Available resources;
- External factors programme;
- Construction methodology;
- Accessibility;
- Specification; and
- Construction innovation.

Lastly, including feedback to improve the construction process, in addition to the proposed Implementation and Control System, will lead to a significantly improvement system.

4.2.2 Details of the framework model: implementation frameworks

1. LC model

From the review of the literature (see Chapter 2), it was decided that the LC phase needed to be further developed by integrating the RIBA PoW with the concept of lean philosophy. The five phases in lean design are the most command practiced design process model in the manufacturing industry, where companies are adopting lean product development (Khan, 2012). This can also be developed for the construction phase. The proposed phases of LC implementation are outlined below in Tables 4.1 and 4.2. Table 4.2 further highlights a checklist of practices derived from this principle that are fit for implementation in the construction industry.

Table 4.1 Proposed construction phases of lean construction implementation

5.0 and 5.1 Planning phase that comprises Stage 0. Define Value and Stage 1. Map Construction Scope *Stage 0. Define value: the initial concept definition is developed based on strategic goals, client requirements, and any other factors that need to be considered;* *Stage 1. Map construction scope: engineers, contractors, workers, or subsystem teams define the scope of the construction work required as well as feasible construction options/regions.*
5.2 Implementation phase which comprises Stage 2. Concept Construction Development (Develop Concept Set) *Stage 2. Concept Construction Development: each builder or subsystem team develops and tests a set of possible conceptual subsystem construction solutions; based on the knowledge produced in this phase some weak alternatives will be eliminated.*
5.3 Monitoring and Control phase comprises Stage 3. Concept Integration (Converge on system) *Stage 3. Concept Integration: 4. Converge on system: subsystem intersections are explored and integrated systems are tested; based on the knowledge produced in this phase the weaker system alternatives will be removed, allowing a final optimum construction solution to progress into the next phase.*
5.4 Review phase comprises Stage 4. Detailed Construction *Stage 4. Detailed construction: the final specification is released; engineers and contractor provide tolerances and the process continues with detailed construction activities.*

Table 4.2 Proposed integration of lean construction into Stage 5 of the RIBA Plan of Work (after RIBA 2013)

RIBA Plan of Work 2013	Stage 5 Construction				
Lean Construction	Stage 0 Define Value	Stage 1 Map Construction Scope	Stage 2 Concept Construction Development	Stage 3 Concept Integration	Stage 4 Detailed Construction
Lean Construction Activities	5.0 – 5.1 Planning		5.2 Implementation	5.3 Monitoring and Control	5.4 Review
	5.0.1 Classify projects	5.1.1 Identify sub-construction solution targets	5.2.1 Extract (Pull) construction concepts	5.3.1 Determine concept construction intersections	5.4.1 Release final specification
	5.0.2 Explore client value	5.1.2 Decide on level of innovation to sub-construction solution	5.2.2 Create concept construction for sub-construction solution	5.3.2 Explore possible constructions	5.4.2 Define Construction tolerances
	5.0.3 Align project with company strategy	5.1.3 Define feasible regions of construction scope	5.2.3 Explore the concept construction for sub-construction solution	5.3.3 Seek conceptual robustness	5.4.3 Full project definition
	5.0.4 Translate value to builders		5.2.4 Capture knowledge and evaluate	5.3.4 Evaluate concept construction for lean construction	5.8 Sustainability Checkpoints 5.8.1 Offsite manufacturing and onsite **Construction** in accordance with **Construction Programme** and resolution of **Design Queries** from site as they arise.

Table 4.2 Proposed integration of lean construction into Stage 5 of the RIBA Plan of Work (after RIBA 2013) (continued)

			5.2.5 Communicate concept constructions to others	5.3.5 Begin process planning for construction	5.8.2 Review and update **Sustainability Strategy** and implement **Handover Strategy**, including agreement of information required for commissioning, training, handover, asset management, future monitoring and maintenance and ongoing compilation of **'As-constructed' Information**. Update **Construction** and **Health and Safety Strategies**.
				5.3.6 Integrate the final concept construction of sub construction solution	
	5.0.5 Internal review	5.1.4 Internal review	5.2.6 Internal review	5.3.7 Internal review	5.4.4 Internal review
Framework Development (Lean Construction)	5.5 Framework Planning		5.6 Framework Procurement		5.7 Framework Operation
	5.5.1 Project need		5.6.1 Project case		5.7.1 Framework management
	5.5.2 Market capacity		5.6.2 Stakeholders		5.7.2 Appropriate governance
	5.5.3 Appropriate governance		5.6.3 Supply chain engagement		5.7.3 Project case review
	5.5.4 (Developed) Design/construction outcomes		5.6.4 Design and construction outcomes		5.7.4 Creating programmes / clusters

Table 4.2 Proposed integration of lean construction into Stage 5 of the RIBA Plan of Work (after RIBA 2013) (continued)

	5.5.5 Supply chain engagement	Administration of **Building Contract**, including regular site inspections and review of progress.	5.7.5 Supply chain engagement
			5.7.6 Framework outcomes
All of the above activities are explained below.			

The followings are the details of each activity in relation to the proposed lean construction model in the Table 1 presented above. There is no particular sequence on the activities due to the provision of flexibility of using the model.

Activity 5.0.1: Classify project: Each project should be classified in order to forecast the time, cost, quality and sustainability commitment. The expected level of innovation at both the system and subsystem level should be clarified in addition to other relevant parameters. The intended market should also be clarified in the case that it impacts subsequent engineering activities.

Activity 5.0.2 Explore client value: Client needs and desires should be thoroughly understood in order to determine system targets and ensure the necessary provision of client value; The extent of this activity will depend on the level of innovation; construction criteria will be determined based on client value amongst other factors, to support the evaluation of alternatives constructions.

Activity 5.0.3 Align with company strategy: Each project should be aligned with the company CONSTRUCTION strategy, in order to take strategic advantages from projects. This will prevent value (benefits) gained through projects from being wasted and ensure the enhancement of the CONSTRUCTION process.

Activity 5.0.4 Translate value to constructors/builders: The information developed in this phase should be compiled in a document referred to as the construction concept definition: both the strategic objectives and the understanding of client value will be translated to the builders that are involved in the project via this document.

Activity 5.1.1 Each subsystem team should decide based on the product concept definition which subsubsystems/components to improve and to what level of innovation; this will help to prevent overengineering while encouraging the necessary innovation and enhancements.

Activity 5.1.2 Identify subsystem targets: Each subsystem or component participant/team will analyse their Engineer and identify their own lower-level targets (lower level requirements) based on the concept definition.

Activity 5.1.3 Define feasible regions of construction scope: Appropriate construction possibilities should be defined based on knowledge and past experience, while considering the views/constraints of different functional groups.

Activity 5.2.1 Extract construction concepts: Concepts should be drawn from previous projects, and competitor products (benchmarking).

Table 4.2 Proposed integration of lean construction into Stage 5 of the RIBA Plan of Work (after RIBA 2013) (continued)

Activity 5.2.2 Create sets for subsystems: This time is scheduled specifically for construction teams to brainstorm and innovate so that a set of possible construction solutions is proposed; The set for a particular subsystem may be only 2 options, while a subsystem or component that is not being changed would not require a set; Alternatives within a set may comprise of differences in fundamental concepts, components, arrangements, properties or geometry. Activity 5.2.3 Explore subsystem sets: alternative solutions shall be simulated, prototyped, and tested for lifecycle cost, quality, and performance. Activity 5.2.4 Knowledge capture and evaluation: Knowledge that has been created will be captured (quantitative and qualitative) in order to evaluate the sets. Activity 5.2.5 Communicate sets to others: Each subsystem or component team will present their set to the other teams at an event (meeting) in order to get feedback and understand constraints. Activity 5.3.1 Determine set intersections: Subsystems that progress into phase 4 can be considered for system integration. The intersection of feasible sets will be reviewed, considering compatibility and interdependencies between subsystems and components. Activity 5.3.2 Explore system sets: Potential systems can be simulated/prototyped (parametric and physical), and tested for cost, quality, and performance. Activity 5.3.3 Seek conceptual robustness: Conceptual robustness will be sought against physical, market, and construction variation in order to reduce risk and improve quality. Activity 5.3.4 Evaluate sets for lean construction: Once the potential systems have been explored, they will be evaluated for lean construction to assess the costs, efficiency, problems etc. Activity 5.3.5 Begin process planning for construction: Once the potential systems have been evaluated, industrial and engineering chains will be considered. The effects on cost, time, quality, sustainability, efficiency, potential problems etc. will also be considered. Activity 5.3.6 Converge on the final set of subsystem concepts: Based on the evaluations and knowledge captured, sub-optimal system designs will be eliminated and the proven optimal design from the system alternatives will be finalized. The lean CONSTRUCTION model provides a process for conceptual construction up until construction freeze and the initiation of detailed construction. There are some activities that have however been included as recommendations for detailed construction that will be described briefly here. Activity 5.4.1 Release final specification: The final specifications will be released once the final system concept is concluded; this is important because by communicating that the specification will be released after all of the activities in phases 1 to 4, it will be more likely that the specification and commitment will be delayed. Activity 5.4.2 Define construction tolerances: Industry will negotiate part tolerances with construction teams; this is another aspect of delaying commitment in construction. Activity 5.4.3 Full system definition: Further detailed construction work will follow; it is assumed that companies may continue with their detailed construction processes for assurance and qualification of construction solutions which is normally industry specific.

Table 4.2 Proposed integration of lean construction into Stage 5 of the RIBA Plan of Work (after RIBA 2013) (continued)

Framework processes for Lean Construction Development
Methodology for activity 5.5 Framework Planning 5.5.1 Construction Project need 5.5.1.1 Classify the essential project needs of the client and specify how they will be reflected in framework planning, procurement and operation. 5.5.1.2 Correctly planned and developed project cases confirming strategy of framework is supported and that project need, income, cost, benefits and the risks are appropriately defined. 5.5.1.3 Involve with all investors, stakeholders, co-design and co-construction the strategy of framework, consider objectives of localism, sustainability, and efficiency strategically. 5.5.1.4 Cooperate with associate administrations in the locality, regionally and nationally, ensuring an overall fit with existing landscape.
5.5.2 Market Capacity 5.5.2.1 To make sure the supply chain attains expectable turnover, outline a feasible amount, which through that the framework makes satisfactory income to pay for management activities. 5.5.2.2 To avoid conflict, do consultation.
5.5.3 Suitable Governance 5.5.3.1 Start framework ownership preparations, agree governance and commercial terms; and ensure the framework is effectively ruled, managed and governed. 5.5.3.2 Consider proper risk sharing procedure to help notify the form of contract for the underlying contracts, competency of contractors, risk transfer and pain / gain share arrangements. 5.5.3.3 Classify a set of complimentary arrangements e.g. consultancy, minor and major works, repairs and maintenance.
5.5.4 Construction Outcomes 5.5.4.1 Agree Lean Construction strategy (LPS, SBCE, and etc.) 5.5.4.2 Agree sustainability strategy: Waste to landfill (WRAP), carbon reduction, whole life cost (Lean Construction), Key performance indicators (KPI), performance measurement and management. 5.5.4.3 Agree economic renewal strategy: reducing the local £, encouraging social enterprise, monitoring engagement.
5.5.5 Supply Chain Engagement 5.5.5.1 Agree engagement of supply chain strategy: Ensure engagement in local and national frameworks; Stress the involvement and integration of contractors and suppliers within the framework and construction team; Ensure clear method and approach and client engagement; and Local sourcing, fair payment provision down the supply chain . measure and monitor engagement. Agree employment and skills strategy: Proactive intervention for jobs, apprenticeships/ local employment outcomes linked to framework processes, and monitor engagement.

Table 4.2 Proposed integration of lean construction into Stage 5 of the RIBA Plan of Work (after RIBA 2013) (continued)

Methodology for activity 5.6 Framework Procurement 5.6.1 Construction Project Case 5.6.1.1 Agree framework management engagements to ensure they work as a "business' on a self-sustaining basis with a desire to deliver excellent outcomes.
5.6.2 Stakeholders 5.6.2.1 Lead or cooperate with other like-minded client organisations. 5.6.2.2 Correctly planned and resourced procurement with engagement of key stakeholders. 5.6.2.3 Quality: Ensure competent procurement professionals are engaged to understand regulations and procurement procedure to ensure quality tenders and few queries and/or challenges from the supply chain.
5.6.3 Supply Chain Engagement: The construction supply chain is main contractor-client based (Matthews, Pellew, Phua, & Rowlinson, 2000). 5.6.3.1 Simplify procurement processes to encourage greater involvement; Ensure obligations in the framework agreement which bring certainty to delivery of engagement strategy (fair payment, collaborative values flow down the supply chain, pipeline visibility, performance management); and Provide mechanisms for greater client influence over negotiations with its supply chain.
5.6.4 Construction Outcomes 5.6.4.1 Value bands: Structure lots and value bands to ensure adequate workload and appropriate risk sharing arrangement to match the right supplier for the type of work being tendered. Continuous improvement. 5.6.4.2 Set measurable targets for continuous improvement (localism, efficiency, sustainability) with stakeholders.
Methodology for activity 5.7 Framework Operation 5.7.1 Framework Management 5.7.1.1 Invest in development and management of framework – dedicated framework management team proactively managing and capturing benefits, supporting clients.
5.7.2 Appropriate Governance 5.7.2.1 Establish relationship and regular forums between framework management, contractors, supply chain, consultants and clients.
5.7.3 Construction Project Case Review 5.7.3.1 Demonstrate value for money and competitive tension are achieved through cost benchmarking and targeting. 5.7.3.2 Demonstrate early engagement of contractors and supply chain in the construction process where their contribution reduces cost and increases whole life value.
5.7.4 Creating Programmes / Clusters (SET BASED LEAN CONSTRUCTION) 5.7.4.1 Sustainable workload in well organised programmes of work in line with predicted throughput. 5.7.4.2 Common delivery and standardisation of work through programmes. 5.7.4.3 Create clusters and programmes of work of sufficient scale and duration to incentivise the supply chain and maximise local economic and social impact, demonstrate continuity of workload for supply chains.

Table 4.2 Proposed integration of lean construction into Stage 5 of the RIBA Plan of Work (after RIBA 2013) (continued)

5.7.5 Supply Chain Engagement 5.7.5.1 Implement mechanisms that bring certainty to intended level of engagement and client visibility of supply chain; Enable clients to have some influence over negotiations and management of supply chain decisions; Early engagement of supply chain to influence specification and buildability decisions; Ensure clear processes are established to ensure collaborative values; Demonstrate fair payment practices are adopted through supply chain to encourage cash flow.
5.7.6 Framework Outcomes 5.7.6.1 Ensure that the Framework achieves its target spend. 5.7.6.2 Implement Lean Construction and whole life cost assessment in the construction process enabling carbon impact and longevity decisions to be made about building components. 5.7.6.3 Demonstrate a reduction in carbon footprint and waste to landfill through products utilised and impact of the supply chain. Continuous Improvement. 5.7.6.4 Encourage innovation and standardisation through supplier groups and champions, strategic forums, capturing lessons learnt, championing new areas of development. 5.7.6.5 Demonstrate continuous improvement in time, cost, Quality, Sustainability (social, economic and environmental) targets and relationship between parties on the framework. 5.7.6.6 Demonstrate decrease in worklessness by providing training and employment opportunities for apprentices and local people through the framework. 5.7.6.7 Actively supports clients through management arrangements ensuring that clients are left with a legacy of improvement. 5.7.6.8 Put in place a structured/managed continuous improvement process to carry across key lessons learnt to any further frameworks being established.

In summary, the proposed framework shown in Figure 4.4 and Tables 4.1 and 4.2 consists of the following LC principles:

- Value identification,
- Value stream map,
- Flows, pull, and perfection.

This will lead to/facilitate the process of achieving:

- Transparency,
- Benchmarking,

- Reduced cycle time,
- Flexibility,
- Improved balance flow with continuous improvement,
- Process simplification,
- Minimised variability,
- A focus on the complete process, and
- Building continuous improvement into the process.

In addition, benchmarking would be possible by using the developed PI (Performance Index) formula (see Chapter 5).

4.2.3 Proposed waste management methods

The impact that waste management has on construction projects is valuable, beneficial, and long-lasting. Assessing sustainable construction, sustainable indicators and benchmarks, and use of waste reduction and minimisation, and SWMPs are needed to provide a means by which to monitor performance and to assess progress toward sustainable development, at various scales.

Based on the analysis and the results and opinions garnered from surveys (see Chapter 5), and to eliminate construction waste with the use of lean enablers, the Waste Process Matrix illustrated in Tables 4.3 and Table 4.4 was developed. This includes guidance on how to eliminate waste and create value with the use of lean enablers on key areas of waste. Based on the questionnaire survey results (Question 49) (see Table 4.4 and Section 4.7.4.2.1), 21 wastes (W1 to W21) were identified, as shown in Table 4.4, which can be eliminated by using the proposed construction process. Therein, lean enablers act to create value and eliminate waste in the construction process. The matrix has been applied in both the UK and Iran, as can be seen within the table; the results are discussed further in Section 4.9.

Table 4.3 Waste management in the construction process

<table>
<tr><td colspan="3">Phase</td></tr>
<tr><td>Stage 0
Define Value</td><td rowspan="2">5.0 – 5.1 Planning</td><td rowspan="2">5.5 Framework Planning</td></tr>
<tr><td>Stage 1
Map Construction Scope</td></tr>
<tr><td>Stage 2
Concept Construction Development</td><td>5.2 Implementation</td><td rowspan="2">5.6 Framework Procurement</td></tr>
<tr><td>Stage 3
Concept Integration</td><td>5.3 Monitoring and Control</td></tr>
<tr><td rowspan="2">Stage 4
Detailed Construction</td><td rowspan="2">5.4 Review</td><td>5.7 Framework Operation</td></tr>
<tr><td>5.8 Sustainability Checkpoints</td></tr>
</table>

Table 4.4 Developed implementation matrix of waste management in the construction process (UK and Iran)

Phase			Activity	Type of Waste																					
				W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21
Stage 0 Define Value	5.0 – 5.1 Planning	5.5 Framework/ Process Planning	5.0.1 Classify projects	✓	✓			✓					✓	✓		✓			✓					✓
			5.0.2 Explore client value	✓														✓	✓					
			5.0.3 Align project with company strategy									✓							✓					
			5.0.4 Translate value to builders	✓		✓												✓	✓					
			5.0.5 Internal review							✓	✓	✓			✓						✓			
Stage 1 Map Construction Scope			5.1.1 Identify sub-construction solution targets			✓																		
			5.1.2 Decide on level of innovation to sub-construction solution			✓																		
			5.1.3 Define feasible regions of construction scope			✓											✓			✓				
			5.1.4 Internal review							✓	✓	✓			✓						✓			
			5.5.1 Project need		✓			✓					✓	✓		✓								✓
			5.5.2 Market capacity													✓								✓
			5.5.3 Appropriate governance		✓			✓					✓	✓		✓								✓
			5.5.4 (Developed) Design/construction outcomes	✓		✓	✓		✓	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓	
			5.5.5 Supply chain engagement								✓				✓									
Stage 2 Concept Construction	5.2 Implementation	5.6 Framework Procurement	5.2.1 Extract (Pull) construction concepts					✓		✓		✓		✓		✓								✓

Table 4.4 Developed implementation matrix of waste management in the construction process (UK and Iran) (continued)

Development			5.2.2 Create concept construction for sub-construction solution							✓														
			5.2.3 Explore the concept construction for sub-construction solution							✓												✓			
			5.2.4 Capture knowledge and evaluate				✓		✓	✓															
			5.2.5 Communicate concept constructions to others				✓			✓	✓														
			5.2.6 Internal review							✓	✓	✓			✓							✓			
Stage 3 Concept Integration	5.3 Monitoring and Control		5.3.1 Determine concept construction intersections				✓			✓														
			5.3.2 Explore possible constructions				✓			✓														
			5.3.3 Seek conceptual robustness																			✓	✓	
			5.3.4 Evaluate concept construction for lean construction							✓														
			5.3.5 Begin process planning for construction				✓			✓													✓	
			5.3.6 Integrate the final concept construction of sub construction solution							✓												✓	✓	
			5.3.7 Internal review							✓	✓	✓			✓							✓		
			5.6.1 Project case	✓			✓		✓										✓					

Table 4.4 Developed implementation matrix of waste management in the construction process (UK and Iran) (continued)

			5.6.2 Stakeholders								✓				✓									
			5.6.3 Supply chain engagement								✓				✓									
			5.6.4 Design and construction outcomes				✓																	
Stage 4 Detailed Construction	5.4 Review	5.7 Framework Operation	5.4.1 Release final specification				✓			✓														
			5.4.2 Define construction tolerances				✓			✓													✓	
			5.4.3 Full project definition				✓			✓														
			5.4.4 Internal review							✓	✓	✓			✓						✓			
			5.7.1 Framework management							✓		✓						✓	✓					
			5.7.2 Appropriate governance							✓		✓						✓	✓					
			5.7.3 Project case review							✓		✓						✓	✓					
			5.7.4 Creating programmes / clusters							✓		✓						✓	✓					
			5.7.5 Supply chain engagement							✓		✓						✓	✓					
			5.7.6 Framework outcomes							✓		✓						✓	✓					
		5.8 Sustainability Checkpoints	5.8.1 Offsite manufacturing and onsite Construction					✓						✓		✓								✓
			5.8.2 Review and update Sustainability Strategy											✓		✓								✓

Table 4.4 Developed implementation matrix of waste management in the construction process (UK and Iran) (continued)

Total	5	3	5	11	5	3	25	10	14	3	6	9	7	2	9	12	2	8	2	5	7

Key:
W1= Poor contractor briefing
W2= Transport
W3= Construction defects
W4= Poor specification
W5= Delays
W6= Poor technical knowledge
W7= Construction changes
W8= Insufficient pre-construction meetings
W9= Poor level of commitment to quality improvement
W10= Unnecessary movements
W11= Excess inventory
W12= Poor communication between construction team
W13= Over-production
W14= Insufficient and unrealistic constraints of project cost
W15= Making construction decisions on cost and not value of work
W16= Lack of project definition
W17= Insufficient and unrealistic constraints of project time
W18= Inadequate involvement of other professionals and teamwork during the construction stage
W19= Effect of standards and construction code on quality
W20= Lack of constructability review of construction
W21= Over-processing

The Proposed Combination Model for the Construction Development of RIBA is shown in Figure 4.5 below.

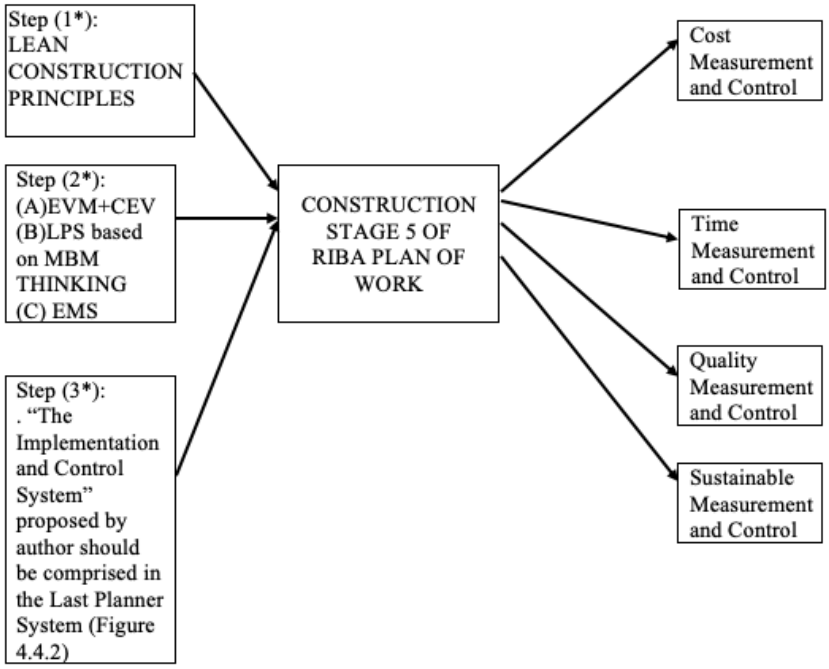


Figure 4.5: Proposed implementation combination model

Figure 4.5 shows the proposed combination model. Regarding Step (1*), this research project proposes a new framework model for the RIBA PoW which uses several LC principles and techniques. Development of the model started by applying LC principles to the RIBA PoW for measuring and controlling Cost, Time, Quality, and Sustainability, to integrate the RIBA PoW with the concept of lean philosophy (see Figure 4.4).

As shown in Figure 4.4, this study proposes a conceptual framework for implementing LC in the construction phase. The proposed lean modelling development cycle (see Figure 4.2) and construction flow with embedded lean principles (see Figure 4.5) are at the heart of Stage 5 – Construction Implementation. Lean production principles, LC theories (TFV), waste in construction, and the relationships between them are also considered in Stage 5 of the proposed framework as shown in Figure 4.4.

Regarding Step (2*) and based on the work of Marhani (2013), several approaches to the key concepts of LC are integrated. This will maximise the customer's satisfaction as well as minimising construction waste, as shown in Table 4.5.

Table 4.5 Proposed combination model: Step (2*) = [(A) + (B) + (C)]

(A): Earned Value Method (EVM) + Customer Earned Value (CEV)
(B): LPS based on Management by Means (MBM) thinking
(C): Environmental Management System (EMS)

where:

(A) is EVM combined with CEV (Kim and Ballard, 2010; Kim et al., 2016),

(B) is LPS based on MBM thinking (Kim and Ballard, 2010), and

(C) incorporates EMS (Environmental Management System)

(Last Planner System is one of the key concepts of lean construction in the construction process).

Regarding Step (3*) (Figure 4.5), in addition, to add value to the production, integration of the Implementation and Control System (ICS) (Figure 4.6) within LPS (see Chapter 2, Section 2.9.1) is proposed.

ICS is a quality tool that should be included in LPS; it is a decision-making tool for controlling production activities and contains all the essential information to make sure a transformation process perfectly generates value to the last product. The proposed control and measurement model will be implemented to improve cost and time performance of construction projects.

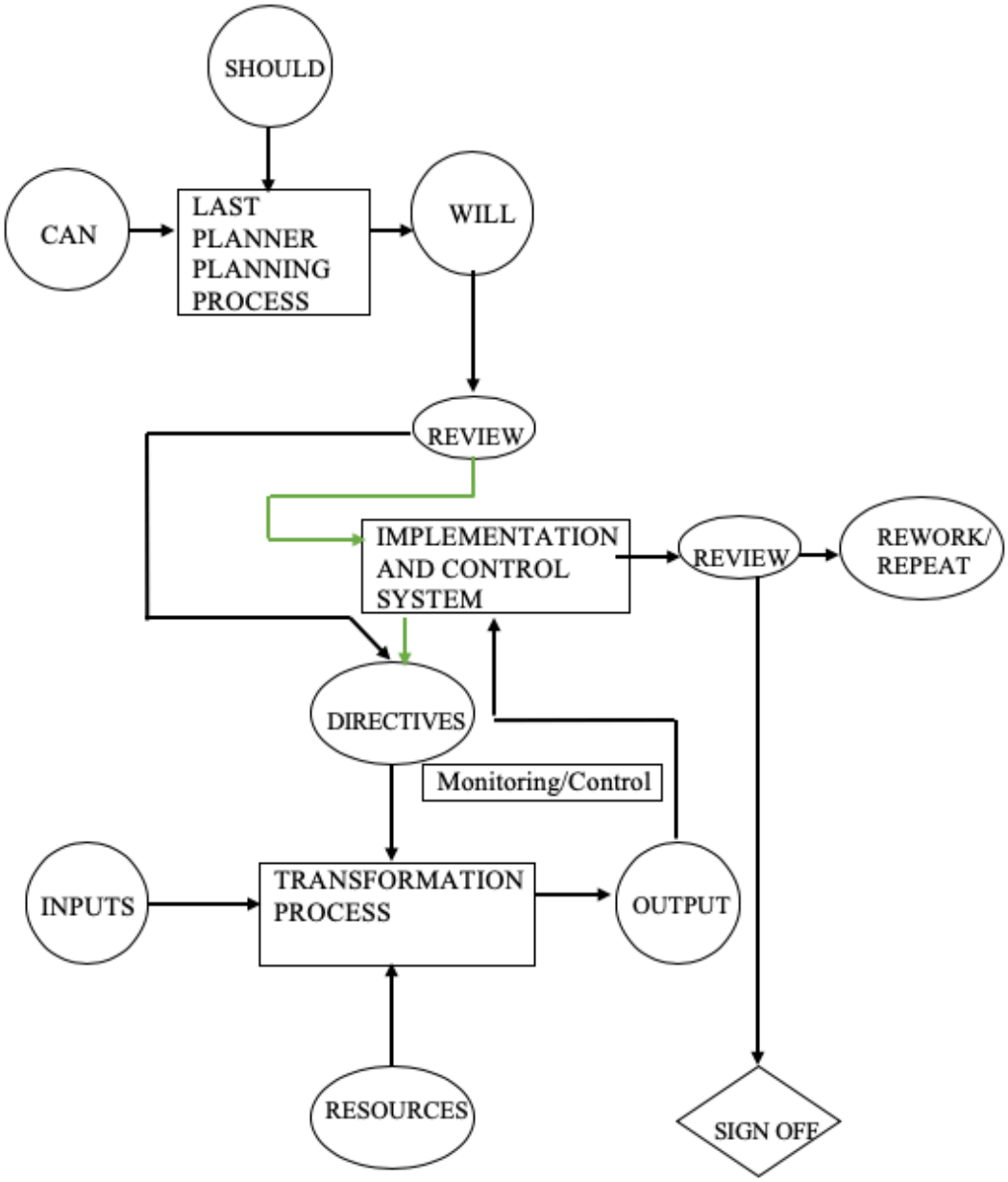


Figure 4.6: The proposed Implementation and Control System included in the Last Planner System

The contribution of this research, set out in Chapter 2, is to use management thinking to underlie the project control tools from the perspective of the theory of project management. However, according to Kim et al. (2010), project control based on Management by Results (MBR) is argued to be inappropriate for managing at the operational level, where tasks are highly interdependent. To fulfil the gap in knowledge (see Chapter 2), the set-based method has been adopted.

Johnson and Broms (2000) proposed a distinction in management theory between MBR and MBM, as noted within this research where EVM is based on MBR thinking and, as supported by Kim and Ballard (2010), LPS is based on MBM thinking.

To manage projects or other forms of organisation entails more than a quantitative summing up of the separate contributions of each part (Johnson, 1992; Johnson and Broms, 2000). The underlying belief of MBM is that what decides an organisation's long-term profitability is the way it organises its work. It is only by looking away from the desired results that an organisation can be achieved this. An excellent example of this philosophy of management is provided by Liker's account of Toyota's management principles, *The Toyota Way* (2004). Gao and Low (2013, 2014) extended Liker's work in *The Toyota Way Model: An Alternative Model*.

The last planner (LPS) is the last in the decision chain of the organisation because the output of the planning process is not a directive for a lower-level planning process but results in production. As stated by Mohammed and Abdelhamid (2005) in Taylor and Francis (2011), a PPC value does not give a true indication of how efficiently assignments have been carried out (Mohammed and Abdelhamid, 2005). It does not measure the level of utilisation of a work crew. Instead, it means production planning effectiveness and workflow reliability.

Whilst LPS is a bottom-up system, Value Engineering (VE) is a top-down one. Therefore use of LPS and VE in combination, and at the same time within the RIBA PoW, will increase performance and benefit the project, as these two methods complement each other (Figure 4.7).

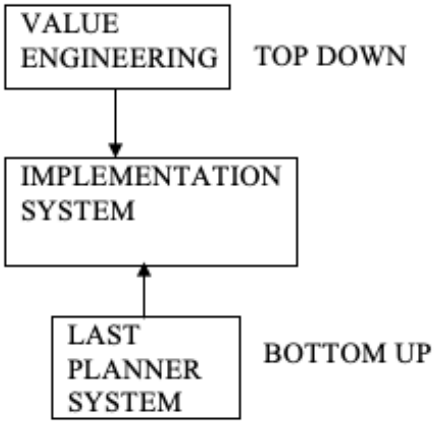


Figure 4.7: Proposed implementation system of combined VE and LPS

According to Marhani (2013), pre-construction and/or construction stages are the best time to integrate the key concepts of LC. This is a view upheld by other researchers due to their criticality in determining resources for the project during pre-construction (Koskela, 1992) and eliminating construction waste during construction (Yahya and Mohamad, 2011).

According to Marhani et al. (2013), an EMS shares the same goal as the lean concept, that is reducing waste. EMS provides an effective framework that can assist companies in fulfilling their responsibilities towards better protecting the world environment (Gbedemah, 2004). Therefore, integrating EMS with key LC concepts within construction sites maximises the customer's satisfaction as well as minimising waste (Mitsuishi et al., 2008). However, according to Puvanasvaran et al. (2011), the potential to achieve both integrations remains relatively unexplored since changes within the business environment and innovative technologies can widely impact operational process and procedures.

Most of these concepts are interconnected and it is important to understand all the key concepts of LC, which may improve performance while minimising construction waste, in other words adopting the 'correct tool at the correct time'. Hence, it is important for the stakeholders to responsibly choose the best approach of the key concepts that can be implemented in their construction sites. The newly developed framework facilitates this.

The current research also addresses standardisation of the Work Breakdown Structure (WBS) for elements of planning, implementation monitoring and control, and review functions.

Figure 4.8 shows the proposed construction flow of the process, integrating the proposed lean modelling development cycle (shown previously in Figure 4.2) with Construction Stage 5 of the RIBA PoW. The adaptations of lean principles with enablers in the proposed framework model are identified and assessed; a combination of different lean methods and techniques as the major enablers are taken into consideration in the construction process. This framework is then integrated and incorporated into the RIBA PoW to implement lean methods and techniques to the construction activities. Cost, Time, Quality, and Sustainability elements will be added to the proposed initial RIBA construction model below (see Figure 4.8).

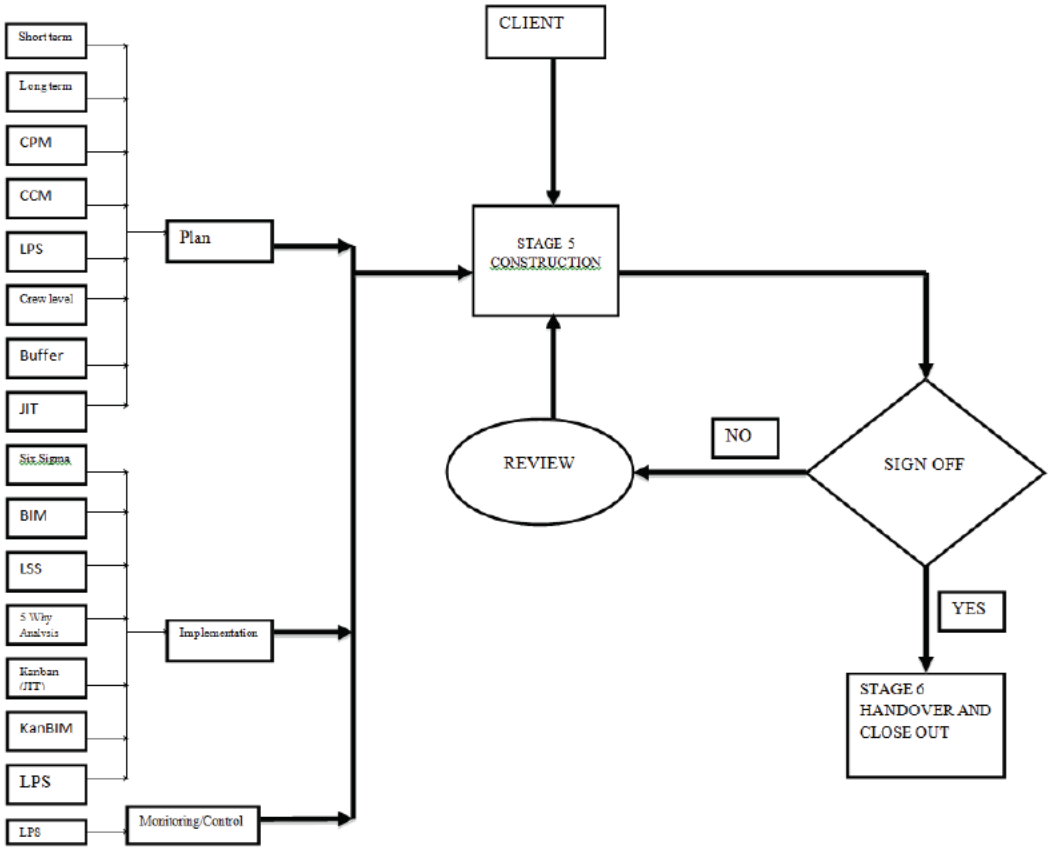


Figure 4.8: Conceptual construction framework with lean construction implementation

The adaptations of lean principles with enablers in the proposed framework model are identified and assessed; a combination of different lean methods and techniques as the major enablers are taken into consideration in the construction process, as shown in Figures 4.9–4.12. This framework is then integrated and incorporated into the RIBA PoW to implement

lean methods and techniques to the construction activities.

First, of course, the methods of working must be decided. This is often referred to as a *method statement*. Usually, the methods to be used for most of the project will be well known and well tried. The method statement will be based on experience and the technical resources available. Only occasionally will there be alternatives of such a profound difference that the implications for the success or otherwise of the project need rigorous investigation by the project manager.

Figure 4.9 shows the proposed model for the *Planning* function with a combination of different lean methods, techniques, and elements as the main enablers to develop a framework for the construction process.

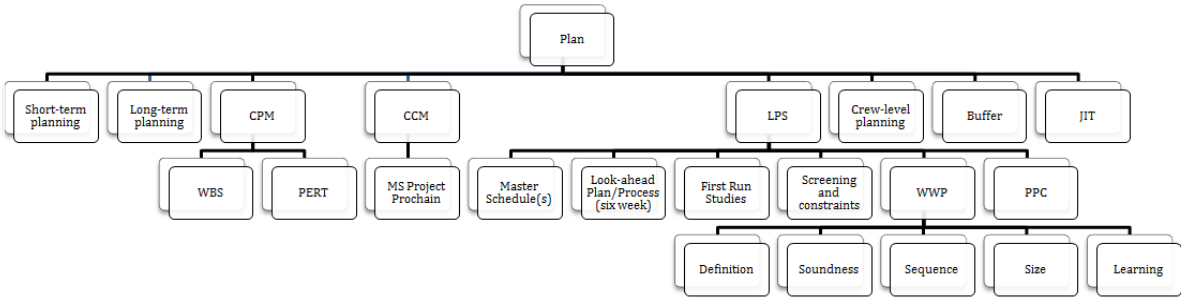


Figure 4.9: Conceptual construction framework with lean construction implementation (planning) WBS

Figure 4.10a shows the proposed model for the *Implementation* function.

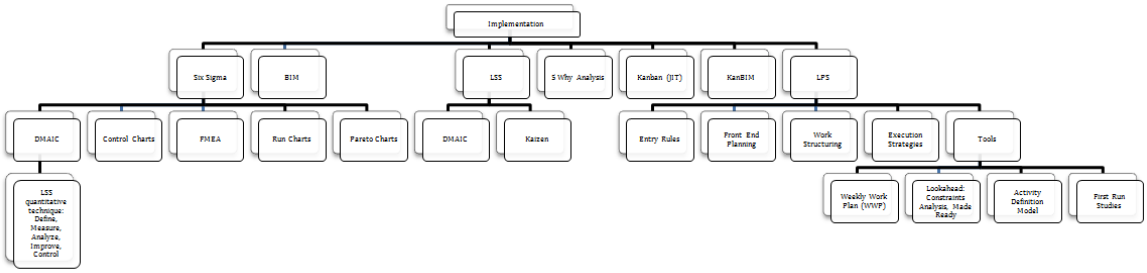


Figure 4.10a: Conceptual construction framework with lean construction implementation (Implementation) WBS

DMAIC (define, measure, analyse, improve, and control) is a quantitative Lean Six Sigma (LSS) technique. Figure 4.10b shows the Six Sigma tools.

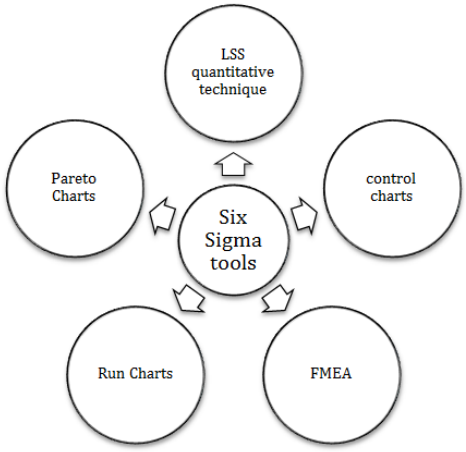


Figure 4.10b: Six Sigma tools

Kanban, a scheduling system for lean methods, focuses on: Production quantity; Time; Method; Sequence or transfer quantity; Transfer time; Destination; Storage point; Transfer equipment; and Container (Ohno, 1988). Every project is different and therefore, to ensure success, each project must be organised, planned, controlled, and reported on in detail. The success will largely depend on the effectiveness of management, planning, and control carried out. Good communication is vital to success, especially in view of the matrix management organisation.

Figure 4.11 shows the proposed model for the *Monitoring and Control* function.

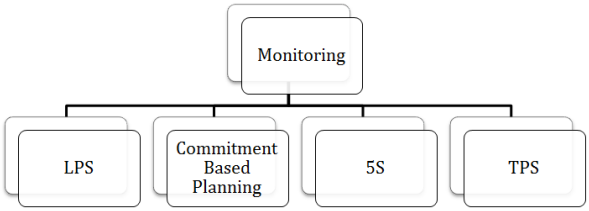


Figure 4.11: Conceptual construction framework with lean construction implementation (monitoring and control) WBS

Figure 4.12 shows the proposed model for the *Review* function.



Figure 4.12: Conceptual construction framework with lean construction implementation (review) WBS

In this study, the further development of the Conceptual Construction Framework with Lean Construction Implementation is proposed, as shown in Figure 4.13.

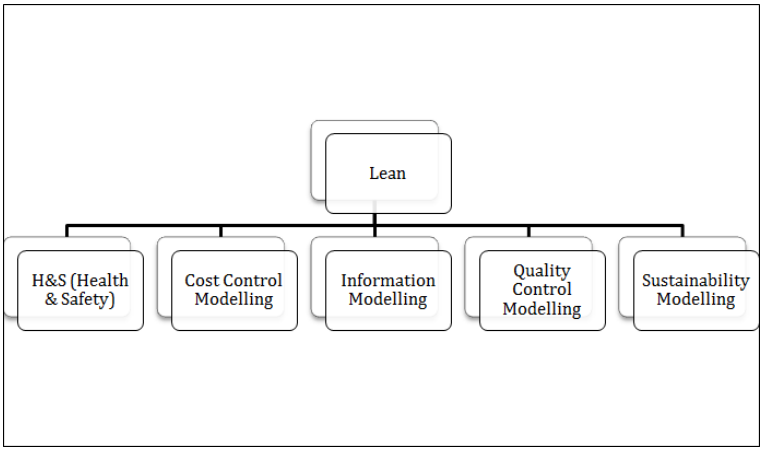


Figure 4.13: Proposed lean modelling developments

The other aspects of the new proposed modelling development are flow improvement, based on the relevance and relationships between the TFV theory of production, lean principles (mainly flow and pull) and LPS, as shown in Figure 4.14a and b. This framework is then integrated into Stage 5 of the RIBA PoW. Herein, flow improvement is located at the heart of the proposed framework.

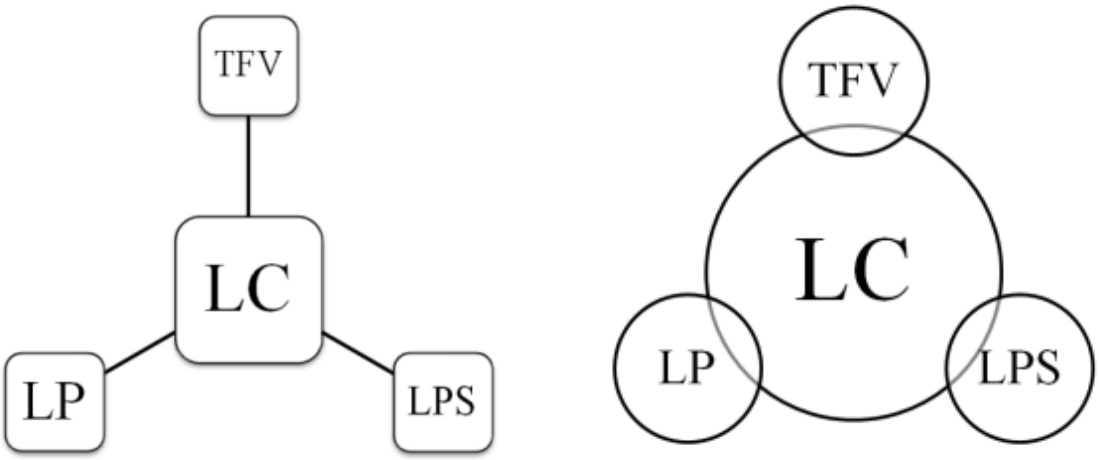


Figure 4.14a: Relationships between TFV (Transformation, Flow, Value generation), Lean Principles (LP), and Last Planner System (LPS) to achieve Lean Construction (LC)

The principles and concept of LC, and the relationships between the principles, are shown in Figure 4.14b. The relationships between the principles demonstrate the accomplishment of the research objectives that indicate and point to the research aim which is to implement LT in the construction management of construction projects.

The subset of TFV shows the overlap with LPS which results in lean pre-construction. In the overlap of flow and pull (lean principles) with TFV, the outcome is lean planning, while the overlap of LPS with Flow and Pull (Lean Principles) results in the construction process which relies on LC. Figure 4.14b shows the developed Lean correlation matrix.

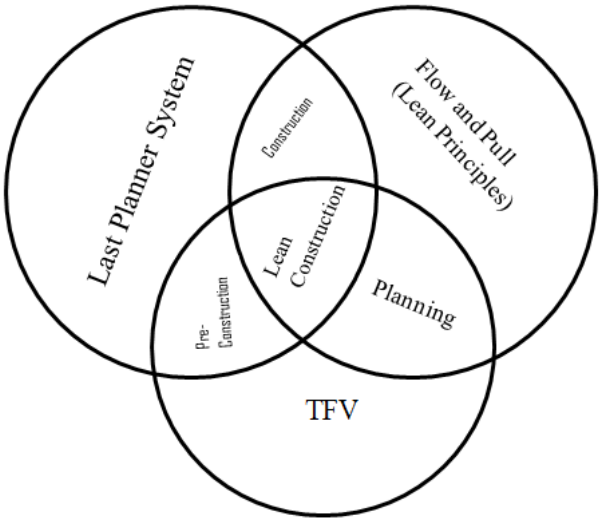


Figure 4.14b: Proposed model of relationships between flow and pull (lean principles), TFV, and Last Planner System to achieve lean construction (lean correlation matrix)

This research has extended and further developed the project management triangle, as shown in Figure 4.15. In the newly proposed model, the Sustainability element has been added, meaning that project management is not considered just as a crucial task of balancing the three targets of Cost, Time, and Quality. As shown in Figure 4.15, the proposed model now includes Cost Management, Time Management, Quality Management, and Sustainability.

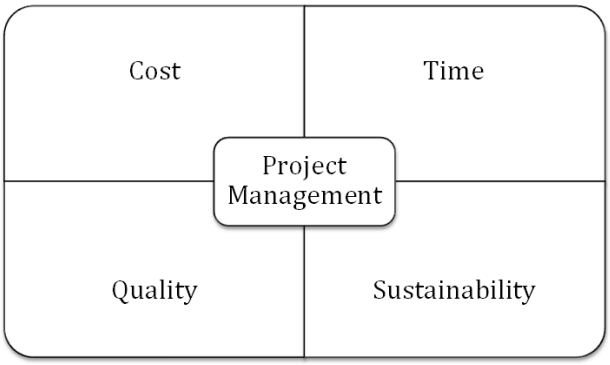


Figure 4.15: Proposed extension of triangular relationship

4.3 A review of the Last Planner Production Control System – Current LC approach for implementation

Figures 4.16 and 4.17 show the ways in which LPS reduces task duration variability.

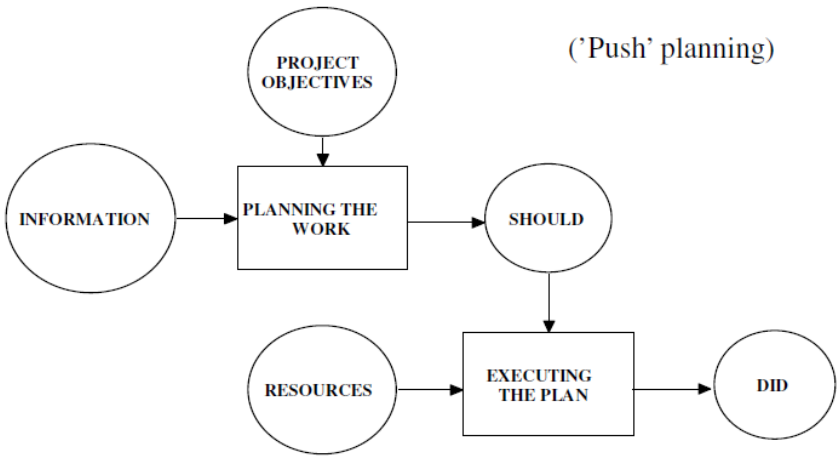


Figure 4.16: A traditional planning system ('push' planning) (Ballard and Howell, 1994b)

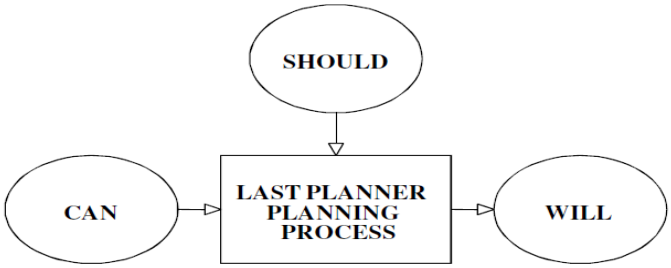


Figure 4.17: The Last Planner System (a pull system) (Ballard, 2000)

Both figures are integrated without modification within the newly developed framework.

Variability is inevitable, although through effective management this can be decreased; moreover, where residual variability exists this can be buffered accordingly. A suitable or appropriate control for dynamic projects is one that causes events to comply with the plan or starts re-planning.

Notwithstanding this, master schedules should not be excessively detailed or outrun future information. This requires a 'look ahead' procedure to make the work ready for weekly work

planning. The key to the reliability of any plan is making quality assignments. Planners will never be perfect, so should continuously learn and refine their thinking.

Lots of, if not most, causes of plan failure are within a circle of control which expands over time. Shielding is an approach to continual improvement as this enables and authorises a decrease in variability and improved methods and techniques (Ballard, 2000).

4.4 Three modes of short-term construction planning

Short-term construction planning requires more than simple interpretation of the project schedule; it rests on the organisation's ability to:

1) Collect information,
2) Identify and solve problems, and
3) Implement change.

Each of three different modes of short-term planning – Mode 1: foreman planning, Mode 2: supervisor quality circles, and Mode 3: operations/systems analysis – makes a unique contribution to detailed short-term planning. Construction sites need all three modes to achieve control, promote innovation, and assure high performance at all levels of the organisation.

Two additional modes of short-term planning which are currently in use are:

1) Supervisory quality circles (SQCs) and
2) Operations/systems analysis (O/SA) (Laufer, Howell, Rosenfield, 1992).

4.5 Waste in the construction process

As discussed in Section 4.2.2, the Waste Process Matrix illustrated in Table 4.4 has been developed to eliminate construction waste with the use of lean enablers as part of LPS.

Therein 21 wastes were identified and, as part of this, SBCE was considered as a core enabler of the construction process model. Please refer to Chapter 2 Section 2.4.7.4 regarding a review of SBCE.

The next innovative and improvement feature of the research concerns the use of LPS and SBCE in the RIBA PoW. Innovation and improvement of the construction process through a newly developed combined LC framework is shown in Figure 4.18.

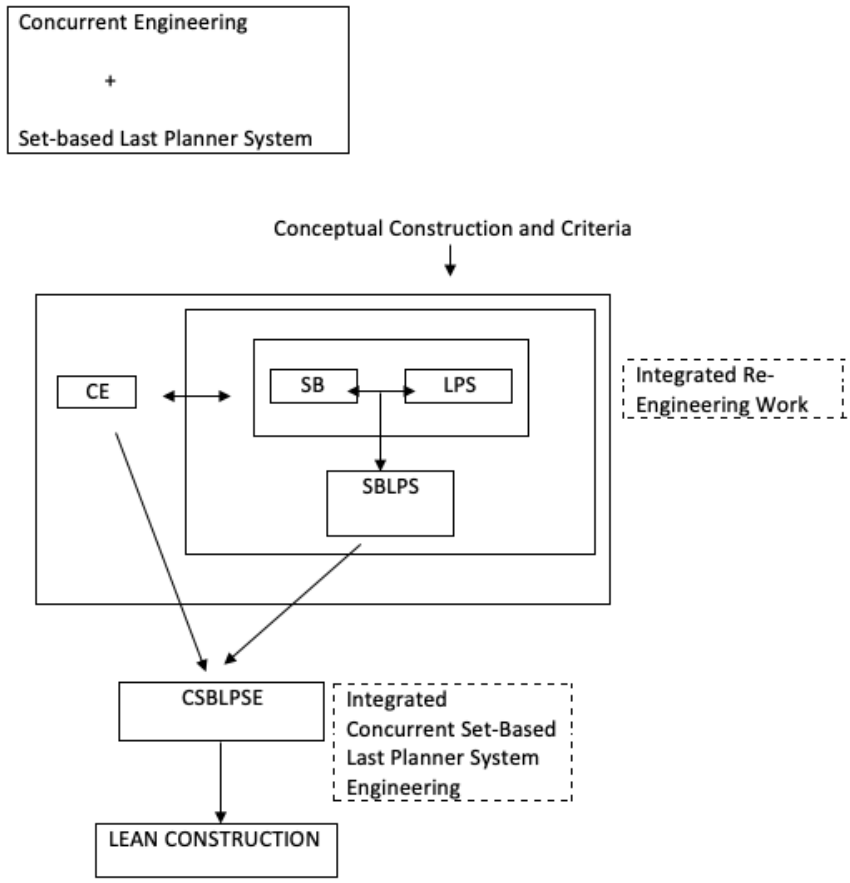


Figure 4.18: Proposed lean construction implementation framework

As can be seen within Figure 4.18, a set-based LPS (SBLPS) and CE approach is followed to transform the conceptual construction and the lean definition into LC. The stages are combined to highlight the value of integration through the re-engineering work, and to consider the fact that construction projects are dynamic. It is expected that through a lean

definition, the project would result in effective conceptual construction and criteria that transformed through the framework into a project that is on time, on cost, acceptable quality, and achieve client satisfaction in a lean process. SBLPS gives the comfort of concurrent thinking in every activity within the process. This suggested implementing the new tool in the case study in terms of percent expected time overrun, percent expected cost overrun, and VE measurements. This can be found in Chapter 5.

All of this would result in waste management and reduction. There is a need for a new method that can manage overlapping activities during the construction stage. The developed framework will address overlapping activities and identify potential problems on the site. The model (see Figure 4.18) has been implemented in the case studies and this is explained further in Chapter 5.

SBCE has attracted a reasonable amount of attention over the last two decades. According to Ballard (2000), the application of SBCE in combination with several additional lean PD enablers would reduce negative iteration in design. A number of strategies for this reduction, suggested by this and other authors (e.g. see Al-Aomar, 2012; Khan, 2011, 2012; Yusof et al., 2015; Yusof, 2018) include:

- Restructure the design process;
- Use value-stream mapping (VSM) to re-sequence;
- Use pull scheduling to reduce batch sizes and achieve greater concurrency;
- Reorganise the design process;
- Make cross-functional teams the organisational unit;
- Use team problem solving (call a meeting);
- Share ranges of acceptable solutions;
- Change how the design process is managed;
- Pursue a least commitment strategy;
- Defer this decision (defer commitment);
- Practice set-based design;
- Use the LPS of production control; and
- Overdesign (design redundancy) when all else fails.

The work presented in this research develops further ideas drawn from Al-Aomar's framework, which has been applied step by step. Other frameworks from where ideas have been drawn include the combined design–supply–assembly LC framework developed by Al-Aomar (2012). Therein, a set-based design and CE approach was followed to transform the conceptual design and lean definition into a lean product/process design.

As shown in Tables 4.6 and 4.7, the integrated use of SBCE* and Cadence, Flow & Pull* results in better waste management, as shown previously in Figure 4.18.

Table 4.6 Countermeasures that the five principles provide against product development waste (Bicheno, 2004)

	Lean Product Development Principles				
Wastes	Value Focus: Knowledge & Operational Value Stream	Entrepreneur System Designer	**Set-Based Concurrent Engineering***	**Cadence, Flow & Pull***	Teams of Responsible Experts
Scatter	Clear Goals	Value-stream Focus	Reduced Uncertainty	Smoothed Workload	Self-Adjustment
Communication Barriers	Blurred boundaries	Cross-boundary translation	Two-way negotiation	Broad knowledge flow	Pull needed knowledge
Poor Tools	Procedures subservient to goals	Results needed	Simple, effective tools needed	Flexibility created	Experts design own work
Hand-off	System Focus	Total Responsibility		Planning and Action Together	Total Responsibility
Useless Information	Defined utility	Hands-on leadership		Simple controls	Self-discipline and peer feedback
Waiting for Knowledge	Incentives to act	Push for action	Concurrency enabled	Concurrent processes	Pull needed knowledge
Wishful Thinking	Excuses not Permitted	Success Required	Knowledge Precedes Decisions	Fast Learning Cycles	Responsible for Decisions Made
Testing to Specifications	Clear evaluation goals	Knowledge needed	Aggressive evaluation	Continuous Evaluation	"Red team"
Discarded Knowledge	Knowledge valued	Knowledge needed	Trade-off curves	Continuous learning	Knowledge built for future work

Table 4.7 Impact of the five principles on high-level product development measures (Bicheno, 2004)

	Lean Product Development Principles				
Measures	Value Focus: Knowledge & Operational Value Stream	Entrepreneur System Designer	**Set-Based Concurrent Engineering***	**Candence, Flow & Pull***	Teams of Responsible Experts
Better Functionality	Focus	Vision	**Innovation& optimization***	**Rapid process improvement***	Expertise and responsibility
More Reliable	Focus	Good decisions	Very low risk	Early evaluations	Expertise and responsibility
Cheaper	Focus	Cross-functional flow	No late failures	Minimal time wasted	Expertise and responsibility
Faster	Focus	Quick decisions	No late failures	Quick response	Quick response

As shown in Figures 4.19 and 4.20 below, the traditional project management triangle has been developed in the present research to successfully implement the developed framework in the construction process.

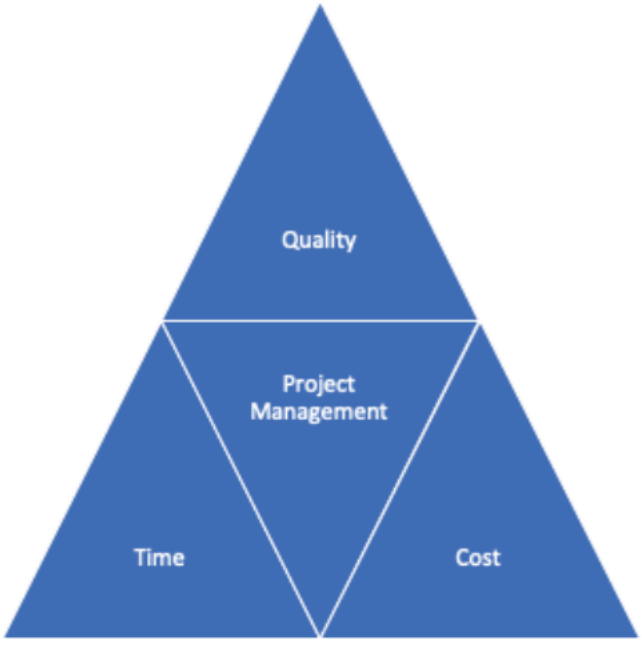


Figure 4.19: Traditional project management triangle

Therein, project management is at the heart of the Time–Cost–Quality triangle. The research presented herein then developed the Cost–Value–Sustainability and Quality–Sustainability–

Waste Management triangles, which together form the newly developed Project Management Triangle (Figure 4.20). Thus, the research integrates the project management triangles as presented in Figure 4.20, which contains the Framework (see Figure 4.19) and the Waste Matrix (see Table 4.4).



Figure 4.20: Developed project management triangle

Lean developments can be achieved through T/F/V concepts of production in construction; LPS; lean supply chain management; integrated project delivery; and prefabrication. There are different phases that need careful attention while using LC: Phase 1 – Basic Evaluation; Phase 2 – Preliminary Design; Phase 3 – Final Design; Phase 4 – Planning Permission Application; Phase 5 – Execution Planning; and Construction. Production is a kind of construction.

The research goals were to propose, define, develop, and test a lean-enabled system to support production and construction planning and day-to-day construction control on construction sites.

According to Ballard (2000), the last planner's objective is to get work done as efficiently as possible, which may or may not be possible within the budgeted amount of money and time. All foreman/men, the main contractor, speciality contractor, project engineer, project manager etc., should work together through a systematic approach to achieve LC.

Also, presentation of information like colour coordination and a pull system in the workplace improves the effectiveness of production planning and control. Visual communication tends to increase the involvement of workers in continuous improvement efforts, which will result in better control and motivation at the workplace. However, when looking at a traditional project management cycle developed by the Port Authority of New York and New Jersey (Zipf, 2000), and as stated in *Reforming Project Management* by Howell and Koskela (2000) (see Figure 4.21), this lacks the element of proper project planning.

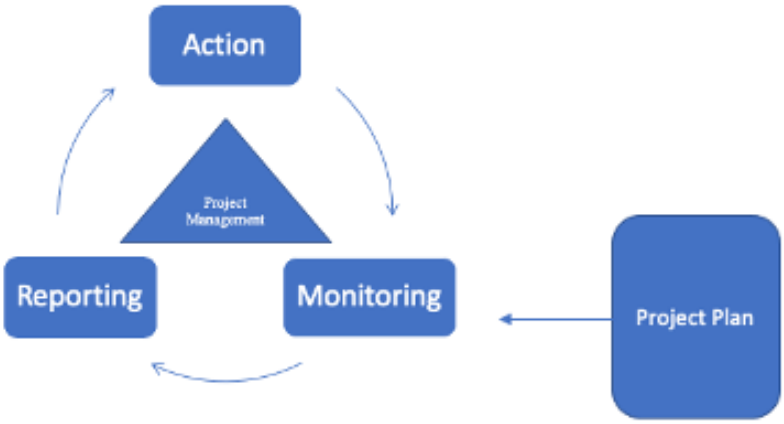


Figure 4.21: Project management applied by a public agency (Zipf, 2000)

Howell and Koskela (2000) suggested reforming project management, and introducing the role of LC to create a transformation model of production, to manage the main deficiency, i.e., the management of workflow. All the frameworks developed in this current research are effective in terms of information management, implementation planning, and overall strategy.

In Figure 4.22, the inclusion of project planning is proposed followed by action, monitoring, and then reporting (activator). As stated by Lari and Asllani (2013), a management support system is a process-oriented, prevention-based strategy that allows for effective management (Hutto, 2000).



Figure 4.22: Developed Project Management Cycle

Defining processes in a way that covers the entire organisation, relating each activity to at least one process, establishing each process, and introducing measurement metrics, are essential for the transformation from functional-based to process-based organisations.

If the entire organisation is defined as a network of interconnected processes with links to external entities, it is logical to assume that the overall performance of the organisation depends on the performance of individual processes and activities.

While it is possible and common to introduce a variety of metrics of different natures to measure the performance of each process, introducing an integrated metric to measure the overall performance of processes is a challenge.

Improvement efforts relate to increasing the efficiency and/or effectiveness of the processes. Performance improvement activities are directly associated with a reduction of some type of waste and an increase in the quality of products or processes.

4.6 Data analysis

The project questionnaire will be discussed in Section 4.8. Please refer to Chapter 3 regarding the various methodologies adopted therein for data analysis, ranking the variables, Spearman's rank correlation test, Kendall's coefficient of concordance and hypothesis testing.

4.7 Project questionnaire on LC

4.7.1 Introduction to the questionnaire

Construction projects are broadly understood as being unpredictable in terms of delivery within budget, on time, and to the quality standards, which leads to low performance, such as cost and time overruns, low quality, and inconsistent value generation.

The area of "Lean Construction" has been chosen and the focus is on "Improvement of Construction Process". As part of the methodology, an interview survey programme and questionnaire were used. The questionnaire survey was aimed at practitioners, Chief Planning Engineers, Construction Managers, Chief Executives, Managing Directors (management team, director/senior management), Commercial Managers, Contracts Managers, Project Managers, and Quantity Surveyors – all of whom are involved (directly or indirectly) in managing the construction process. The questionnaire shown in this section was designed to explore the application of lean principles and the questions are therefore framed as, '*in your organisation - based on your experience*'. To allow for an understanding of how the framework can be used in different contexts and local conditions, both the questionnaire and interview survey were conducted in the UK and Iran.

Questionnaires (related to LC) were sent to Contractors only. This was because LC is only adopted by Contractors. Consultants, on the other hand, answered the questionnaire related to management of design.

The questionnaire was sent through email and LinkedIn, and was posted online with a survey link sent out through email to anyone who interacted with the post. Additionally, printed

paper versions of the questionnaire were provided for several respondents in Iran – this included the provision of translated versions for ease of understanding. The reason for using the UK and Iran as case studies is shown below:

(1) The UK constituted the context of a developed country. Herein, the Top 100 contractors with the UK were approached to partake in the study. Contractors were approached (found from Glenigan's contractor league table obtained from Glenigan.com.) to take part in the study. Emails were also forwarded to newsletter@glenigan.com. Additionally, the author lived here during her studies and therefore access to information on prospective respondents was relatively easy to obtain.

(2) Iran constituted the context of a developing country, contrasting nicely with the context of the UK. In addition, the author was born there, and it is her home country. The author benefits from a wide pool of industrial contacts, enabling a good range of respondents to be contacted. Hence, once again information on contacts was relatively straightforward to find.

As it turned out, Iranian firms appeared to have more interest in the topic area than UK firms, as only 30 out of the total of 120 surveyed contacts in the UK (25% of total) replied; and 20 out of 50 surveyed contacts in Iran (40% of total) replied. The low, yet acceptable return rate is disappointing but understandable, as industrialists are busy people. That said, all the respondents had considerable experience in the field. Moreover, all the surveyed companies had a direct responsibility to project practice.

Through discussion with the general directors of the Iranian companies, they showed an interest in exploring the current situation of their companies' planning and control system and permitted the author to carry out the survey using this as a basis for their involvement. Also, it was agreed that the results of the survey would be interpreted to recognise their own specific problems; therefore, recommendations could be given to the companies on a case-by-case basis.

4.7.2 Purpose of the questionnaire

The overall purpose of the questionnaire can be stated as, '*Exploring project planning practice, the measurement and control methods, and the use of Lean Construction by the UK's and Iran's construction companies*'.

The questionnaire was designed to explore the application of lean principles in respondents' organisation based on their experience.

4.7.3 Methodology

The implemented procedure was to email the questionnaire to the companies and individuals. Furthermore, the survey was aimed at Contractors only. The participation and the information supplied was treated as private and confidential.

4.7.3.1 Questionnaire design

All 62 questions in the questionnaire were designed to be as direct, brief, clear, and simple to interpret as possible. Most of them were therefore in multiple-choice form with others being either ranking-type questions or open questions (of which there are only five). Questions 1, 2, 3, 4, 5, and 6 were designed to extract general demographic information about the respondents. The remainder of the questions were designed to investigate the areas of project practice (Table 4.8). Please refer to the Appendix B for further details of the questionnaire.

Table 4.8 Areas of project practice

Areas of concern	Questions No.
General Information/Questions	1,2,3,4,5,6
Planning and Time Control	7
Time Control Techniques and Software Applications	8,9,10,11,12,13,14
Lean Time Planning Techniques	15,16,17,18,19,20,21,22(opened question),23,24
Production Control in Construction	25,26(opened question),27,28
Planning Reliability	29
Cost Management of Construction Projects: Cost Control Practices	30
Cost Control Techniques	31,32
Cost Overruns	33
Quality Management and Control	34,35,36
Sustainability Management and Control	37(opened question),38
Development of the Measurement and Control Methods	39,40,41,42,43,44,45,46
Waste: Waste in Production Process	47,48
Types of Waste	49,50,51,52(opened question),53
Training (continuous learning and training)	54
Inhibiting Factors & Mitigating Measures	55,56,57,58
Earned Value Method	59
Any other comments regarding the survey questions	60(opened question)
The consent form	61
The consent question	62

4.7.4 Result analysis

4.7.4.1 Overall appraisal

Thirty of the 120 contacts from the UK, and 20 of the 50 contacts from Iran answered the questionnaire, thus the response rate to the UK and Iran questionnaires is 25% and 40%, respectively, which is considered acceptable for this type of survey (Rowe and Wright, 1999; Adnan and Morledge, 2003). Unfortunately, not all the respondents answered all 62 questions.

Before proceeding with any further detailed interpretation of the result, it is necessary to understand who the respondents were. Hence Questions 1 to 6 include information regarding the respondents themselves.

All the respondents have considerable experience in the field. All the surveyed companies have a direct responsibility for project practice. A total of 170 questionnaires were administered, 120 to the top construction companies in the UK by company turnover and 50 to the top construction companies in Iran by the number of professional staff employed and company fee earnings. This list was obtained from the Glenigan annual league tables (and other *Building* magazine annual league tables) and the Institution of Civil Engineers. This ensured a very good response as 30 questionnaires (25% response rate) from the UK and 20 questionnaires (40% response rate) from Iran were returned.

4.7.4.2 Detailed assessment

4.7.4.2.1 Data interpretation

This section presents the raw data on a question-by-question basis with little supporting narrative. Detailed interpretation of the results of the questionnaire is given in each area of concern in Section 4.7.3.1. Data are shown for UK Round 1. Other rounds are set out in Chapter 5.

QUESTIONS 1 to 62

Please answer the following questions to investigate the present system of project planning, controls, and measurement methods in practice at UK sites (Round 1). These questions are grouped around key themes for ease of presentation. There are 19 themes, and these are presented below.

Theme 1: Questions 1 to 6 – General Information Questions

Q1 – What is your company class? (30 completed, 2 skipped).

The results to Question 1 (Figure 4.23) show that 83.33% of the respondents are principal contractors and 3.33% are subcontractors. Additionally, 16.67% are classified as other (e.g.

client, consultants, government agency etc.), such as senior lecturer, client organisation – Network Rail, and education; some of them are consultants who previously worked as contractors. (83% contractor and 3% sub-contractor).

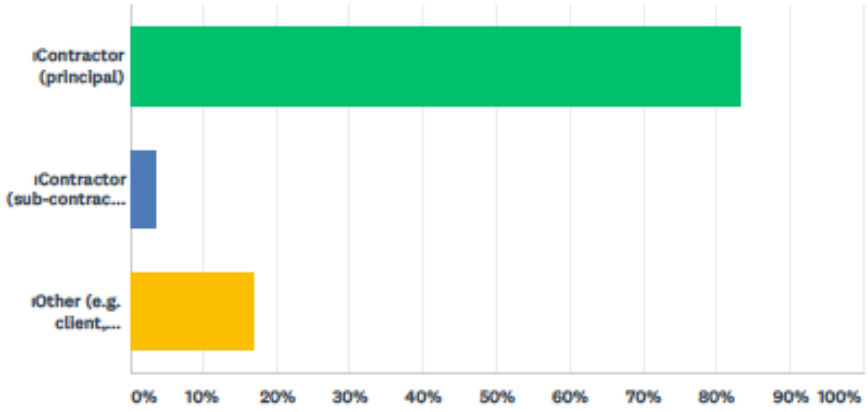


Figure 4.23: Q1 responses – Respondents' company class

ANSWER CHOICES	RESPONSES	
Contractor (principal)	83.33%	25
Contractor (sub-contractor)	3.33%	1
Other (e.g. client, consultancy, government agency etc.): Please specify	16.67%	5
Total Respondents: 30		

#	PLEASE SPECIFY
1	senior lecturer
2	Client Organisation – Network Rail
3	Education

According to an interviewee engineer, the best consultant is one who has previously worked as a contractor (Heydarbarghi, *pers comms*). Within this research, a good number of respondents had experience in both sectors.

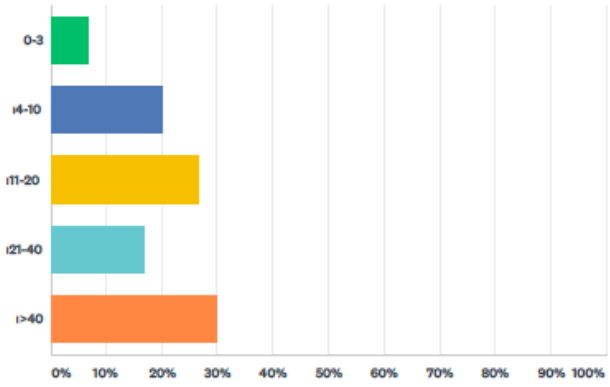
Q2 – What is your main responsibility/position/role? (30 completed, 2 skipped).

Whilst the responsibility of the 30 respondents is highly varied (see list below) the main Position/Role (which covers 13/30 respondents) was project engineer/manager. However, it can be seen also that several of the other respondents were either at a senior level (4 respondents), or CEO (1 respondent) – see also the results for Q3.

#	RESPONSES
1	Project engineer and manager
2	Project manager
3	Project Engineer
4	Engineer
5	Quantity surveyor and project manager
6	Project Engineer/Civil Engineer/Project Manager
7	Senior management
8	Civil Engineer
9	Project Manager
10	Project Manager/Lean Manager
11	Civil Engineer
12	Project manager
13	Construction manager
14	Director/senior management
15	Director/senior management
16	Construction manager
17	Project Controls (Planning and Cost Control)
18	Risk Manager
19	Construction Project Manager
20	Project manager
21	Project Engineer
22	senior lecturer
23	Planning engineer
24	Project Engineer
25	University Teacher and Trainer including Lean Planning and Project Management
26	Project Engineer
27	Project Manager
28	CEO, Managing director
29	Lecturer
30	Senior Risk Manager

Q3 – How many years of experience do you have? (30 completed, 2 skipped).

From Figure 4.24, it can be seen that 30% of respondents have more than 40 years of experience. This showed that there was great depth in the experience possessed by the respondents. Additionally, there is good representation throughout all experience ranges – this is key to obtaining data that is both meaningful and translatable (Olawale and Sun, 2010).



ANSWER CHOICES	RESPONSES	
0-3	6.67%	2
4-10	20.00%	6
11-20	26.67%	8
21-40	16.67%	5
>40	30.00%	9
TOTAL		30

Figure 4.24: Q3 – Respondents' years of experience

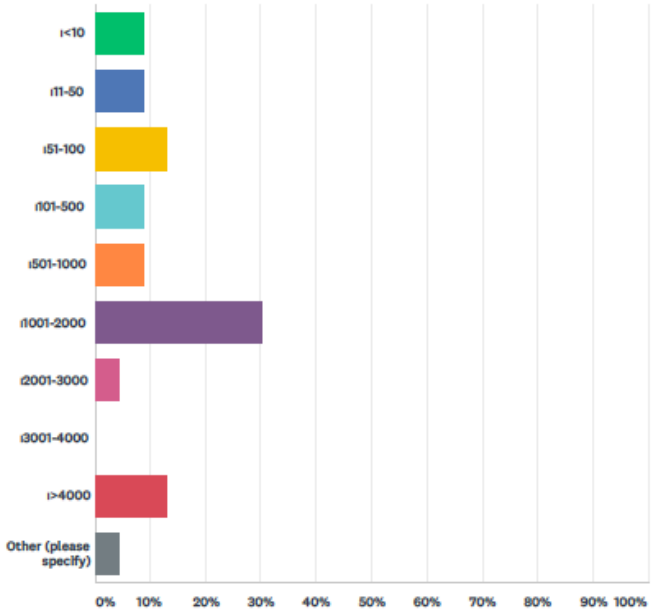
Q4 – What type of projects do/have you worked on? (26 answered, 6 skipped).

The list below shows that the majority (22 out of 30) of respondents were either working on, or had worked on, building projects. Two respondents had worked on railway projects, with one of these working also on power systems. One other respondent had worked on bridge projects.

#	RESPONSES
1	Building
2	Building
3	Building
4	Building
5	Building, bridge, construction
6	Building
7	Building
8	Building
9	Building
10	building and construction
11	building
12	Building and construction
13	Construction
14	Building construction
15	Building construction and civil engineering
16	building construction, civil engineering
17	building
18	building
19	building
20	building
21	building
22	building
23	Power Systems, Building Power Stations, SCADA systems & Rail Systems
24	Buildings(dwelling)
25	buildings, roads, sewage plants
26	Railway

Q5 – What is your company's total turnover (£m)? (23 answered, 9 skipped).

This question sought to find the value of turnover for the companies in which respondents' worked. Out of the 23 responses, the most frequent (with 7/26 – 30% of responses) was £1001m to £2000m.



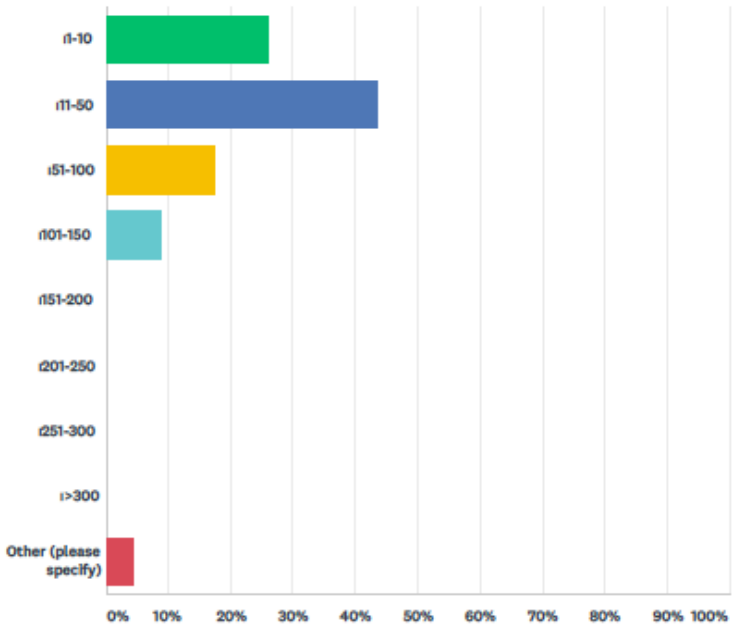
ANSWER CHOICES	RESPONSES	
£<10	8.70%	2
£11-50	8.70%	2
£51-100	13.04%	3
£101-500	8.70%	2
£501-1000	8.70%	2
£1001-2000	30.43%	7
£2001-3000	4.35%	1
£3001-4000	0.00%	0
£>4000	13.04%	3
Other (please specify)	4.35%	1
TOTAL		23

#	OTHER (PLEASE SPECIFY)
1	cannot answer this as many of the projects were done decades ago

Figure 4.25: Respondents' companies' total turnover

Q6 – How many live contracts do you have? (23 answered, 9 skipped).

From Figure 4.26, it can be seen that 10 out of 23 (43% of total) respondents had between 11 and 50 live contracts at the time of undertaking the questionnaire. This was followed by 6 out of 23 (26% of total) respondents having between 1 and 10 contracts and 4 out of 10 (17%) having between 51 and 100 contracts. Only 1 respondent had no live contracts.



ANSWER CHOICES	RESPONSES	
1-10	26.09%	6
11-50	43.48%	10
51-100	17.39%	4
101-150	8.70%	2
151-200	0.00%	0
201-250	0.00%	0
251-300	0.00%	0
>300	0.00%	0
Other (please specify)	4.35%	1
TOTAL		23

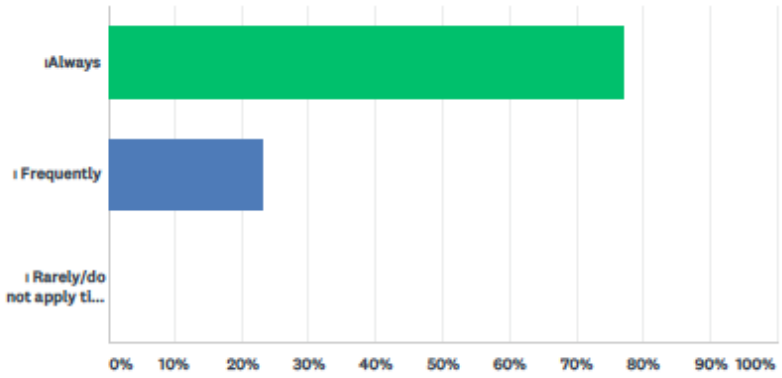
#	OTHER (PLEASE SPECIFY)
1	None

Figure 4.26: Number of live contracts

Theme 2: Question 7 – Planning and Time Control

Q7 – Do you apply time controls to your projects? (26 answered, 6 skipped).

From looking at Figure 4.27 it would appear that 20 out of 26 (76.92%) of the respondents always apply time controls to their project. Six respondents (23.08%) frequently apply time controls, and none of them (0.00%) rarely/do not apply time control techniques during projects.



ANSWER CHOICES	RESPONSES	
Always	76.92%	20
Frequently	23.08%	6
Rarely/do not apply time control techniques during projects	0.00%	0
TOTAL		26

Figure 4.27: Application of time controls

The results show that most of the respondents apply time controls to their project, which is an excellent response and shows that they would likely be keen and interested in the topic area and the new framework development.

Theme 3: Questions 8 to 13 – Time Control Techniques and Software Applications

Q8 – In terms of planning and time control, which of the following control techniques do you use? (24 answered, 8 skipped).

Respondents were asked to rank/order the control techniques from the most important to the least important (extremely important – 1; important – 2; neutral/no change – 3; unimportant – 4; extremely unimportant – 5).

As can be seen from the bar chart and score results shown in Figure 4.28a and b, the precedence network diagram (PND) ranks as the most used technique and Gantt bar chart the lowest.

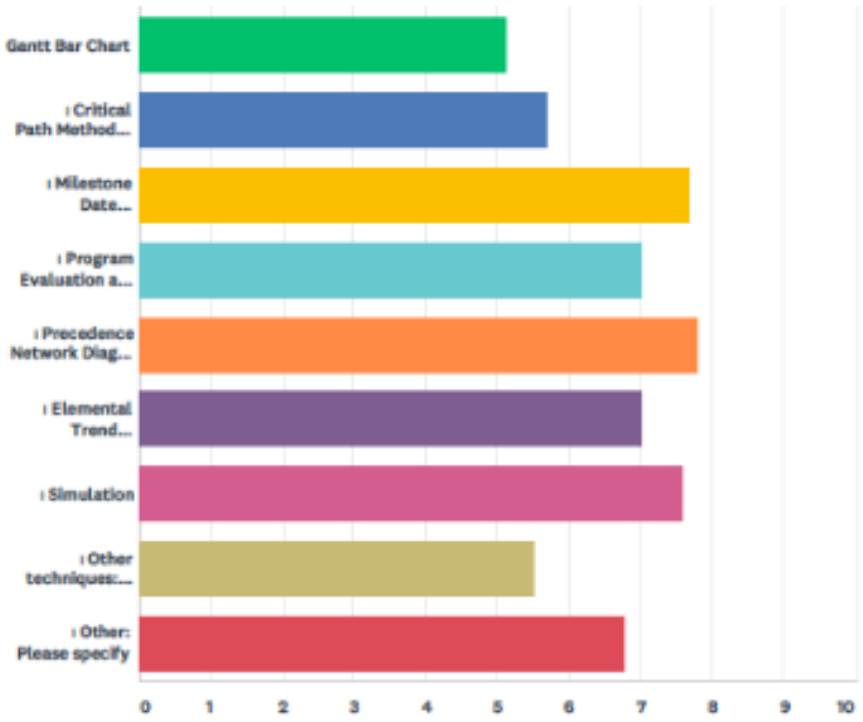


Figure 4.28a: Techniques used for project planning and time control

	1	2	3	4	5	6	7	8	9	TOTAL	SCORE
Gantt Bar Chart	4.35% 1	8.70% 2	0.00% 0	8.70% 2	65.22% 15	0.00% 0	4.35% 1	4.35% 1	4.35% 1	23	5.13
Critical Path Method (CPM) (Critical Path Networks/Method)	0.00% 0	0.00% 0	13.64% 3	68.18% 15	4.55% 1	4.55% 1	4.55% 1	4.55% 1	0.00% 0	22	5.68
Milestone Date Programming Technique	25.00% 3	33.33% 4	33.33% 4	0.00% 0	8.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	12	7.67
Program Evaluation and Review Technique (PERT)	17.65% 3	35.29% 6	17.65% 3	5.88% 1	11.76% 2	5.88% 1	5.88% 1	0.00% 0	0.00% 0	17	7.00
Precedence Network Diagram (PND)	20.00% 1	40.00% 2	40.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	7.80
Elemental Trend Analysis/Line of Balance (LOB)	0.00% 0	33.33% 1	33.33% 1	33.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	7.00
Simulation	60.00% 6	0.00% 0	0.00% 0	20.00% 2	20.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	10	7.60
Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	0.00% 0	0.00% 0	41.67% 5	16.67% 2	16.67% 2	16.67% 2	0.00% 0	0.00% 0	8.33% 1	12	5.50
Other: Please specify	25.00% 1	0.00% 0	25.00% 1	25.00% 1	25.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	6.75

Figure 4.28b: Techniques used for project planning and time control

The RII, Mean, and Weighting of all the responses with rank/scale 1 to 5 were also computed. The rankings for the responses are as follows:

	For each item, enter the frequency with which each response option was observed:					*Computed values, given the 5 frequency entries:*				
Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII	Item Mean	
1	15	2	0	2	1	20	88	0.880	4.400	Q8
2	1	15	3	0	0	19	74	0.779	3.895	
3	1	0	4	4	3	12	28	0.467	2.333	
4	2	1	3	6	3	15	38	0.507	2.533	
5	0	0	2	2	1	5	11	0.440	2.200	
6	0	1	1	1	0	3	9	0.600	3.000	
7	2	2	0	0	6	10	24	0.480	2.400	
8	2	2	5	0	0	9	33	0.733	3.667	
9	1	1	1	0	1	4	13	0.650	3.250	

Figure 4.28c: Techniques used for project planning and time control (RII, Mean, and Weighting)

PND scores 7.80 (RII = 0.440), the milestone data programming technique scores 7.67 (RII = 0.467), simulation scores 7.60 (RII = 0.480), PERT (RII = 0.507) and LOB (RII = 0.600) have similar scores of 7.00, other scores 6.75 (RII = 0.650), CPM scores 5.68 (RII = 0.779), and other techniques including CSA, CCM, LPS, 4D planning, LPDS, DSM, scheduling reciprocal process, and visualising the schedule score 5.50 (RII = 0.733); the Gantt bar chart scores 5.13 (RII = 0.880) respectively.

Nonparametric correlations and tests, Kendall's W Test, Ranks, Test Statistics, Mean and Standard Deviation in SPSS including Descriptive Statistics were also calculated (see Figure 4.28d and 4.28g).

Correlations

			Gantt Bar Chart	Critical Path Method (CPM) (Critical Path Networks/Method)	Milestone Date Programming Technique	Program Evaluation and Review Technique (PERT)	Precedence Network Diagram (PND)	Elemental Trend Analysis/Line of Balance (LOB)	Simulation	Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	Other: Please specify
Kendall's tau_b	Gantt Bar Chart	Correlation Coefficient	1.000	.497*	-.040	.530*	.000	.333	.030	-.104	-.183
		Sig. (2-tailed)	.	.011	.877	.012	1.000	.602	.917	.686	.718
		N	23	21	12	16	5	3	10	12	4
	Critical Path Method (CPM) (Critical Path Networks/Method)	Correlation Coefficient	.497*	1.000	.295	.389	.118	.333	.545	.100	-.333
		Sig. (2-tailed)	.011	.	.262	.061	.788	.602	.058	.714	.602
		N	21	22	12	17	5	3	10	11	3
	Milestone Date Programming Technique	Correlation Coefficient	-.040	.295	1.000	-.055	-.354	.333	-.065	.182	-1.000
		Sig. (2-tailed)	.877	.262	.	.825	.420	.602	.859	.656	.
		N	12	12	12	12	5	3	7	6	2
	Program Evaluation and Review Technique (PERT)	Correlation Coefficient	.530*	.389	-.055	1.000	.447	.333	.031	.740*	-1.000
		Sig. (2-tailed)	.012	.061	.825	.	.296	.602	.915	.013	.
		N	16	17	12	17	5	3	10	9	2
	Precedence Network Diagram (PND)	Correlation Coefficient	.000	.118	-.354	.447	1.000	-.816	.000	.500	1.000
		Sig. (2-tailed)	1.000	.788	.420	.296	.	.221	1.000	.480	.
		N	5	5	5	5	5	3	3	3	2
	Elemental Trend Analysis/Line of Balance (LOB)	Correlation Coefficient	.333	.333	.333	.333	-.816	1.000	.333	-1.000	-1.000
		Sig. (2-tailed)	.602	.602	.602	.602	.221	.	.602	.	.
		N	3	3	3	3	3	3	3	2	2
	Simulation	Correlation Coefficient	.030	.545	-.065	.031	.000	.333	1.000	.630	-1.000
		Sig. (2-tailed)	.917	.058	.859	.915	1.000	.602	.	.154	.
		N	10	10	7	10	3	3	10	5	2
	Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	Correlation Coefficient	-.104	.100	.182	.740*	.500	-1.000**	.630	1.000	1.000
		Sig. (2-tailed)	.686	.714	.656	.013	.480	.	.154	.	.
		N	12	11	6	9	3	2	5	12	2
	Other: Please specify	Correlation Coefficient	-.183	-.333	-1.000**	-1.000**	1.000**	-1.000**	-1.000**	1.000**	1.000
		Sig. (2-tailed)	.718	.602	.	.	.	.	.	.	.
		N	4	3	2	2	2	2	2	2	4

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 4.28d: Techniques used for project planning and time control (Kendall's W Test)

Correlations

			Gantt Bar Chart	Critical Path Method (CPM) (Critical Path Networks/Method)	Milestone Date Programming Technique	Program Evaluation and Review Technique (PERT)	Precedence Network Diagram (PND)	Elemental Trend Analysis/Line of Balance (LOB)	Simulation	Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	Other: Please specify
Spearman's rho	Gantt Bar Chart	Correlation Coefficient	1.000	.527*	-.023	.549*	-.053	.500	.014	.000	-.316
		Sig. (2-tailed)	.	.014	.942	.027	.933	.667	.969	1.000	.684
		N	23	21	12	16	5	3	10	12	4
	Critical Path Method (CPM) (Critical Path Networks/Method)	Correlation Coefficient	.527*	1.000	.322	.444	.135	.500	.621	.209	-.500
		Sig. (2-tailed)	.014	.	.308	.074	.828	.667	.055	.538	.667
		N	21	22	12	17	5	3	10	11	3
	Milestone Date Programming Technique	Correlation Coefficient	-.023	.322	1.000	-.067	-.460	.500	-.073	.183	-1.000
		Sig. (2-tailed)	.942	.308	.	.837	.436	.667	.876	.728	.
		N	12	12	12	12	5	3	7	6	2
	Program Evaluation and Review Technique (PERT)	Correlation Coefficient	.549*	.444	-.067	1.000	.527	.500	.014	.843**	-1.000
		Sig. (2-tailed)	.027	.074	.837	.	.361	.667	.969	.004	.
		N	16	17	12	17	5	3	10	9	2
	Precedence Network Diagram (PND)	Correlation Coefficient	-.053	.135	-.460	.527	1.000	-.866	.000	.500	1.000
		Sig. (2-tailed)	.933	.828	.436	.361	.	.333	1.000	.667	.
		N	5	5	5	5	5	3	3	3	2
	Elemental Trend Analysis/Line of Balance (LOB)	Correlation Coefficient	.500	.500	.500	.500	-.866	1.000	.500	-1.000	-1.000
		Sig. (2-tailed)	.667	.667	.667	.667	.333	.	.667	.	.
		N	3	3	3	3	3	3	3	2	2
	Simulation	Correlation Coefficient	.014	.621	-.073	.014	.000	.500	1.000	.803	-1.000
		Sig. (2-tailed)	.969	.055	.876	.969	1.000	.667	.	.102	.
		N	10	10	7	10	3	3	10	5	2
	Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	Correlation Coefficient	.000	.209	.183	.843**	.500	-1.000**	.803	1.000	1.000
		Sig. (2-tailed)	1.000	.538	.728	.004	.667	.	.102	.	.
		N	12	11	6	9	3	2	5	12	2
	Other: Please specify	Correlation Coefficient	-.316	-.500	-1.000**	-1.000**	1.000**	-1.000**	-1.000**	1.000**	1.000
		Sig. (2-tailed)	.684	.667	.	.	.	.	.	.	.
		N	4	3	2	2	2	2	2	2	4

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 4.28e: Techniques used for project planning and time control (Spearman's rank correlation coefficient)

There is statistical significance, the descriptive statistics available, as well as the ranks, and the sample size, the test statistics Kendall's W, the Chi square, and the degrees of freedom = df. We have more information using this method.

So, looking at the descriptive statistics, we can see we have the N = sample size (raters), the mean, that matches the mean rank in the ranks table, and the standard deviation, minimum, and maximum.

It can also be seen that PND, the Milestone data programming technique, Simulation, PERT and LOB techniques were all ranked as the best by at least one of the raters and, similarly,

other techniques and the Gantt bar chart each received the lowest rank from one of the raters, because all raters are represented here.

Moving down to the ranks and test statistics tables we can see that Milestone data programming technique overall was ranked the best at 2, and the least used technique was the Gantt Bar Chart at 8.5.

Looking at the test statistics (Figure 4.28f) we have in this case Kendall's W = 0.842 which shows a reasonable level of agreement. [To have a high level of agreement, a value of 0.9 or above is required.]

Ranks

	Mean Rank
Gantt Bar Chart	8.50
Critical Path Method (CPM) (Critical Path Networks/Method)	7.50
Milestone Date Programming Technique	2.00
Program Evaluation and Review Technique (PERT)	6.50
Precedence Network Diagram (PND)	2.50
Elemental Trend Analysis/Line of Balance (LOB)	3.00
Simulation	4.50
Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	7.50
Other: Please specify	3.00

Test Statistics

N	2
Kendall's W[a]	.842
Chi-Square	13.467
df	8
Asymp. Sig.	.097

a. Kendall's Coefficient of Concordance

Figure 4.28f: Techniques used for project planning and time control (ranks and test statistics)

Herein, it can be seen that in terms of chi-square test, we have df = 8 as we have nine different techniques. In addition, the significance level (p value) shown here is 0.097; as $p > 0.05$, the results are not statistically significant. Therefore, the null hypothesis is retained, and we do not reach significance. [A significance level is typically set at 0.05, but sometimes it can be adjusted to as little as 0.01 or as much as 0.1.]

Descriptive Statistics

	N	Mean	Std. Deviation
Gantt Bar Chart	23	4.8696	1.71370
Critical Path Method (CPM) (Critical Path Networks/Method)	22	4.3182	1.21052
Milestone Date Programming Technique	12	2.3333	1.15470
Program Evaluation and Review Technique (PERT)	17	3.0000	1.80278
Precedence Network Diagram (PND)	5	2.2000	.83666
Elemental Trend Analysis/Line of Balance (LOB)	3	3.0000	1.00000
Simulation	10	2.4000	1.83787
Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	12	4.5000	1.83402
Other: Please specify	4	3.2500	1.70783
Valid N (listwise)	2		

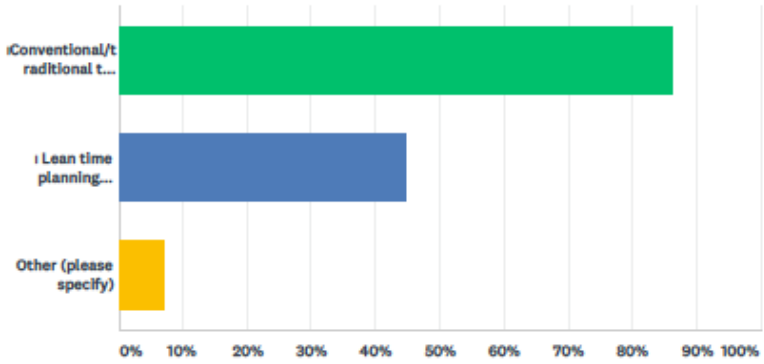
Figure 4.28g: Techniques used for project planning and time control (descriptive statistics)

According to results, they could choose as much as they want for having the complete view regarding the issue.

This question was further analysed in Round 2 of the questionnaires and interviews in the UK. For more accurate results, respondents were asked to choose only the Top 5 answers; this showed that the most popular time planning and control technique is PND, closely followed by the Milestone Data Programming Technique. The popularity of these techniques might be due to their being the most established techniques in the industry, though ease of use and applicability to the construction process can also be argued as being responsible for their popularity. Other techniques used include those mentioned above. This echoes the results of Olawale and Sun (2010), who conducted a two-part UK-based survey on (a) the techniques and (b) the software packages used for project planning and time control.

Q9 – What kind of planning techniques do you use for construction projects? (29 answered, 3 skipped).

When asked what kind of planning techniques respondents preferred, 86.21% (25 out of 29 respondents) have used conventional/traditional time planning techniques (e.g. CCM, Bar charts) for construction projects (Figure 4.29).



ANSWER CHOICES	RESPONSES	
Conventional/traditional time planning techniques (e.g. Critical Path Methods, Bar charts)	86.21%	25
Lean time planning techniques (e.g. Critical Chain Programming and Last Planner)	44.83%	13
Other (please specify)	6.90%	2
Total Respondents: 29		

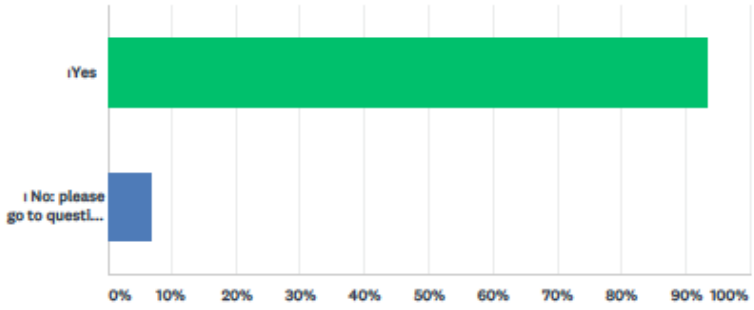
#	OTHER (PLEASE SPECIFY)
1	Monte Carlo Simulation for Planning (Pertmaster)
2	Quantitative & Qualitative Risk Assessment of Programme activities

Figure 4.29: Kind of planning techniques used by respondents

Additionally, 44.83% (13/26) have used lean time planning techniques such as Critical Chain programming and Last Planner, whilst 6.90% (2/26) have used other techniques such as Monte Carlo Simulation for Planning (Pertmaster), and quantitative and qualitative risk assessment of programme activities.

Q10 – For project planning do you utilise computer programs/packages? (30 answered, 2 skipped).

The results for this question show that when project planning, 93.33% of the respondents utilised computer programs/packages (28 out of 30), and two respondents (6.67%) did not (Figure 4.30).

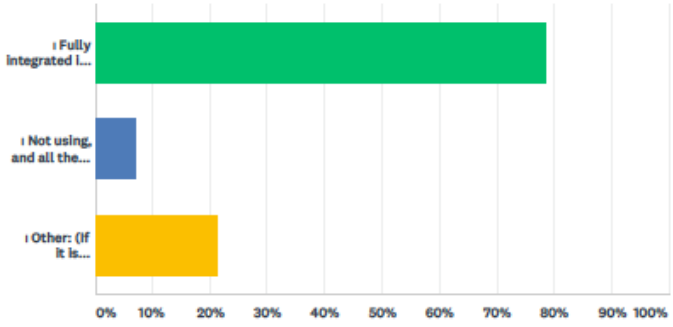


ANSWER CHOICES	RESPONSES	
ıYes	93.33%	28
ı No: please go to question 13	6.67%	2
TOTAL		30

Figure 4.30: Utilisation of computer programs for project planning

Q11 – For the planning activity of the company, what is the degree of computer software utilisation and/or how do you rank/assess and evaluate that? (28 answered, 4 skipped).

Concerning the degree to which computer software is utilised for the planning activity of the company (Figure 4.31), 78.57% of respondents mentioned that it is fully integrated in all planning levels; 21.43% mentioned that it is integrated partly and only two respondents (7.14%) suggested they are not using it (in which case they were directed to Question 13 rather than answering Question 12).



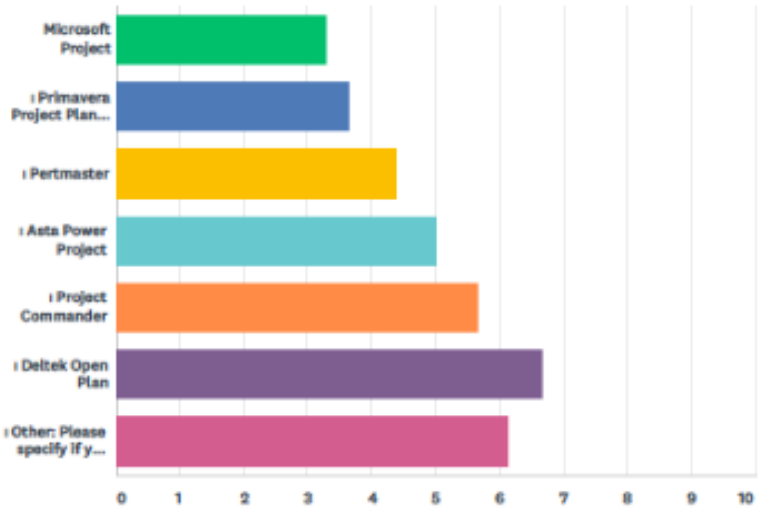
ANSWER CHOICES	RESPONSES	
Fully integrated in all planning levels	78.57%	22
Not using, and all the planning process are prepared and complete by hand	7.14%	2
Other: (If it is integrated partly, please state the part(s) which require software program utilization), Please specify	21.43%	6
Total Respondents: 28		

#	OTHER (PLEASE SPECIFY)
1	Use both computer software and by hand - partly
2	It all depends on the type of project
3	Partly
4	It all depends on the kind of planning activity
5	Partly integrated
6	don't know the answer to this, as Planning Office undertook all such activities

Figure 4.31: Degree of computer software utilisation for planning

Q12 – What software programs do you use for planning and scheduling? (27 answered, 5 skipped).

As can be seen from Figure 4.32a, the use of software programs to support planning is widespread. The three clear leading applications are Deltek Open Plan, Project Commander, and Asta Powerproject.



	1	2	3	4	5	6	7	TOTAL	SCORE
Microsoft Project	0.00% 0	0.00% 0	16.00% 4	4.00% 1	76.00% 19	0.00% 0	4.00% 1	25	3.28
Primavera Project Planner	0.00% 0	0.00% 0	8.00% 2	60.00% 15	24.00% 6	4.00% 1	4.00% 1	25	3.64
Pertmaster	0.00% 0	5.56% 1	50.00% 9	27.78% 5	11.11% 2	5.56% 1	0.00% 0	18	4.39
Asta Power Project	0.00% 0	50.00% 4	0.00% 0	50.00% 4	0.00% 0	0.00% 0	0.00% 0	8	5.00
Project Commander	0.00% 0	66.67% 2	33.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	5.67
Deltek Open Plan	66.67% 2	33.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	6.67
Other: Please specify if you are using any other software packages.	50.00% 4	12.50% 1	37.50% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	6.13

Figure 4.32a: Software programs used for planning and scheduling

As can be seen from the bar chart (Figure 4.32a) and score results (Figure 4.32b), Deltek Open Plan ranks as the most used software (score = 6.67; RII = 0.267) and Microsoft Project as the lowest (score = 3.28; RII = 4.625).

	For each item, enter the frequency with which each response option was observed:					*Computed values, given the 5 frequency entries:*					
Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII		Item Mean	
1	19	1	4	0	0	24	111	0.925		4.625	Q12
2	6	15	2	0	0	23	96	0.835		4.174	
3	2	5	9	1	0	17	59	0.694		3.471	
4	0	4	0	4	0	8	24	0.600		3.000	
5	0	0	1	2	0	3	7	0.467		2.333	
6	0	0	0	1	2	3	4	0.267		1.333	
7	0	0	3	1	4	8	15	0.375		1.875	

Figure 4.32b: Software programs used for planning and scheduling (RII, mean, and weighting)

Looking at the test statistics table (Figure 4.32c), we have in this case Kendall's W = 0.893; this shows a strong positive correlation and indicates strong agreement between the rankings. We have df = 6 because we have seven different software programs, and the significance level (p value) shown here is 0.098. Therefore p > 0.05, which means we fail to reach significance and we retain the null hypothesis.

Ranks

	Mean Rank
Microsoft Project	6.00
Primavera Project Planner	6.50
Pertmaster	5.50
Asta Power Project	4.00
Project Commander	2.50
Deltek Open Plan	1.50
Other:Please specify if you are using any other software packages.	2.00

Test Statistics

N	2
Kendall's W[a]	.893
Chi-Square	10.714
df	6
Asymp. Sig.	.098

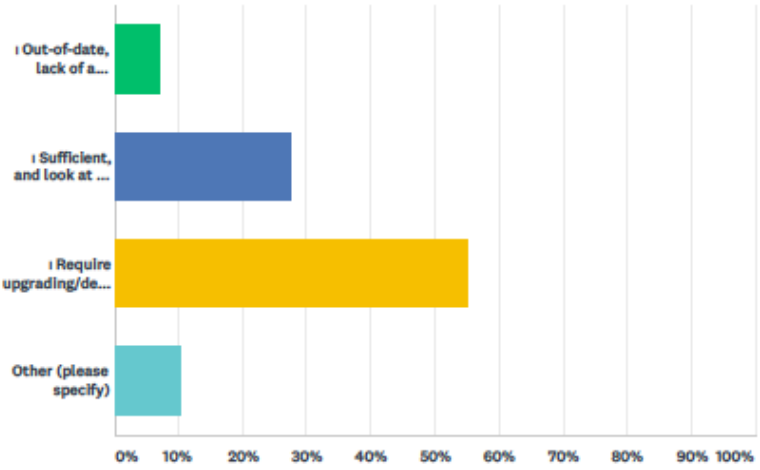
a. Kendall's Coefficient of Concordance

Figure 4.32c: Software programs used for planning and scheduling (rank and test statistics)

This question was further analysed in Round 2 of the questionnaires and interviews in the UK.

Q13 – How do you assess the present methods of project planning? (29 answered, 3 skipped).

As can be seen from Figure 4.33, 55.17% (16/27) of the respondents mentioned that the present methods of project planning require upgrading/development, and additional aspects, such as human factors, need to be analysed.



ANSWER CHOICES	RESPONSES	
Out-of-date, lack of a number of important aspects, such as human factor	6.90%	2
Sufficient, and look at the whole aspects/parts of a project	27.59%	8
Require upgrading/development, additional aspects need to be analyze, such as human factor	55.17%	16
Other (please specify)	10.34%	3
TOTAL		29

#	OTHER (PLEASE SPECIFY)
1	Sufficient, and look at the whole aspects/parts of a project Require upgrading/development, additional aspects need to be analyze, such as human factor
2	Out-of-date, lack of a number of important aspects, such as human factor. REGULAR UPDATING NEEDED ON COMPUTER FOR CCP. LP CAN BE MANUAL FOR SIMPLE PROJECTS. Question 10. No BUT I HAVE TAUGHT PERTMASTER.
3	" Require upgrading/development, additional aspects need to be analyze, such as human factor. The high level of planning is done well. The lower tiers of planning i.e. what happens on the ground needs to be addressed. This is where the risk lies & also delays.

Figure 4.33: Assessment of the present project planning methods

Theme 4: Question 14 – Time Overruns

Q14 – What factors lead to project time overruns? (23 answered, 9 skipped).

The following questions were asked to identify the most common factors that lead to project time overruns, in regard to the frequency of time overruns experienced. Poor labour productivity, a lack of project funding, and a shortage of materials rank highest (Figure 4.34).

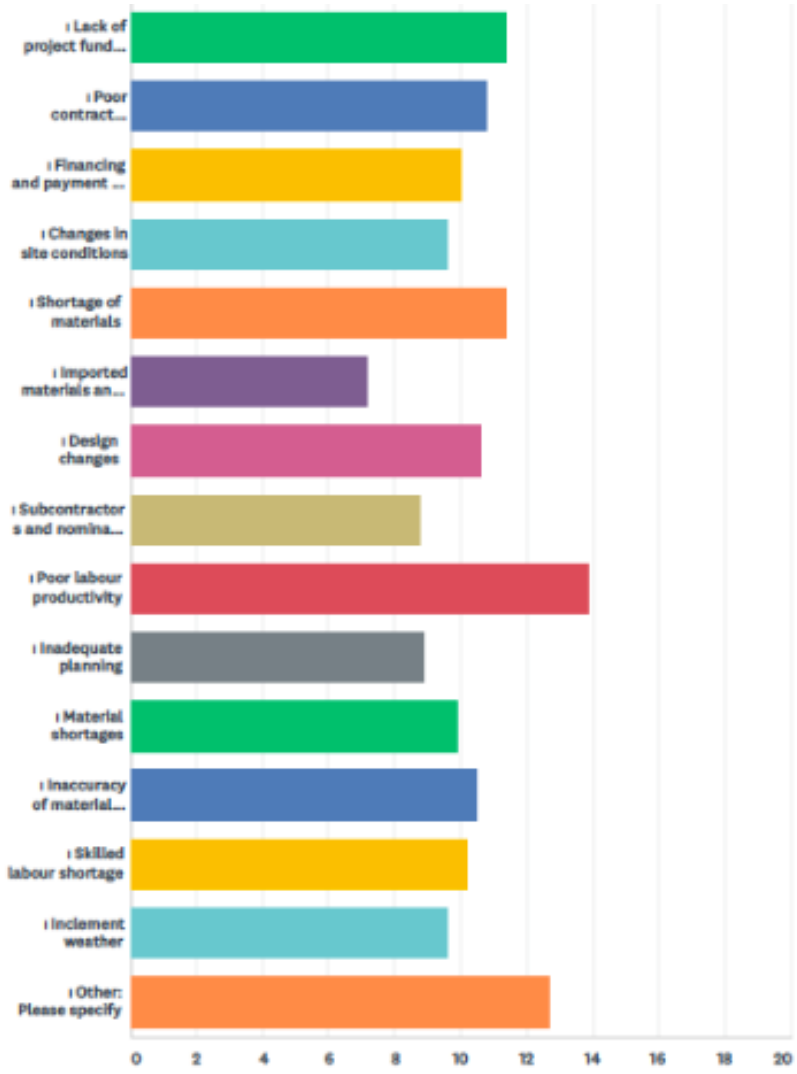


Figure 4.34a: Factors that lead to project time overruns

	For each item, enter the frequency with which each response option was observed:					*Computed values, given the 5 frequency entries:*					
Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII		Item Mean	
1	2	1	1	4	4	12	29	0.483		2.417	Q14
2	2	3	5	1	1	12	40	0.667		3.333	
3	0	1	2	1	0	4	12	0.600		3.000	
4	0	2	2	2	0	6	18	0.600		3.000	
5	1	1	1	1	1	5	15	0.600		3.000	
6	1	0	0	0	0	1	5	1.000		5.000	
7	3	7	1	3	1	15	53	0.707		3.533	
8	0	2	3	0	2	7	19	0.543		2.714	
9	0	1	1	3	2	7	15	0.429		2.143	
10	10	2	1	0	0	13	61	0.938		4.692	
11	1	1	1	0	2	5	14	0.560		2.800	
12	2	1	2	0	0	5	20	0.800		4.000	
13	0	0	2	3	2	7	14	0.400		2.000	
14	0	0	0	3	1	4	7	0.350		1.750	
15	0	0	0	0	5	5	5	0.200		1.000	

Figure 4.34b: Factors that lead to project time overruns

Ranks

	Mean Rank
Lack of project funding	9.60
Poor contract management	9.40
Financing and payment of completed works	7.20
Changes in site conditions	7.80
Shortage of materials	5.20
Imported materials and plant items	9.00
Design changes	10.40
Subcontractors and nominated suppliers	12.80
Poor labour productivity	2.60
Inadequate planning	13.20
Material shortages	7.60
Inaccuracy of material estimate	6.80
Skilled labour shortage	9.80
Inclement weather	7.60
Other: Please specify	1.00

Test Statistics

N	5
Kendall's W[a]	.547
Chi-Square	38.260
df	14
Asymp. Sig.	.000

a. Kendall's Coefficient of Concordance

Figure 4.34c: Factors that lead to project time overruns

The result of this test is W = 0.547, indicating agreement between the rankings. And the significance level (p value) shown here is 0.000, which means we have a statistically significant result.

Descriptive Statistics

	N	Mean	Std. Deviation
Lack of project funding	16	4.6250	4.44035
Poor contract management	16	5.1875	3.60035
Financing and payment of completed works	7	6.0000	3.91578
Changes in site conditions	11	6.3636	3.98178
Shortage of materials	8	4.6250	2.55999
Imported materials and plant items	6	8.8333	3.18852
Design changes	21	5.3810	3.69427
Subcontractors and nominated suppliers	13	7.2308	5.19862
Poor labour productivity	7	2.1429	1.06904
Inadequate planning	20	7.1000	3.94568
Material shortages	9	6.1111	4.53995
Inaccuracy of material estimate	8	5.5000	2.39046
Skilled labour shortage	13	5.8462	4.70543
Inclement weather	10	6.4000	4.94862
Other: Please specify	6	3.3333	5.71548
Valid N (listwise)	5		

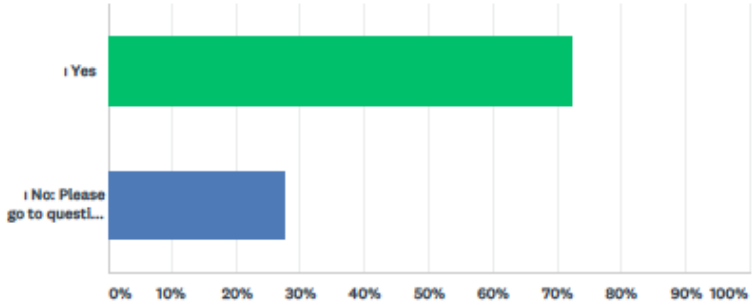
Figure 4.34d: Factors that lead to project time overruns

Theme 5: Questions 15 to 24 – Lean Time Planning Techniques

Questions 15 to 24 were derived to establish the knowledge (and application) of respondents when it comes to the plethora of lean time planning techniques that currently exist.

Q15 – Are you aware of the Last Planner System (LPS)? (29 answered, 3 skipped).

Twenty-one respondents (72.41%) said that they are aware of LPS whilst eight (27.59%) are not (Figure 4.35).

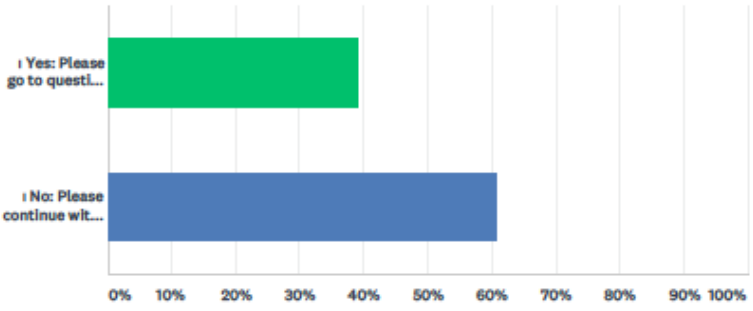


ANSWER CHOICES	RESPONSES	
Yes	72.41%	21
No: Please go to question 19	27.59%	8
TOTAL		29

Figure 4.35: Awareness of the Last Planner System

Q16 – Do you use the Last Planner System (LPS)? (23 answered, 9 skipped).

Fourteen out of 23 respondents don't use LPS (60.87%) and nine of them (39.13%) do (Figure 4.36).

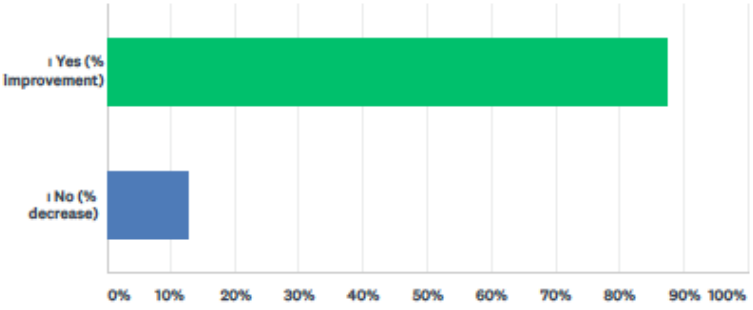


ANSWER CHOICES	RESPONSES	
Yes: Please go to question 17	39.13%	9
No: Please continue with Question 20	60.87%	14
TOTAL		23

Figure 4.36: Use of the Last Planner System

Q17 – After the Last Planner System (LPS) was adopted have you seen an improvement in Cost Performance Index (CPI)? (8 answered, 24 skipped).

Respondents were asked if they had seen any increase in CPI since LPS was adopted. What is interesting here is that only eight (circa 25%) of the respondents answered this question. This may suggest they do not know or did not understand fully the question posed – unfortunately, a 'do not know' option was not included. Of those that did respond, 87.5% (7 respondents) said they did see an improvement in CPI, whereas 12.5% (1 respondent) saw no increase (Figure 4.37).

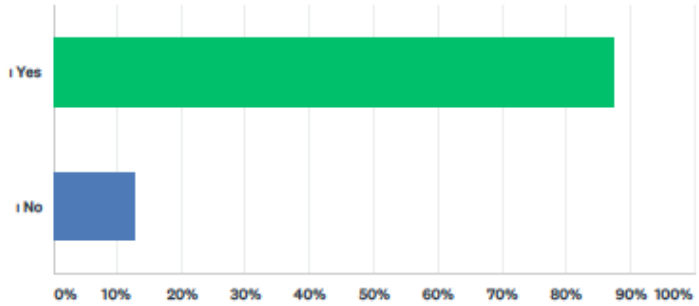


ANSWER CHOICES	RESPONSES	
Yes (% improvement)	87.50%	7
No (% decrease)	12.50%	1
TOTAL		8

Figure 4.37: Improvement of CPI after LPS adopted

Q18 – Do you use Percent Plan Complete (PPC) as a measure? (8 answered, 24 skipped).

Respondents were asked if they use PPC as a measure. Once again, what is interesting to see is that only eight (circa 25%) respondents answered this question. This may suggest they do not know or did not understand fully the question posed – unfortunately, a 'do not know' option was not included. Of those that did respond, 87.5% (7 respondents) said they did use PPC as a measure, whereas 12.5% (1 respondent) said they did not (Figure 4.38).

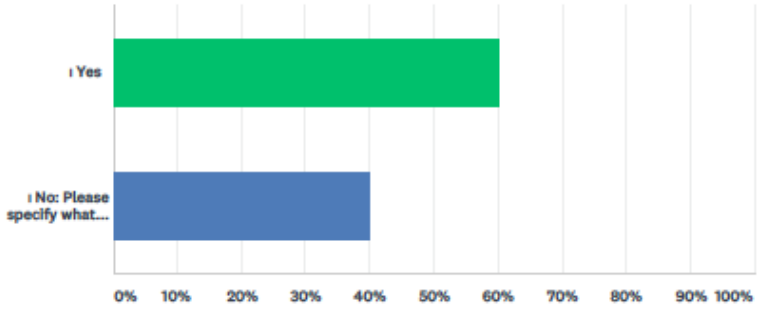


ANSWER CHOICES	RESPONSES	
Yes	87.50%	7
No	12.50%	1
TOTAL		8

Figure 4.38: Use of PPC as a measurement

Q19 – If you are not using LPS, have you ever considered using it? (10 answered, 22 skipped).

Respondents who were not using LPS were asked if they had ever considered using it (Figure 4.39). What is interesting here is that only 10 (circa 25%) respondents answered this question. Of those, six said they had considered adopting LPS, whilst four said they had not. When asked for further details, two respondents said they were using LPS (although not under this name).



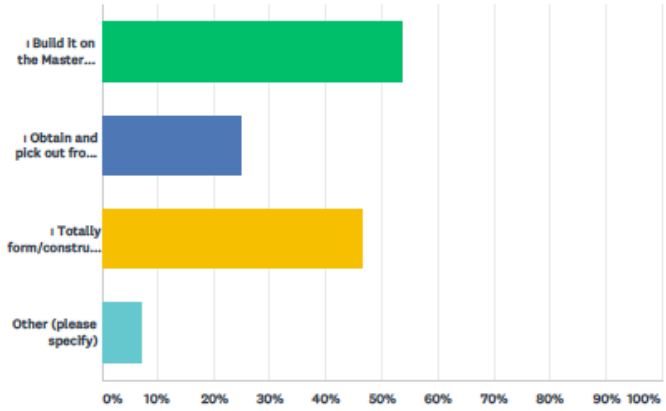
ANSWER CHOICES	RESPONSES	
Yes	60.00%	6
No: Please specify what reasons convinced you NOT to use it?	40.00%	4
TOTAL		10

#	PLEASE SPECIFY
1	It is not called the last planner system but the principles are relatively similar
2	Not had to use anything sophisticated
3	The last planner system is not called last planner system in the company – the principals however used are the same as LPS. The level of control for plans and programme & level of planning is also defined.

Figure 4.39: Consideration of using LPS

Q20 – How do you currently structure Weekly Work Plans (WWPs)? (28 answered, 4 skipped).

Respondents were asked how they currently structured their WWPs. Figure 4.40 shows that 54% of respondents (15/28) build them on the master schedule, whilst 46% (13/28) construct a modern work plan. As can be seen from Figure 4.40, 54% (15/28) of the respondents mentioned that they currently structure WWPs by building them on the master schedule and creating additional information.



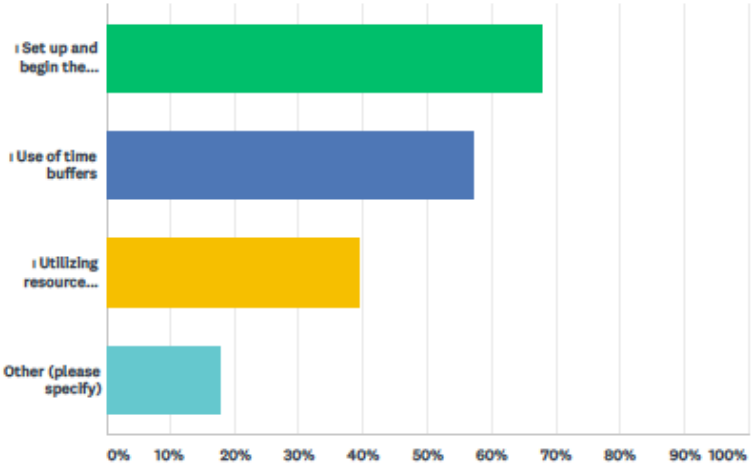
ANSWER CHOICES	RESPONSES	
Build it on the Master schedule and form/create additional information	53.57%	15
Obtain and pick out from the master schedule	25.00%	7
Totally form/construct a modern work plan	46.43%	13
Other (please specify)	7.14%	2
Total Respondents: 28		

#	OTHER (PLEASE SPECIFY)
1	Build it on the Master schedule and form/create additional information FROM MADE READY ASSIGNMENTS
2	It depends on the task – sometimes the master schedule is used when the activities are of high importance and need to be reported. If the activities are minor and does not need reporting – a separate work plan is constructed.

Figure 4.40: Current structure of WWPs

Exactly 25% (7/28) obtained information and picked it out from the master schedule, whilst 7% (2/28) adopted another approach, which they specified.

Q21 – In order to accommodate uncertainties in the last phases of work, which of the following is your preferred technique in the planning phase? (28 answered, 4 skipped).



ANSWER CHOICES	RESPONSES	
Set up and begin the process early (fast and quickly)	67.86%	19
Use of time buffers	57.14%	16
Utilizing resource buffers	39.29%	11
Other (please specify)	17.86%	5
Total Respondents: 28		

#	OTHER (PLEASE SPECIFY)
1	All of the above
2	Use cost buffers on the project to increase resources/ speed up the process.
3	All the above with the use of risk analysis method
4	IT ALL DEPENDS ON COMPLEXITY OF PROJECT. LEAN PLANNING WORKS BACKWARDS FROM PROJECT COMPLETION.
5	I tend to include time buffer for activities & also start the leading & critical activities earlier in the process.

Figure 4.41: Preferred technique to accommodate uncertainties in planning

Respondents were asked what their preferred technique in the planning phase is, to accommodate uncertainties in the last phases of work. Figure 4.41 shows that 68% of respondents (19/28) set up and begin the process early (fast and quickly), whilst 57% (16/28) use time buffers.

According to Howell and Koskela (2000), project management as taught by professional societies and applied in current practice must be reformed because it is inadequate today and

its performance will continue to decline as projects become more uncertain, complex, and pressed for speed, and because of a deficient definition of control.

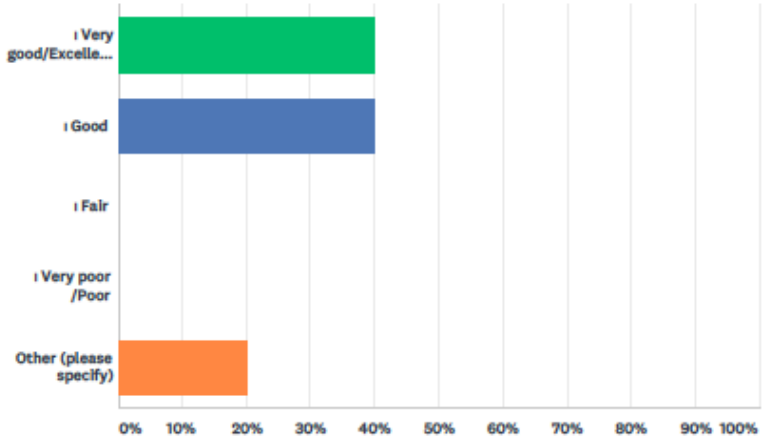
Significant uncertainty exists throughout a project (Howell and Laufer, 1993). Project management based on an illusion of certainty cannot be effective. Laufer has suggested practices for project managers related to identifying, reducing, and coping with uncertainty (Laufer, 1997).

*Q22 – **open-ended** – If you have been using the Last Planner System, can you please say what it was that resulted in its adoption by your company? (Has it had an impact? Has it been useful? Do you find this effective)? (5 answered, 27 skipped).*

#	RESPONSES
1	The system is not exactly called the last planner system, however the principles are the same.
2	The system is not adopted as particularly being called 'Last Planner System', but due to experienced planner on the project the system gets followed intuitively. In railway construction industry it is mandatory to deliver on time so: 1. We need backward planning to ensure the end product is delivered on time, 2. Strong stakeholder management with train operating companies, Freight operating companies and Line-side neighbors / local councils so we deliver the product with their interests in mind, also to assist in possession management. 3. Strong team work due to technicality of works, we require experts from different departments to take part in planning phase.
3	N/A
4	LARGE PROJECTS THAT USE IT HAVE BEEN SHOWN TO ACHIEVE BETTER PROJECT COMPLETION – ON TIME AND REDUCED COSTS etc.
5	The layering of programme is the reason the company likes to use the principles. It allows various level of control at different organisation level to be in place and also allows reporting at different levels. The company works will major development and programme this enable better control.

The list above shows that use of LPS by the respondents has been shown to achieve better project completion in their company – on time and reduced costs etc. Although some of them mentioned that the system is not exactly called LPS, the principles are the same. They mentioned that programme layering is the reason the company likes to use the principles.

Q23 – If you use the Last Planner System, I'd like to explore its effectiveness. How have you measured its effectiveness? And how do you know it's been effective? (10 answered, 22 skipped).



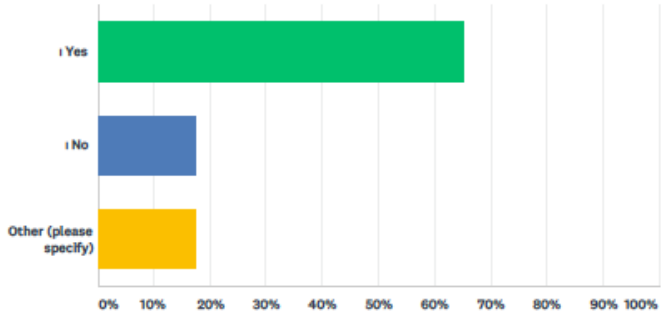
ANSWER CHOICES	RESPONSES	
Very good/Excellent	40.00%	4
Good	40.00%	4
Fair	0.00%	0
Very poor /Poor	0.00%	0
Other (please specify)	20.00%	2
TOTAL		10

#	OTHER (PLEASE SPECIFY)
1	N/A
2	SEE Q22 ANSWER

Figure 4.42: Effectiveness of using the LPS

As can be seen from Figure 4.42, 40% (4/10) of the respondents said the effectiveness is Very good/Excellent and 40% (4/10) measured its effectiveness as Good.

Q24 – Are there any shortcomings that you can tell me about? (23 answered, 9 skipped).



ANSWER CHOICES	RESPONSES	
Yes	65.22%	15
No	17.39%	4
Other (please specify)	17.39%	4
TOTAL		23

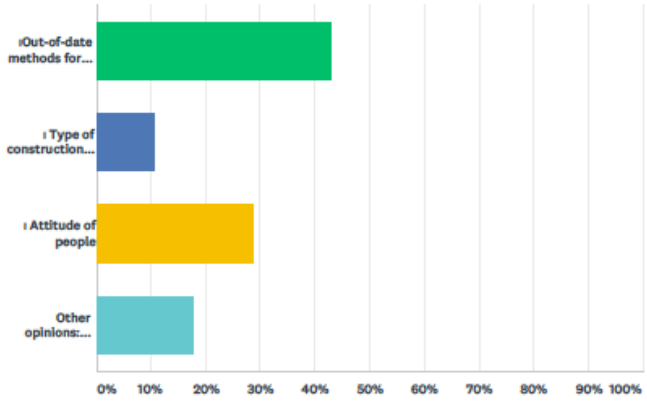
#	OTHER (PLEASE SPECIFY)
1	Yes, require development
2	N/A
3	IT REQUIRES COLLABORATIVE WORKING BETWEEN PARTIES AND IS NOT SUITABLE FOR WORK UNDERTAKIEN BETWEEN CONFRONTATIONAL CONVENTIONAL CONTRACTING PARTIES (- ALTHOUGH ANY ONE PARTY CAN USE IT 'INTERNALLY' TO PLAN AND EXECUTE IT'S WORK).
4	Yes - In the company the master, phased & reporting element is well understood. However the process of actually learning & recording & converting into meaningful data is not understood. There is a need to create a system or process to enable feedback into the programme.

Figure 4.43: Any shortcomings

As can be seen from Figure 4.43, 65% (15/23) of the respondents mentioned that there are shortcomings, which require development.

Theme 6: Questions 25 to 28 – Production Control in Construction

Q25 – For production control/management in construction, which of the following is the most common/presently most important problem? (28 answered, 4 skipped).



ANSWER CHOICES	RESPONSES	
ıOut-of-date methods for production management/control	42.86%	12
ı Type of construction projects	10.71%	3
ı Attitude of people	28.57%	8
Other opinions: Please specify	17.86%	5
TOTAL		28

#	OTHER OPINIONS: PLEASE SPECIFY
1	All of the above
2	ıAttitude of people ıType of construction projects
3	REQUIRES A CHANGE OF CULTURE FROM CONVENTIONAL CONTRACTING
4	The production control in the area I work in has major issue when it comes to IT issues. I think it's the testing of the finished material where the problem lies. A more efficient testing & defect identification process is required.
5	Type of construction projects Attitude of people

Figure 4.44: The most important problems for production control

From Figure 4.44, it can be seen that out-of-date methods for production management/control are the most common/presently most important problem as stated by 43% (12/28) of the respondents.

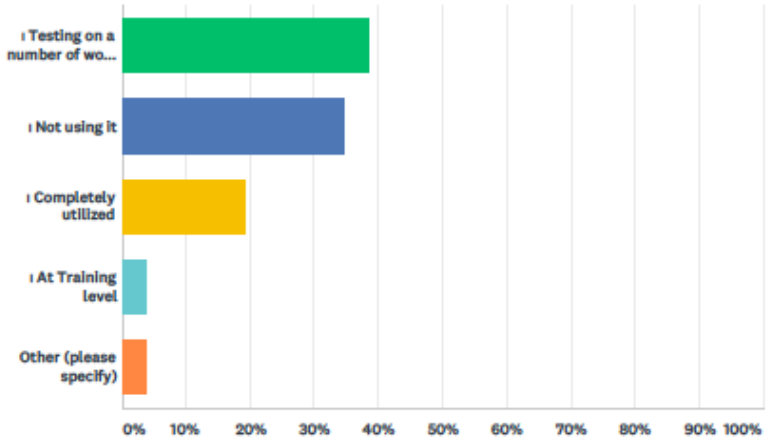
Q26 – Which factors hamper the effective controlling of projects? (3 answered, 29 skipped).

#	RESPONSES
1	The pressure to keep constructing & deliver does not provide enough time to effectively look at improvement options.
2	Finance and Payments, Poor labour productivity and shortage of materials.
3	communications

According to three respondents, the pressure to keep constructing and deliver does not provide enough time to effectively look at improvement options. Finance and payments, poor labour productivity, shortage of materials, and communications are also factors that hamper the effective controlling of projects.

According to Howell and Koskela (2000), contracts can be managed by controlling against outcome variance from standards. Production management, which takes care of how work gets done, requires a more active sense of control. Unfortunately, control actions applied in today's form of project management are not benign. In effect, efforts to optimise activity performance reduce project performance.

Q27 – For production management/control in your firm, to what extent is lean construction or The Last Planner System utilised? (26 answered, 6 skipped).



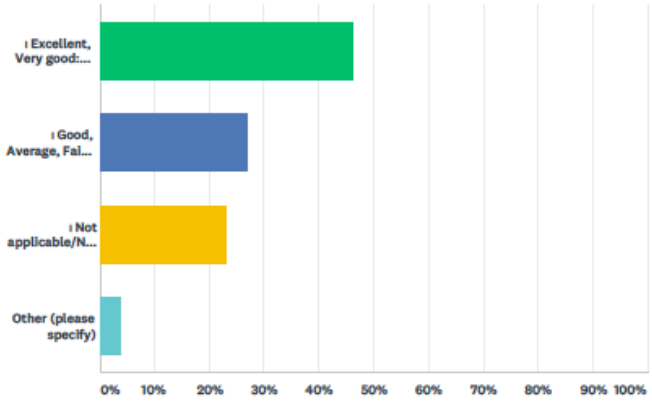
ANSWER CHOICES	RESPONSES	
Testing on a number of works	38.46%	10
Not using it	34.62%	9
Completely utilized	19.23%	5
At Training level	3.85%	1
Other (please specify)	3.85%	1
TOTAL		26

#	OTHER (PLEASE SPECIFY)
1	Cannot answer this

Figure 4.45: Extent of utilisation of LC or LPS

Regarding the extent of utilisation of LC or LPS, as can be seen from Figure 4.45, 38% (10/26) of the respondents carry out testing on several works.

Q28 – Based on your experience so far, how do you assess/evaluate the impact on production management of implementing The Last Planner System? (26 answered, 6 skipped).



ANSWER CHOICES	RESPONSES	
Excellent, Very good: control and management gets better/increase significantly all over and everywhere in production	46.15%	12
Good, Average, Fair: Improvement/development can be seen and is visible	26.92%	7
Not applicable/Not working/Not practical: Does not assist to advance production control/management	23.08%	6
Other (please specify)	3.85%	1
TOTAL		26

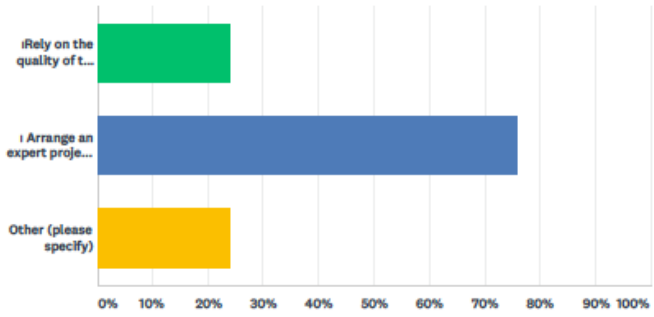
#	OTHER (PLEASE SPECIFY)
1	Excellent, Very good: control and management gets better/increase significantly all over and everywhere in production PROVIDING PARTIES ARE NOT PLAYING GAMES WITH EACH OTHER ie COLLABORATIVE 'OPEN BOOK' TYPE WORKING

Figure 4.46: Impact of implementing LPS

The results in Figure 4.46 shows that 46% (12/26) of the respondents said that the impact of implementing LPS is Excellent or Very good, and that control and management gets better and significantly increases all over and everywhere in production.

Theme 7: Question 29 – Planning Reliability

Q29 – What should be done to guarantee that the real work on site will follow the plan and conform to it? (29 answered, 3 skipped).



ANSWER CHOICES	RESPONSES	
ıRely on the quality of the subcontractor's work	24.14%	7
ı Arrange an expert project management group	75.86%	22
Other (please specify)	24.14%	7
Total Respondents: 29		

#	OTHER (PLEASE SPECIFY)
1	Close monitoring of works and reacting quickly to any change. Having day to day production schedules and measurement through Earned Value Management / Quantity tracking.
2	Have robust monitoring and feedback system in place. Record and report on near misses accidents and reflect on lessons learnt.
3	A structured site management team with designated responsibility to plan, implement and maintain the construction programme.
4	Make regular checks on site to view work against KPI's X
5	Difficult to answer this as residents engineer's task is to ensure that work is conducted to a certain standard.
6	OPENNESS, REGULAR MEETINGS (AS WEEKLY RISK MANAGEMENT MEETING UNDER NEC)
7	Aligning quantified progress (%) & cost (Earned Value Technique) with quality. The programme update to be conducted by the team when work is finished – on site access to programme update and not just central management function.

Figure 4.47: Things to do to follow the plan

From Figure 4.47, it can seen that 76% (22/29) of the respondents said that they should arrange an expert project management group to guarantee that the real work on site will follow the plan and conform to it.

According to Ochao (2014), the process of delivering a high-performance sustainable building has led to a more complex construction practice through the increment of specialised processes. Such complexities have affected construction sequencing and timing, leading to workflow variability and excess in the estimated construction time and cost. In this study,

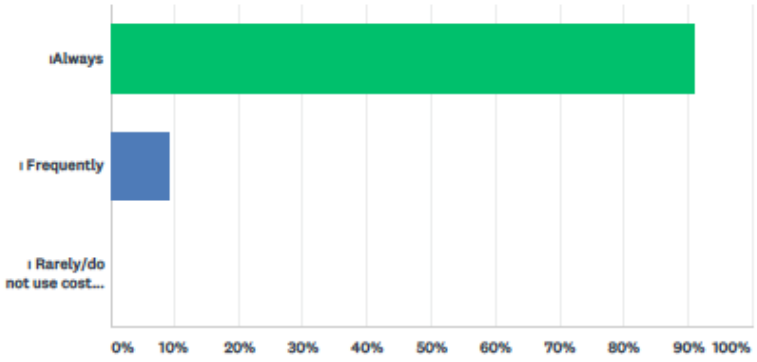
reducing plan variations is considered a key improvement in the delivery process of sustainable building projects. This research used LPS to develop a more reliable production planning process to reduce plan variations. The implementation of LPS resulted in a significant reduction of plan variations. As variability decreased, the production performance of activities increased.

Plan variations are influenced by the amount of uncertainty (Wambeke et al., 2012), for example, whether materials and/or equipment are delivered at the right time, or the recurrence of rework due to inexperienced workers, or even the frequency of design errors encountered (Thomas and Sanvido, 2000; Horman et al., 2004). Plan variations not only comprise the delivery of sustainable building projects but when delays occur they are also considered to be a form of waste (Koskela, 2000; Liker, 2004).

Theme 8: Questions 30 to 32 – Cost Management of Construction Projects

Cost Control Practices

Q30 – Do you apply cost controls to your project? (22 answered, 10 skipped).



ANSWER CHOICES	RESPONSES	
Always	90.91%	20
Frequently	9.09%	2
Rarely/do not use cost control during projects	0.00%	0
TOTAL		22

Figure 4.48: Application of cost controls

From Figure 4.48, it can be seen that the application of cost control is more overwhelming with 90.91% (20/22) of respondents indicating that they always apply their cost control method and 9.09% (2/22) indicating that they frequently apply cost control methods to their projects. None (0.00%) of the respondents indicated that they rarely or do not use cost control techniques, buttressing the importance placed on cost control by construction project practitioners in the UK. According to Sun et al. (2010), this confirms the suggestion of Sohail et al. (2002) that construction professionals seem to pay more attention to the cost performance of projects than they do to time performance.

Cost Control Techniques

Q31 – For project cost control, which of the following control methods/techniques do you use? (23 answered, 6 skipped).

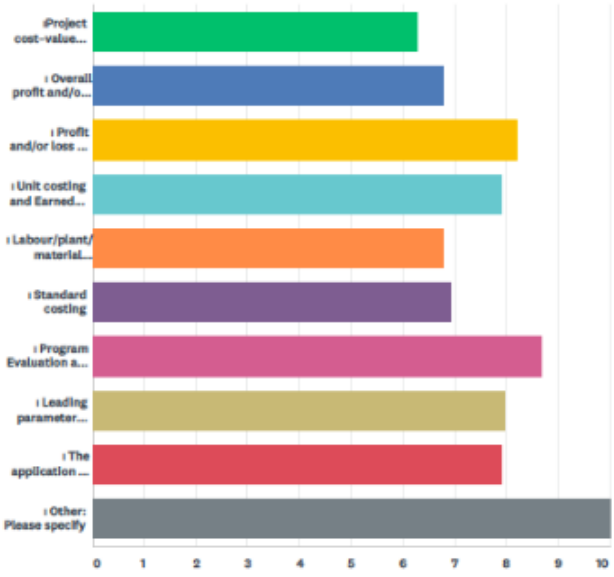


Figure 4.49a: Cost control techniques used

	1	2	3	4	5	6	7	8	9	10	TOTAL	SCORE
Project cost–value reconciliation	7.14% 1	14.29% 2	0.00% 0	14.29% 2	50.00% 7	0.00% 0	0.00% 0	7.14% 1	0.00% 0	7.14% 1	14	6.29
Overall profit and/or loss	0.00% 0	21.43% 3	7.14% 1	42.86% 6	14.29% 2	0.00% 0	7.14% 1	0.00% 0	7.14% 1	0.00% 0	14	6.79
Profit and/or loss on each contract at valuation dates	38.46% 5	7.69% 1	38.46% 5	0.00% 0	0.00% 0	7.69% 1	0.00% 0	7.69% 1	0.00% 0	0.00% 0	13	8.23
Unit costing and Earned value analysis	23.81% 5	14.29% 3	23.81% 5	14.29% 3	19.05% 4	0.00% 0	4.76% 1	0.00% 0	0.00% 0	0.00% 0	21	7.90
Labour/plant/material (actual versus forecast reconciliation)	5.26% 1	26.32% 5	10.53% 2	5.26% 1	31.58% 6	10.53% 2	5.26% 1	0.00% 0	0.00% 0	5.26% 1	19	6.79
Standard costing	0.00% 0	5.88% 1	29.41% 5	35.29% 6	11.76% 2	17.65% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	17	6.94
Program Evaluation and Review Technique (PERT/COST)	28.57% 2	42.86% 3	0.00% 0	28.57% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	7	8.71
Leading parameter method	0.00% 0	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	8.00
The application of principles of Value Engineering	36.36% 4	9.09% 1	9.09% 1	18.18% 2	9.09% 1	18.18% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	11	7.91
Other: Please specify	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	10.00

Figure 4.49b: Cost control techniques used

	For each item, enter the frequency with which each response option was observed:					*Computed values, given the 5 frequency entries:*					
Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII	Item Mean		
1	7	2	0	2	1	12	48	0.800	4.000		Q31
2	2	6	1	3	0	12	43	0.717	3.583		
3	0	0	5	1	5	11	22	0.400	2.000		
4	4	3	5	3	5	20	58	0.580	2.900		
5	6	1	2	5	1	15	51	0.680	3.400		
6	2	6	5	1	0	14	51	0.729	3.643		
7	0	2	0	3	2	7	16	0.457	2.286		
8	0	0	1	0	0	1	3	0.600	3.000		
9	1	2	1	1	4	9	22	0.489	2.444		
10	0	0	0	0	1	1	1	0.200	1.000		

Figure 4.49c: Cost control techniques used

Descriptive Statistics

	N	Mean	Std. Deviation
Project cost-value reconciliation	14	4.7143	2.30146
Overall profit and/or loss	14	4.2143	1.92867
Profit and/or loss on each contract at valuation dates	13	2.7692	2.12736
Unit costing and Earned value analysis	21	3.0952	1.70014
Labour/plant/material (actual versus forecast reconciliation)	19	4.2105	2.22558
Standard costing	17	4.0588	1.19742
Program Evaluation and Review Technique (PERT/COST)	7	2.2857	1.25357
Leading parameter method	1	3.0000	.
The application of principles of Value Engineering	11	3.0909	2.02260
Other: Please specify	1	1.0000	.
Valid N (listwise)	1		

Figure 4.49d: Cost control techniques used

From Figure 4.49, it can be seen that PERT/COST ranks as the most used technique and project cost-value reconciliation the least used. The three clearly leading applications are PERT/COST, profit and/or loss on each contract at valuation dates, and the leading parameter method.

Several techniques have been used, such as other, PERT/COST, leading parameter method, the application of principles of VE, and unit costing and earned value analysis. Respondents might have chosen the response ‘other’ if, for example, they use several methods or one or more techniques together. Olawale and Sun (2010) conducted a survey on the techniques and software packages used for project cost control in the UK.

This question was further analysed in Round 2 of the questionnaires and interviews in the UK.

Q32 – For cost control, which of the following software packages do you use? (22 answered, 10 skipped).

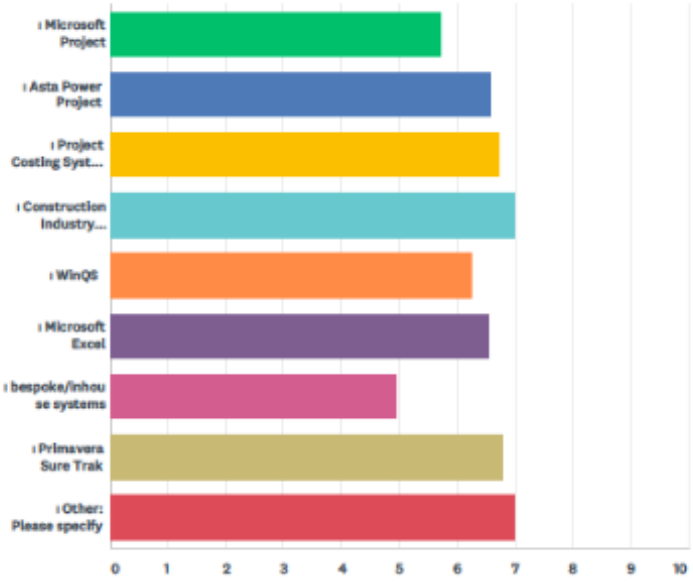


Figure 4.50a: Software packages used for cost control

	1	2	3	4	5	6	7	8	9	TOTAL	SCORE
Microsoft Project	13.64% 3	0.00% 0	4.55% 1	27.27% 6	45.45% 10	4.55% 1	0.00% 0	4.55% 1	0.00% 0	22	5.73
Asta Power Project	10.00% 1	30.00% 3	30.00% 3	10.00% 1	0.00% 0	10.00% 1	0.00% 0	10.00% 1	0.00% 0	10	6.60
Project Costing System (PCS)	13.33% 2	26.67% 4	26.67% 4	13.33% 2	6.67% 1	0.00% 0	13.33% 2	0.00% 0	0.00% 0	15	6.73
Construction Industry Software (COINS)	20.00% 1	0.00% 0	40.00% 2	40.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	7.00
WinQS	0.00% 0	50.00% 2	0.00% 0	0.00% 0	25.00% 1	25.00% 1	0.00% 0	0.00% 0	0.00% 0	4	6.25
Microsoft Excel	13.64% 3	4.55% 1	36.36% 8	31.82% 7	0.00% 0	9.09% 2	4.55% 1	0.00% 0	0.00% 0	22	6.55
bespoke/inhouse systems	10.53% 2	10.53% 2	5.26% 1	5.26% 1	26.32% 5	15.79% 3	10.53% 2	5.26% 1	10.53% 2	19	4.95
Primavera Sure Trak	15.00% 3	40.00% 8	10.00% 2	15.00% 3	10.00% 2	0.00% 0	0.00% 0	5.00% 1	5.00% 1	20	6.80
Other: Please specify	66.67% 4	0.00% 0	0.00% 0	0.00% 0	16.67% 1	0.00% 0	0.00% 0	0.00% 0	16.67% 1	6	7.00

	For each item, enter the frequency with which each response option was observed:					*Computed values, given the 5 frequency entries:*					
Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII		Item Mean	
1	10	6	1	0	3	20	80	0.800		4.000	Q32
2	0	1	3	3	1	8	20	0.500		2.500	
3	1	2	4	4	2	13	35	0.538		2.692	
4	0	2	2	0	1	5	15	0.600		3.000	
5	1	0	0	2	0	3	9	0.600		3.000	
6	0	7	8	1	3	19	57	0.600		3.000	
7	5	1	1	2	2	11	38	0.691		3.455	
8	2	3	2	8	3	18	47	0.522		2.611	
9	1	0	0	0	4	5	9	0.360		1.800	

Figure 4.50b: Software packages used for cost control

Ranks

	Mean Rank
Microsoft Project	3.75
Asta Power Project	4.50
Project Costing System (PCS)	5.00
Construction Industry Software (COINS)	3.50
WinQS	3.75
Microsoft Excel	5.75
bespoke/inhouse systems	8.25
Primavera Sure Trak	6.50
Other: Please specify	4.00

Test Statistics

N	4
Kendall's W[a]	.333
Chi-Square	10.667
df	8
Asymp. Sig.	.221

a. Kendall's Coefficient of Concordance

Figure 4.50c: Software packages used for cost control

From Figure 4.50, it can be seen that the cost control software programs used are COINS, Primavera SureTrak, Project Costing System (PCS), Asta Powerproject, and Microsoft Excel.

This question was further analysed in Round 2 of questionnaires and interviews in the UK.

Theme 9: Question 33 – Cost Overruns

Please answer the following questions to identify the most common factors that lead to project cost overruns.

Q33 – Which of the following are among the most common influencing factors that often lead to project cost overruns? (22 answered, 10 skipped).

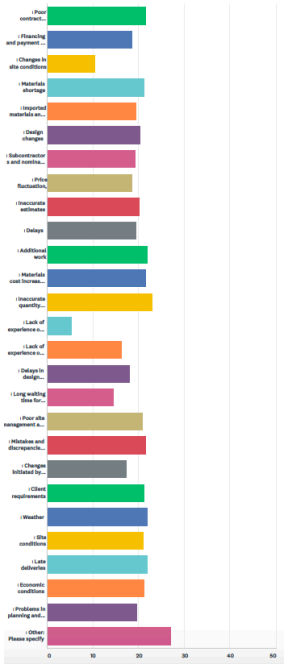


Figure 4.51a: Cost overrun factors

Test Statistics

N	2
Kendall's W[a]	.732
Chi-Square	38.079
df	26
Asymp. Sig.	.060

a. Kendall's Coefficient of Concordance

Item	F equency of 5 esponses	F equency of 4 esponses	F equency of 3 esponses	F equency of 2 esponses	F equency of 1 esponses	Total espondents (N)	We ghted total	RII	Item Mean	
1	3	1	4	3	2	13	39	0.600	3.000	Q33
2	2	0	1	1	1	5	16	0.640	3.200	
3	0	0	0	0	0	0	0	#DIV/0!	#DIV/0!	
4	0	3	1	1	1	6	18	0.600	3.000	
5	1	1	1	0	0	3	12	0.800	4.000	
6	0	0	3	4	1	8	18	0.450	2.250	
7	0	2	0	0	3	5	11	0.440	2.200	
8	1	0	1	2	0	4	12	0.600	3.000	
9	2	2	1	2	0	7	25	0.714	3.571	
10	1	1	0	0	2	4	11	0.550	2.750	
11	0	0	1	1	1	3	6	0.400	2.000	
12	0	1	0	1	1	3	7	0.467	2.333	
13	1	0	1	1	1	4	11	0.550	2.750	
14	0	0	0	0	0	0	0	#DIV/0!	#DIV/0!	
15	2	1	0	0	2	5	16	0.640	3.200	
16	4	0	0	1	0	5	22	0.880	4.400	
17	0	1	0	0	0	1	4	0.800	4.000	
18	0	4	1	1	0	6	21	0.700	3.500	
19	0	0	1	0	1	2	4	0.400	2.000	
20	1	0	1	0	0	2	8	0.800	4.000	
21	1	1	0	1	0	3	11	0.733	3.667	
22	1	1	0	0	1	3	10	0.667	3.333	
23	0	1	0	0	0	1	4	0.800	4.000	
24	0	0	1	0	0	1	3	0.600	3.000	
25	0	0	2	1	0	3	8	0.533	2.667	
26	1	1	2	1	1	6	18	0.600	3.000	
27	0	0	0	0	3	3	3	0.200	1.000	

Figure 4.51b: Cost overrun factors

Descriptive Statistics

	N	Mean	Std. Deviation
Poor contract management	17	6.4706	6.67193
Financing and payment of completed works	11	9.4545	7.03369
Changes in site conditions	4	17.5000	3.00000
Materials shortage	10	6.8000	6.19677
Imported materials and plant items	6	8.5000	5.68331
Design changes	12	7.7500	8.57189
Subcontractors and nominated suppliers	10	8.8000	8.21651
Price fluctuation,	7	9.4286	8.63823
Inaccurate estimates	14	7.9286	7.56982
Delays	9	8.5556	7.45170
Additional work	5	6.0000	5.56776
Materials cost increased by inflation	6	6.5000	4.72229
Inaccurate quantity take-off	6	5.0000	3.74166
Lack of experience of project location	4	22.7500	3.30404
Lack of experience of project type	11	11.7273	10.04083
Delays in design information	9	9.8889	8.55050
Long waiting time for approval of drawings	5	13.6000	8.59069
Poor site management and supervision	10	7.2000	6.39097
Mistakes and discrepancies in design documents	6	6.5000	3.78153
Changes initiated by designers	7	10.7143	7.22759
Client requirements	7	6.8571	3.71612
Weather	7	6.1429	3.23669
Site conditions	3	7.0000	3.00000
Late deliveries	3	6.0000	3.00000
Economic conditions	6	6.8333	5.63619
Problems in planning and design as main causes of change orders	13	8.3846	7.21732
Other: Please specify	3	1.0000	.00000
Valid N (listwise)	2		

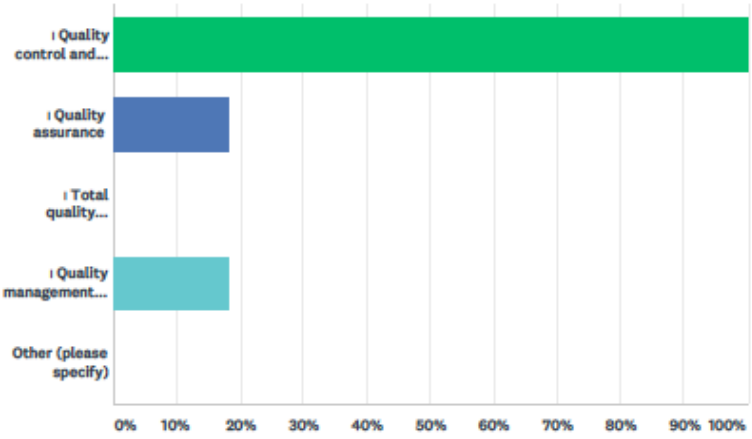
Figure 4.51c: Cost overrun factors

From Figure 4.51, it can seen that 'inaccurate quantity take-off 'ranks highest and a 'lack of experience of the project location' ranks lowest.

Despite the wide application of cost and time control techniques and software, cost and time overruns are still quite common in construction projects.

Theme 10: Questions 34 to 36 – Quality Management and Control

Q34 – Which of the following steps do you consider while doing quality management and control? (22 answered, 10 skipped).



ANSWER CHOICES	RESPONSES	
Quality control and inspection: Quality control implemented in construction: The Specifications and contract drawings, Visual quality checks and Quantifable quality checks	100.00%	22
Quality assurance	18.18%	4
Total quality management (TQM)	0.00%	0
Quality management systems	18.18%	4
Other (please specify)	0.00%	0
Total Respondents: 22		

#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 4.52: Quality management and control steps

Quality schemes include the EFQM (European Foundation for Quality Management) Excellence Model, the Malcolm Baldrige Quality Performance (Malcolm Baldrige National Quality Award (MBNQA)), and Six Sigma.

From Figure 4.52, it can be seen that 100% (22/22) of the respondents consider 'quality control and inspection' as a quality management and control step.

Q35 – Which of the following quality tools have you used in order to improve quality and productivity?

	For each item, enter the frequency with which each response option was observed:					*Computed values, given the 5 frequency entries:*					
Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII		Item Mean	
1	0	2	2	0	0	4	14	0.700		3.500	Q35
2	20	1	0	0	0	21	104	0.990		4.952	
3	0	0	0	0	0	0	0	#DIV/0!		#DIV/0!	
4	0	2	1	0	0	3	11	0.733		3.667	
5	0	2	0	0	0	2	8	0.800		4.000	
6	0	0	0	0	0	0	0	#DIV/0!		#DIV/0!	
7	0	2	1	1	0	4	13	0.650		3.250	
8	0	0	0	0	1	1	1	0.200		1.000	
9	0	0	0	2	0	2	4	0.400		2.000	
10	0	0	2	1	0	3	8	0.533		2.667	
11	1	4	2	1	1	9	30	0.667		3.333	
12	0	0	0	0	3	3	3	0.200		1.000	
13	0	0	1	0	0	1	3	0.600		3.000	

Figure 4.53a: Quality improvement tools

Descriptive Statistics

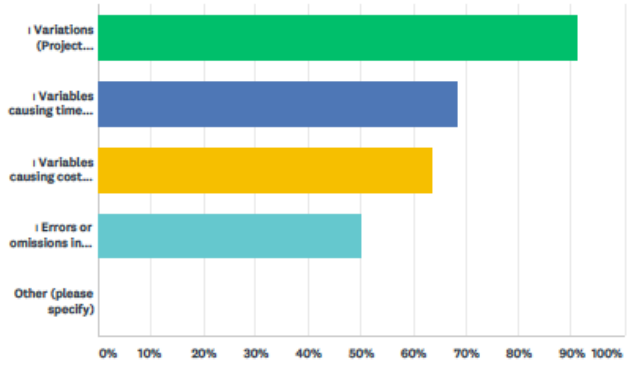
	N	Mean	Std. Deviation
Use of statistical methods/statistical process control (SPC)	5	4.2000	1.64317
Quality control	22	5.1818	1.09702
Quality circles	0		
Zero defects	3	3.6667	.57735
Total quality management (TQM)	2	4.0000	.00000
Baldridge	0		
ISO9000	5	3.8000	1.48324
Continuous Process Improvement	3	6.0000	4.35890
Reengineering	3	4.3333	4.04145
Six sigma	4	3.5000	1.73205
Lean Production	9	3.3333	1.22474
Quality Assignments	3	1.0000	.00000
Other: Please specify	1	3.0000	.
Valid N (listwise)	0		

Figure 4.53b: Quality improvement tools

From Figure 4.53, it can be seen that 'quality assignments' ranks highest and 'continuous process improvement' ranks lowest.

This question was further analysed in Round 2 of the questionnaires and interviews in the UK.

Q36 – Which of the following factors lead to the problem of reduced and low quality? (22 answered, 10 skipped).



ANSWER CHOICES	RESPONSES	
Variations (Project charactrstics, Characteristics of client, Project organization factors)	90.91%	20
Variables causing time overruns	68.18%	15
Variables causing cost overruns	63.64%	14
Errors or omissions in construction work	50.00%	11
Other (please specify)	0.00%	0
Total Respondents: 22		

#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 4.54: Low quality factors

The results in Figure 4.54 show that 'variations' is the most important factor leading to the problem of reduced and low quality as chosen by 90.91% (20/22) of the respondents.

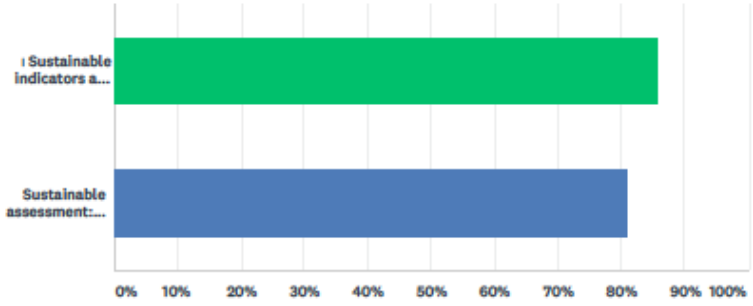
Theme 11: Questions 37 to 38 – Sustainability Management and Control

Q37: Please answer the following questions regarding sustainable measurement and control. Please describe/explain how you manage and control sustainability. (2 answered, 30 skipped).

The respondents' answers regarding the sustainability management and control can be seen below.

#	RESPONSES
1	Sustainability is an important element at all design phase & discussed as part of design group. Sustainability & environment impacts during and post construction are considered & a report prepared accordingly. This report is updated at each stage of the project and shared with the local authority. Also the maintainability and whole life cost considered at design stage.
2	Use of standard materials in quality control, Use of experienced labour.

Q38 –Which of the following factors do you consider regarding sustainability? (21 answered, 11 skipped).



ANSWER CHOICES	RESPONSES	
Sustainable indicators and benchmark: Please explain	85.71%	18
Sustainable assessment: Please explain	80.95%	17
Total Respondents: 21		

#	PLEASE EXPLAIN
1	The sustainability benchmarks in terms of impact on environment or long term impact of constructed items is considered. It is considered a moral & ethical responsibility. Assessment carried out at early design phase, construction phase and at project closeout. Specialist hired to conduct the study.

Figure 4.55: Factors considered by respondents regarding sustainability

From Figure 4.55, it can be seen that 86% (18/21) of the respondents consider 'sustainable indicators and benchmark' as a factor regarding sustainability. According to Ogunbiyi et al. (2014), regarding integrating lean and sustainability factors, Houvila and Koskela (1998) raised the potential and profitability of lean principles to promote sustainable construction and a requirement framework was presented.

Ogunbiyi et al. (2014) conducted research and a questionnaire survey on the impact of LC techniques on sustainable construction in the UK; their results are shown below.

Benefits of synchronising lean and sustainability include:

- Improved corporate image,
- Increased productivity,
- Reduction in waste,
- Reduction in energy consumption,
- Improvement in sustainable innovation,
- Improved process flow,
- Reduction in material usage,
- Reduced cost and lead time,
- Improvement in health and safety,
- Improvement in environmental quality,
- Reduction in water usage,
- Increased sustainable competitive advantage,
- Increased compliance with customers' expectation,
- Increased employee morale and commitment.

Lean principles/techniques for enabling sustainability include:

- Just-in-time,
- Visualisation tool,
- Daily huddle meetings,
- Value analysis,
- Value stream mapping,
- TQM,
- Fail safe for quality,
- 5Ss,
- Total preventive maintenance,
- First run studies,
- Last Planner,
- Concurrent engineering,
- Pull approach,
- Kanban,
- Kaizen,
- Six Sigma.

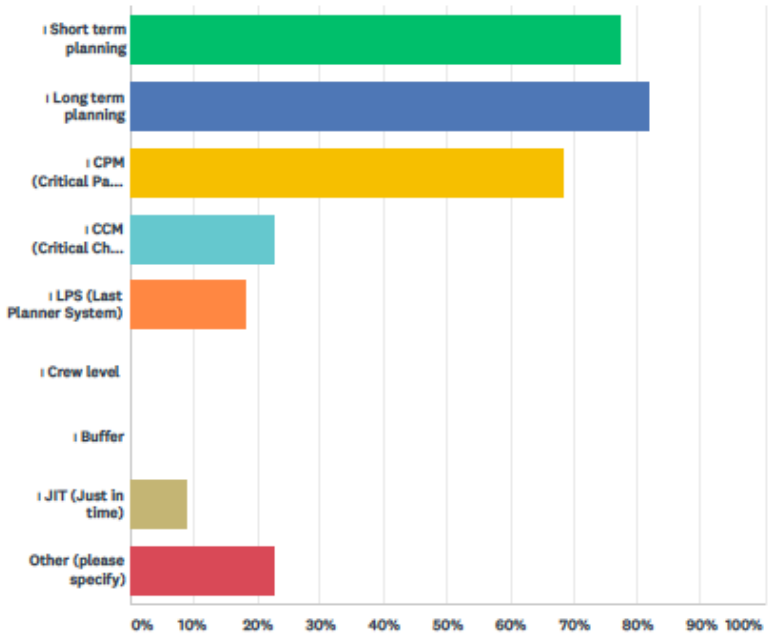
Areas of linkage between LC and sustainability:

- Waste reduction,
- Environmental management,
- Value maximisation,
- Health and safety improvement,
- Performance maximisation,
- Design optimisation,
- Quality improvement,
- Resource management,
- Energy minimisation,
- Elimination of unnecessary process,
- Continuous improvement,
- Cost reduction

Theme 12: Questions 39 to 46 – Development of the Measurement and Control Methods

The adaptation of lean principles with identified enablers is assessed, where a combination of different lean principles and techniques will be considered as the main enablers to develop a new framework for the construction process. Please answer the following questions regarding each of the Plan, Implementation, and Monitoring/Control and Review functions.

Q39 – For construction planning efforts, which of the following methods have been used by you in your company? (22 answered, 10 skipped).



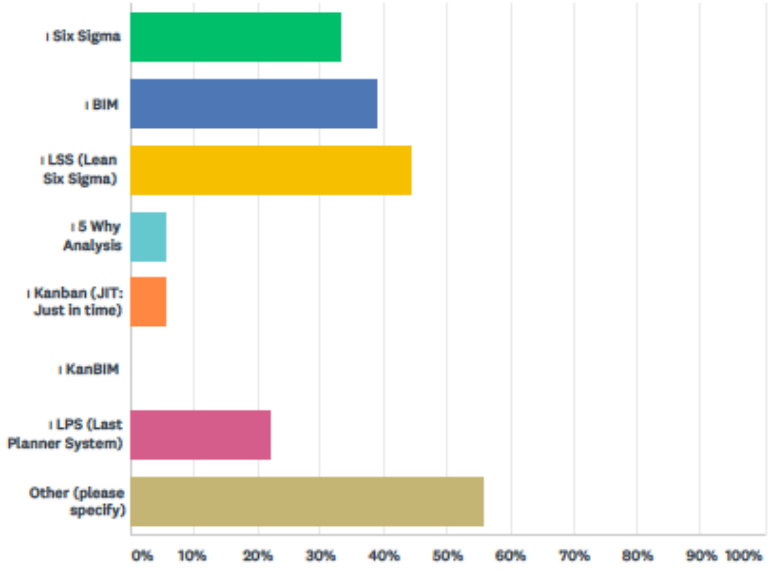
ANSWER CHOICES	RESPONSES	
Short term planning	77.27%	17
Long term planning	81.82%	18
CPM (Critical Path Method)	68.18%	15
CCM (Critical Chain Method)	22.73%	5
LPS (Last Planner System)	18.18%	4
Crew level	0.00%	0
Buffer	0.00%	0
JIT (Just in time)	9.09%	2
Other (please specify)	22.73%	5
Total Respondents: 22		

#	OTHER (PLEASE SPECIFY)
1	sequencing of construction activities, collaborative production planning,process mapping, daily outputs and visual programmes
2	Lean awareness training, Deploy collaborative production/programme planning and design of system, visual management and continuous improvement
3	Traditional methods and techniques
4	Daily meetings In lean do consultation first, from the start know risk and reduce it, save money Collaboration process with all the relevant parties, all the time, geotechnical process Time is the most important factor to save cost Time is critical Program shortening
5	Training, collaborative planning

Figure 4.56: Methods used for planning

As can be seen from Figure 4.56, long-term planning (82%), short-term planning (77%), and CPM (68%) are the three clear leading methods used for planning.

Q40 – For implementation, which of the following methods have you used in your company? (18 answered, 14 skipped).



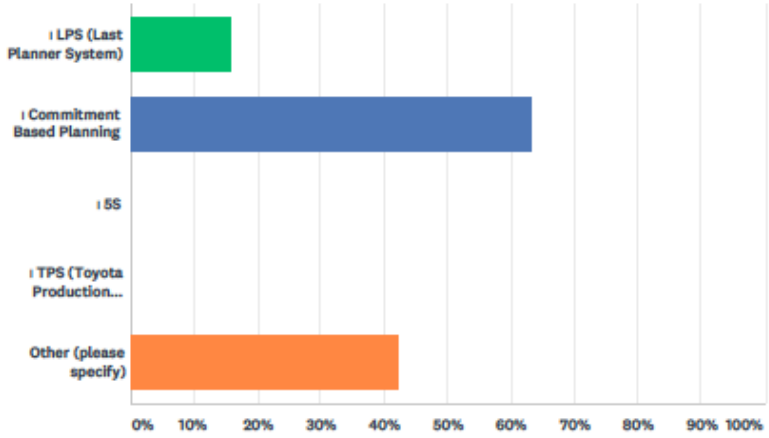
ANSWER CHOICES	RESPONSES	
Six Sigma	33.33%	6
BIM	38.89%	7
LSS (Lean Six Sigma)	44.44%	8
5 Why Analysis	5.56%	1
Kanban (JIT: Just in time)	5.56%	1
KanBIM	0.00%	0
LPS (Last Planner System)	22.22%	4
Other (please specify)	55.56%	10
Total Respondents: 18		

#	OTHER (PLEASE SPECIFY)
1	Implementing lean visual management
2	Implementing collaborative production planning Implementing lean visual management Plant management
3	Traditional techniques
4	Traditional methods
5	Value management Value engineering - labour cost
6	other
7	Value stream mapping, LSS(DMAICT)
8	other methods
9	other
10	Other methods

Figure 4.57: Methods used for implementation

As can be seen from Figure 4.57, LSS (45%), BIM (39%), and Six Sigma (34%) are the three clear leading methods used for implementation.

Q41 – For monitoring/control, which of the following methods have you used in your company? (19 answered, 13 skipped).



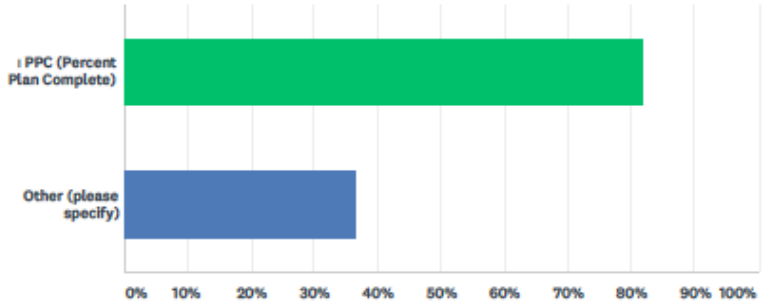
ANSWER CHOICES	RESPONSES	
LPS (Last Planner System)	15.79%	3
Commitment Based Planning	63.16%	12
5S	0.00%	0
TPS (Toyota Production System)	0.00%	0
Other (please specify)	42.11%	8
Total Respondents: 19		

#	OTHER (PLEASE SPECIFY)
1	daily outputs and comprehensive quality checks and daily reports
2	Creating dashboard reports/continuous improvement Maintaining benefits realised Feedback from the team
3	Traditional methods
4	Traditional methods
5	Improvement workshops, Process improvement, strategy development, lean visual management and continuous improvement
6	other methods
7	other
8	Only by control of maps and eye and lab control.

Figure 4.58: Methods used for monitoring and control

As can be seen from Figure 4.58, commitment-based planning (63%), other methods (42%), and LPS (16%) are the three clear leading methods used for monitoring and control.

Q42 – How do you review your construction process? (22 answered, 10 skipped).



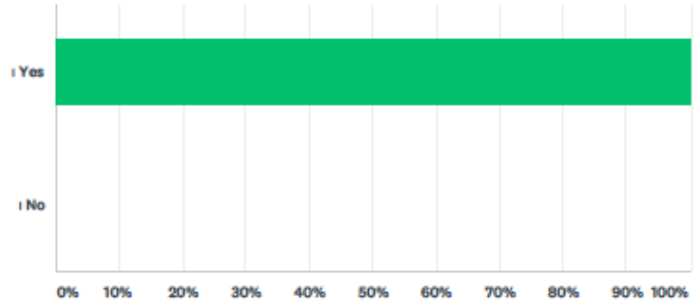
ANSWER CHOICES	RESPONSES	
PPC (Percent Plan Complete)	81.82%	18
Other (please specify)	36.36%	8
Total Respondents: 22		

#	OTHER (PLEASE SPECIFY)
1	Feedback and continued measure and analysis
2	Feedback from the team Trend analysis Transferability
3	In traditional way
4	Traditional methods
5	Other
6	Lean improvement plan
7	other
8	Also Financial control.

Figure 4.59: Methods used for review

As can be seen from Figure 4.59, PPC (82%) is the clear leading method used for review.

Q43 – Do you measure reasons for failure of the project process? (22 answered, 10 skipped).

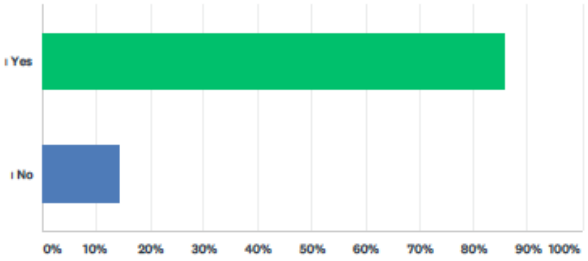


ANSWER CHOICES	RESPONSES	
Yes	100.00%	22
No	0.00%	0
TOTAL		22

Figure 4.60: Measurement of reasons for failure of the project

From the results to this question, it appears that 100% of the respondents measure a reason for failure of the project process (Figure 4.60).

Q44 – Do you use root cause analysis? (21 answered, 11 skipped).

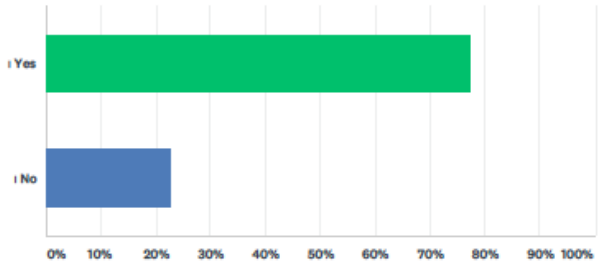


ANSWER CHOICES	RESPONSES	
Yes	85.71%	18
No	14.29%	3
TOTAL		21

Figure 4.61: Root cause analysis

From the results for this question, it appears that 86% of the respondents use root cause analysis (Figure 4.61).

Q45 – At the operational level, do you measure cost performance? (22 answered, 10 skipped).

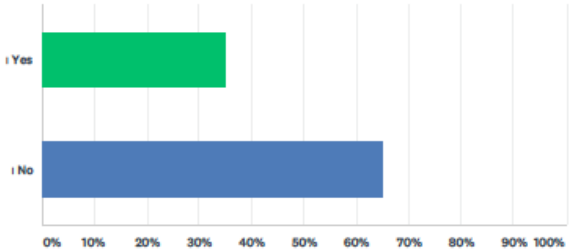


ANSWER CHOICES	RESPONSES	
Yes	77.27%	17
No	22.73%	5
TOTAL		22

Figure 4.62: Cost performance measurement

From the results for this question, it appears that 77% of the respondents measure cost performance at the operational level (Figure 4.62).

Q46 – In assigning tasks, is shielding essential/important? (20 answered, 12 skipped).



ANSWER CHOICES	RESPONSES	
Yes	35.00%	7
No	65.00%	13
TOTAL		20

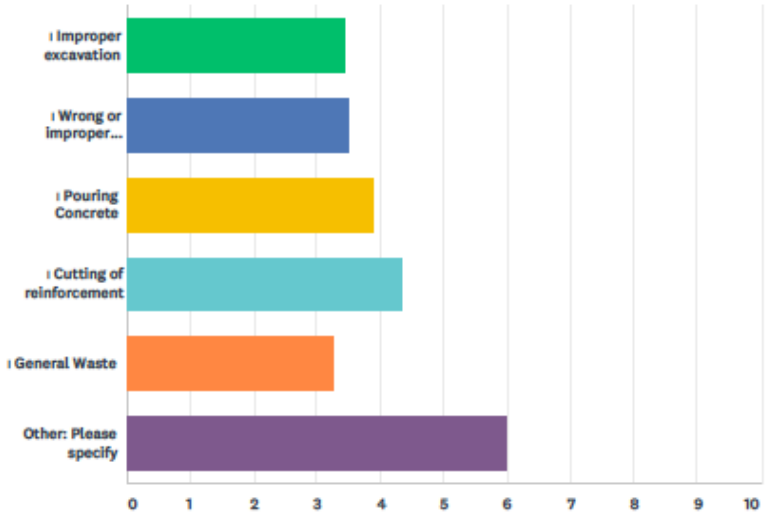
Figure 4.63: Importance of shielding

From the results for this question, it appears that 65% of the respondents believe that in assigning tasks, shielding is essential and important (Figure 4.63).

Theme 13: Question 47 – Waste in the Production Process

For total improvement in lean production, the basic procedure is to recognise waste in the process, therefore removing it. Waste in the production process could be the waste of overproduction of goods not needed, waiting by employees for procedures, unnecessary motions, transporting (or conveyance), overprocessing (or inappropriate processing), unnecessary inventory, and defects in products.

Q47 – Regarding the following issues and operations related to waste in Iranian sites, please can you rank/order from the most important to the least important? (12 answered, 20 skipped).



	1	2	3	4	5	6	TOTAL	SCORE
Improper excavation	22.22% 2	11.11% 1	0.00% 0	33.33% 3	22.22% 2	11.11% 1	9	3.44
Wrong or improper welding	0.00% 0	20.00% 2	40.00% 4	10.00% 1	30.00% 3	0.00% 0	10	3.50
Pouring Concrete	0.00% 0	30.00% 3	30.00% 3	40.00% 4	0.00% 0	0.00% 0	10	3.90
Cutting of reinforcement	33.33% 3	22.22% 2	11.11% 1	11.11% 1	22.22% 2	0.00% 0	9	4.33
General Waste	16.67% 2	8.33% 1	16.67% 2	8.33% 1	41.67% 5	8.33% 1	12	3.25
Other: Please specify	100.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	6.00

Figure 4.64a: Issues and operations related to waste on site

	For each item, enter the frequency with which each response option was observed:					*Computed values, given the 5 frequency entries:*						
Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII		Item Mean		
1	2	3	0	1	2	8	26	0.650		3.250		Q47
2	3	1	4	2	0	10	35	0.700		3.500		
3	0	4	3	3	0	10	31	0.620		3.100		
4	2	1	1	2	3	9	24	0.533		2.667		
5	5	1	2	1	2	11	39	0.709		3.545		
6	0	0	0	0	2	2	2	0.200		1.000		

Figure 4.64b: Issues and operations related to waste on site

Correlations

			Improper excavation	Wrong or improper welding	Pouring Concrete	Cutting of reinforcement	General Waste	Other: Please specify
Kendall's tau_b	Improper excavation	Correlation Coefficient	1.000	.204	.000	.032	-.222	.
		Sig. (2-tailed)	.	.494	1.000	.912	.440	.
		N	9	9	9	9	9	2
	Wrong or improper welding	Correlation Coefficient	.204	1.000	.471	-.136	-.160	.
		Sig. (2-tailed)	.494	.	.107	.648	.562	.
		N	9	10	10	9	10	2
	Pouring Concrete	Correlation Coefficient	.000	.471	1.000	-.035	-.358	.
		Sig. (2-tailed)	1.000	.107	.	.909	.204	.
		N	9	10	10	9	10	2
	Cutting of reinforcement	Correlation Coefficient	.032	-.136	-.035	1.000	-.191	.
		Sig. (2-tailed)	.912	.648	.909	.	.508	.
		N	9	9	9	9	9	2
	General Waste	Correlation Coefficient	-.222	-.160	-.358	-.191	1.000	.
		Sig. (2-tailed)	.440	.562	.204	.508	.	.
		N	9	10	10	9	12	2
	Other: Please specify	Correlation Coefficient	.	.	.	.	.	.
		Sig. (2-tailed)	.	.	.	.	.	.
		N	2	2	2	2	2	2
Spearman's rho	Improper excavation	Correlation Coefficient	1.000	.203	-.081	.057	-.454	.
		Sig. (2-tailed)	.	.601	.836	.884	.219	.
		N	9	9	9	9	9	2
	Wrong or improper welding	Correlation Coefficient	.203	1.000	.569	-.284	-.256	.
		Sig. (2-tailed)	.601	.	.086	.459	.476	.
		N	9	10	10	9	10	2
	Pouring Concrete	Correlation Coefficient	-.081	.569	1.000	.000	-.464	.
		Sig. (2-tailed)	.836	.086	.	1.000	.176	.
		N	9	10	10	9	10	2
	Cutting of reinforcement	Correlation Coefficient	.057	-.284	.000	1.000	-.188	.
		Sig. (2-tailed)	.884	.459	1.000	.	.629	.
		N	9	9	9	9	9	2
	General Waste	Correlation Coefficient	-.454	-.256	-.464	-.188	1.000	.
		Sig. (2-tailed)	.219	.476	.176	.629	.	.
		N	9	10	10	9	12	2
	Other: Please specify	Correlation Coefficient	.	.	.	.	.	.
		Sig. (2-tailed)	.	.	.	.	.	.
		N	2	2	2	2	2	2

Figure 4.64c: Issues and operations related to waste on site

Ranks

	Mean Rank
Improper excavation	5.00
Wrong or improper welding	4.00
Pouring Concrete	3.00
Cutting of reinforcement	4.00
General Waste	4.00
Other: Please specify	1.00

Test Statistics

N	2
Kendall's W[a]	.543
Chi-Square	5.429
df	5
Asymp. Sig.	.366

a. Kendall's Coefficient of Concordance

Descriptive Statistics

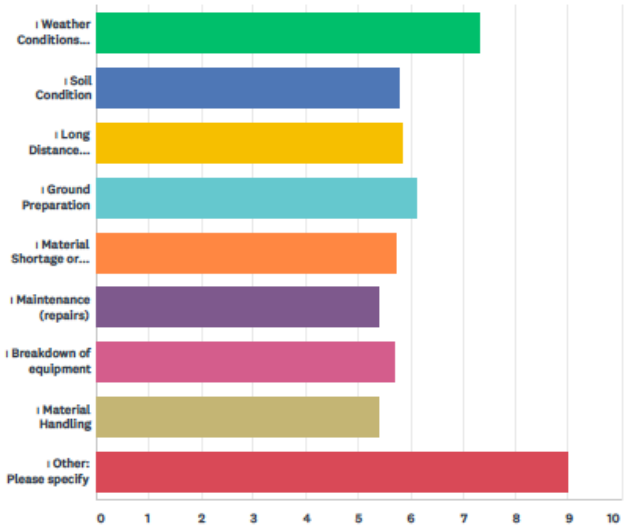
	N	Mean	Std. Deviation
Improper excavation	9	3.5556	1.81046
Wrong or improper welding	10	3.5000	1.17851
Pouring Concrete	10	3.1000	.87560
Cutting of reinforcement	9	2.6667	1.65831
General Waste	12	3.7500	1.71226
Other: Please specify	2	1.0000	.00000
Valid N (listwise)	2		

Figure 4.64d: Issues and operations related to waste on site

From Figure 4.64 it can be seen that cutting of reinforcement ranks highest and general waste ranks lowest.

Theme 14: Question 48 – Waste and Value-Loss

Q48 – In the following, the waste and value-loss found on site are explained. Identification can be an excellent pointer and guide for the possible impact of the Lean Construction Philosophy. Please can you rank/order from the most important to the least important? (21 answered, 11 skipped).



	1	2	3	4	5	6	7	8	9	TOTAL	SCORE
Weather Conditions (Rain, Snow, etc)	27.78% 5	16.67% 3	33.33% 6	16.67% 3	0.00% 0	0.00% 0	5.56% 1	0.00% 0	0.00% 0	18	7.33
Soil Condition	0.00% 0	21.43% 3	14.29% 2	21.43% 3	28.57% 4	0.00% 0	7.14% 1	7.14% 1	0.00% 0	14	5.79
Long Distance Equipment Displacement	0.00% 0	16.67% 2	33.33% 4	16.67% 2	16.67% 2	0.00% 0	0.00% 0	16.67% 2	0.00% 0	12	5.83
Ground Preparation	21.05% 4	5.26% 1	15.79% 3	5.26% 1	36.84% 7	10.53% 2	0.00% 0	5.26% 1	0.00% 0	19	6.11
Material Shortage or Deficiency	11.76% 2	23.53% 4	5.88% 1	23.53% 4	11.76% 2	0.00% 0	5.88% 1	0.00% 0	17.65% 3	17	5.71
Maintenance (repairs)	0.00% 0	20.00% 2	0.00% 0	30.00% 3	10.00% 1	30.00% 3	10.00% 1	0.00% 0	0.00% 0	10	5.40
Breakdown of equipment	25.00% 5	5.00% 1	10.00% 2	15.00% 3	10.00% 2	5.00% 1	20.00% 4	5.00% 1	5.00% 1	20	5.70
Material Handling	0.00% 0	26.67% 4	13.33% 2	6.67% 1	20.00% 3	13.33% 2	0.00% 0	20.00% 3	0.00% 0	15	5.40
Other: Please specify	100.00% 4	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	9.00

Figure 4.65a: Waste and value-loss on site

	For each item, enter the frequency with which each response option was observed:					*Computed values, given the 5 frequency entries:*						
Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII		Item Mean		
1	0	3	6	3	5	17	41	0.482		2.412		Q48
2	4	3	2	3	0	12	44	0.733		3.667		
3	2	2	4	2	0	10	34	0.680		3.400		
4	7	1	3	1	4	16	54	0.675		3.375		
5	2	4	1	4	2	13	39	0.600		3.000		
6	1	3	0	2	0	6	21	0.700		3.500		
7	2	3	2	1	5	13	35	0.538		2.692		
8	3	1	2	4	0	10	33	0.660		3.300		
9	0	0	0	0	4	4	4	0.200		1.000		

Figure 4.65b: Waste and value-loss on site

Correlations

			Weather Conditions (Rain, Snow, etc)	Soil Condition	Long Distance Equipment Displacement	Ground Preparation	Material Shortage or Deficiency	Maintenance (repairs)	Breakdown of equipment	Material Handling	Other: Please specify
Kendall's tau_b	Weather Conditions (Rain, Snow, etc)	Correlation Coefficient	1.000	-.018	.158	.125	.177	-.033	.147	.144	.
		Sig. (2-tailed)	.	.941	.565	.538	.394	.910	.448	.523	.
		N	18	12	10	17	16	9	18	14	4
	Soil Condition	Correlation Coefficient	-.018	1.000	.079	.444	.184	-.222	.073	-.328	.
		Sig. (2-tailed)	.941	.	.773	.063	.466	.440	.750	.263	.
		N	12	14	10	12	11	9	13	9	4
	Long Distance Equipment Displacement	Correlation Coefficient	.158	.079	1.000	-.106	.156	.104	-.123	-.367	.
		Sig. (2-tailed)	.565	.773	.	.679	.567	.704	.612	.216	.
		N	10	10	12	11	10	10	12	9	4
	Ground Preparation	Correlation Coefficient	.125	.444	-.106	1.000	-.184	-.420	-.245	-.164	.
		Sig. (2-tailed)	.538	.063	.679	.	.357	.148	.186	.439	.
		N	17	12	11	19	17	9	19	15	4
	Material Shortage or Deficiency	Correlation Coefficient	.177	.184	.156	-.184	1.000	.250	.349	.015	.
		Sig. (2-tailed)	.394	.466	.567	.357	.	.425	.073	.949	.
		N	16	11	10	17	17	8	17	13	4
	Maintenance (repairs)	Correlation Coefficient	-.033	-.222	.104	-.420	.250	1.000	.649*	.170	.
		Sig. (2-tailed)	.910	.440	.704	.148	.425	.	.017	.570	.
		N	9	9	10	9	8	10	10	9	4
	Breakdown of equipment	Correlation Coefficient	.147	.073	-.123	-.245	.349	.649*	1.000	.419*	.
		Sig. (2-tailed)	.448	.750	.612	.186	.073	.017	.	.045	.
		N	18	13	12	19	17	10	20	15	4
	Material Handling	Correlation Coefficient	.144	-.328	-.367	-.164	.015	.170	.419*	1.000	.
		Sig. (2-tailed)	.523	.263	.216	.439	.949	.570	.045	.	.
		N	14	9	9	15	13	9	15	15	4
	Other: Please specify	Correlation Coefficient	.	.	.	.	.	.	.	.	.
		Sig. (2-tailed)	.	.	.	.	.	.	.	.	.
		N	4	4	4	4	4	4	4	4	4

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 4.65c: Waste and value-loss on site

Ranks

	Mean Rank
Weather Conditions (Rain, Snow, etc)	4.00
Soil Condition	5.00
Long Distance Equipment Displacement	4.50
Ground Preparation	4.25
Material Shortage or Deficiency	8.50
Maintenance (repairs)	5.50
Breakdown of equipment	6.75
Material Handling	5.50
Other: Please specify	1.00

Test Statistics

N	4
Kendall's W[a]	.560
Chi-Square	17.933
df	8
Asymp. Sig.	.022

a. Kendall's Coefficient of Concordance

Descriptive Statistics

	N	Mean	Std. Deviation
Weather Conditions (Rain, Snow, etc)	18	2.6667	1.53393
Soil Condition	14	4.2143	1.80506
Long Distance Equipment Displacement	12	4.1667	2.03753
Ground Preparation	19	3.8947	2.02470
Material Shortage or Deficiency	17	4.2941	2.73324
Maintenance (repairs)	10	4.6000	1.71270
Breakdown of equipment	20	4.3000	2.63778
Material Handling	15	4.6000	2.26148
Other: Please specify	4	1.0000	.00000
Valid N (listwise)	4		

Figure 4.65d: Waste and value-loss on site

From Figure 4.65, it can be seen that weather conditions rank highest and material handling ranks lowest.

According to Abdulmalek et al. (2007), TPS or Lean Manufacturing focuses on pinpointing the major sources of waste, and then using tools such as JIT, production smoothing, setup reduction, and others to eliminate it. The most common lean tools are JIT, kanban, TPM, TQM, and 5Ss.

VSM is a way of collecting all actions (value-added) that are required to bring a product (or a group of products that use the same resources) through the main flows, starting with raw material and ending with the customer (Rotherham and Shook, 1999). These actions consider the flow of both information and materials within the overall supply chain. The goal of VSM is to identify all types of waste in the value stream and to take steps to try and eliminate these (Rotherham and Shook, 1999).

According to Salem et al. (2006), the combined effect of on-site, one-of-a-kind, and complex production is uncertainty. In a construction project, 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.

Theme 15: Questions 49 to 53 – Types of Waste

As shown in the following questions and based on the present literature, several types of waste in the construction process of construction projects are recognised, which can be eliminated by using the proposed construction process. The following waste types are the results of the literature review done by the researcher. The purpose of this study is to elaborate on construction waste.

Q49 – From the most important to the least important, please can you rank/order the following types of waste which are mostly relevant to the activities during the construction phase? (21 answered, 11 skipped).

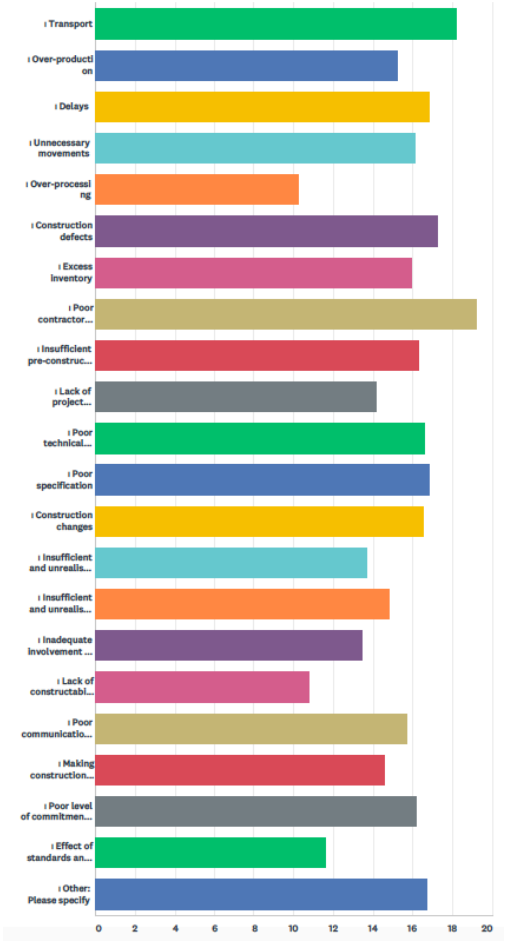


Figure 4.66a: Types of waste

Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII		Item Mean		
1	1	0	1	2	3	7	15	0.429		2.143		Q49
2	1	0	0	0	0	1	5	1.000		5.000		
3	0	1	0	0	2	3	6	0.400		2.000		
4	0	0	0	1	1	2	3	0.300		1.500		
5	0	0	0	0	0	0	0	#DIV/0!		#DIV/0!		
6	1	1	0	2	0	4	13	0.650		3.250		
7	0	1	0	0	1	2	5	0.500		2.500		
8	1	0	3	1	1	6	17	0.567		2.833		
9	3	0	3	2	0	8	28	0.700		3.500		
10	2	0	1	2	1	6	18	0.600		3.000		
11	1	4	0	0	1	6	22	0.733		3.667		
12	0	2	3	0	0	5	17	0.680		3.400		
13	1	0	1	2	0	4	12	0.600		3.000		
14	7	3	1	0	0	11	50	0.909		4.545		
15	0	8	2	2	0	12	42	0.700		3.500		
16	1	0	0	2	1	4	10	0.500		2.500		
17	0	0	1	0	1	2	4	0.400		2.000		
18	1	0	2	1	1	5	14	0.560		2.800		
19	1	0	1	1	2	5	12	0.480		2.400		
20	0	1	1	2	1	5	12	0.480		2.400		
21	0	0	0	1	1	2	3	0.300		1.500		
22	0	0	0	0	3	3	3	0.200		1.000		

Figure 4.66b: Types of waste

Descriptive Statistics

	N	Mean	Std. Deviation
Transport	10	4.8000	4.44222
Over-production	4	7.7500	2.21736
Delays	6	6.1667	5.11534
Unnecessary movements	6	6.8333	4.53505
Over-processing	4	12.7500	6.39661
Construction defects	8	5.7500	4.09704
Excess inventory	4	7.0000	5.47723
Poor contractor briefing	8	3.7500	2.05287
Insufficient pre-construction meetings	12	6.6667	5.17570
Lack of project definition	11	8.8182	7.38672
Poor technical knowledge	10	6.4000	4.47710
Poor specification	7	6.1429	5.01427
Construction changes	7	6.4286	4.96176
Insufficient and unrealistic constraints of project time	18	9.3333	6.91120
Insufficient and unrealistic constraints of project cost	19	8.1579	6.93031
Inadequate involvement of other professionals and teamwork during the construction stage	9	9.5556	7.50185
Lack of constructability review of construction	8	12.2500	7.18630
Poor communication between construction team	11	7.2727	5.69370
Making construction decisions on cost and not value of work	10	8.4000	7.35149
Poor level of commitment to quality improvement	10	6.8000	5.30827
Effect of standards and construction code on quality	7	11.4286	6.45128
Other: Please specify	4	6.2500	10.50000
Valid N (listwise)	4		

Test Statistics

N	4
Kendall's W[a]	.516
Chi-Square	43.364
df	21
Asymp. Sig.	.003

a. Kendall's Coefficient of Concordance

Figure 4.66c: Types of waste

From Figure 4.66, it can be seen that poor contractor briefing ranks highest and over-processing ranks lowest.

To reduce waste, improvement should be focused on eliminating non-value-adding or flow activities and to make conversion or value adding activities more efficient. Waste in the production process comes in many forms, for example Ohno's seven wastes (1998):

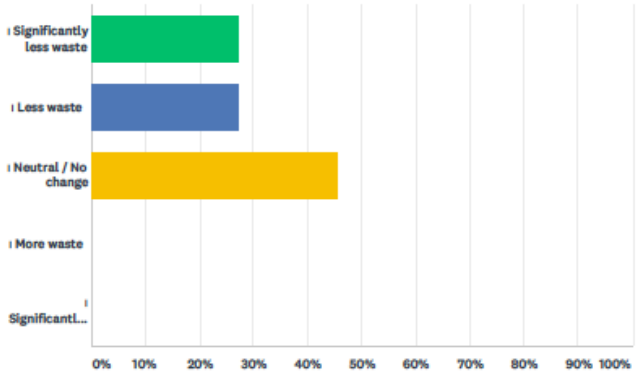
(1) the waste of overproduction of goods not needed (producing more or doing more than is needed);
(2) waiting by employees for a procedure;
(3) unnecessary motions;
(4) transporting (or conveyance);
(5) overprocessing (or inappropriate processing);
(6) unnecessary inventory; and
(7) defects in products that must be corrected.

Womack and Jones (1996) added to this list 'goods and services that do not meet customer needs'; Terry and Smith (2011) also suggested skills misuse could also be considered as waste.

Waste in construction impacts in many ways, not least regarding (Koskela et al., 2013):

(1) Quality costs;
(2) External quality cost during facility use;
(3) Lack of constructability;
(4) Variation in material requirement (poor materials management);
(5) Excess consumption of materials on site;
(6) Working time used for non-value-adding activities on site; and
(7) Lack of safety.

Q50 – Since adopting the Last Planner System, what impact have you seen on waste on site? (11 answered, 21 skipped).

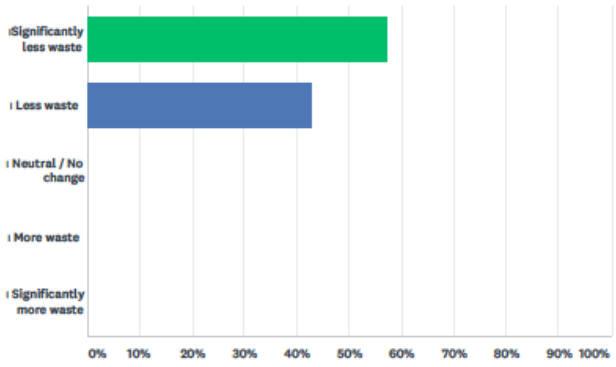


ANSWER CHOICES	RESPONSES	
Significantly less waste	27.27%	3
Less waste	27.27%	3
Neutral / No change	45.45%	5
More waste	0.00%	0
Significantly more waste	0.00%	0
TOTAL		11

Figure 4.67: Impact on waste by adopting the LPS

Since adopting LPS, 45% of the respondents mentioned they have seen neutral/no change on waste on site, while 27.27% mentioned significantly less waste and less waste, respectively (Figure 4.67).

Q51 – By developing and adopting new construction control, measurement, and performance methods, how do you assess/evaluate the impact on waste on site? (21 answered, 11 skipped).



ANSWER CHOICES	RESPONSES	
Significantly less waste	57.14%	12
Less waste	42.86%	9
Neutral / No change	0.00%	0
More waste	0.00%	0
Significantly more waste	0.00%	0
TOTAL		21

Figure 4.68: Impact on waste of development of new methods

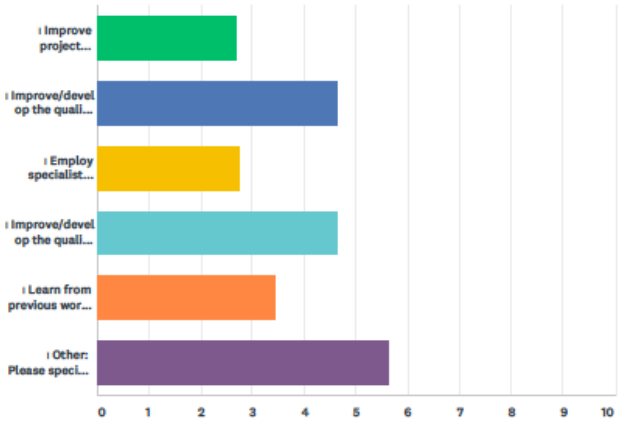
From Figure 4.68 it can be seen that 57% of the respondents mentioned that following development and adoption of new methods, there is significantly less waste on site.

Q52 – By adopting the new methods, which of the wastes mentioned in this questionnaire do you think will be eliminated from the construction process? Please also write a list of other wastes that would be eliminated or reduced as a result of adopting the new methods and give your idea regarding the impact on construction works. (2 answered, 30 skipped).

#	RESPONSES
1	N/A
2	Question 49

Question 49 was regarding types of waste; respondents were asked to rank/order the types of waste which are mostly relevant to activities during the construction phase, from the most important to the least important.

Q53 – For improving the reliability of planning, can you rate the significance of the following techniques? (28 answered, 4 skipped).



	1	2	3	4	5	6	TOTAL	SCORE
Improve project planner's abilities	7.14% 2	3.57% 1	7.14% 2	25.00% 7	46.43% 13	10.71% 3	28	2.68
Improve/develop the quality of material	30.43% 7	39.13% 9	8.70% 2	13.04% 3	4.35% 1	4.35% 1	23	4.65
Employ specialist teams	4.35% 1	4.35% 1	21.74% 5	13.04% 3	43.48% 10	13.04% 3	23	2.74
Improve/develop the quality of labour	19.23% 5	42.31% 11	23.08% 6	15.38% 4	0.00% 0	0.00% 0	26	4.65
Learn from previous works and projects	3.85% 1	3.85% 1	42.31% 11	34.62% 9	15.38% 4	0.00% 0	26	3.46
Other: Please specify	87.50% 7	0.00% 0	0.00% 0	12.50% 1	0.00% 0	0.00% 0	8	5.63

Figure 4.69a: Improving the reliability of planning

	For each item, enter the frequency with which each response option was observed:					*Computed values, given the 5 frequency entries:*					
Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII		Item Mean	
1	13	7	2	1	2	25	103	0.824		4.120	Q53
2	1	3	2	9	7	22	48	0.436		2.182	
3	10	3	5	1	1	20	80	0.800		4.000	
4	0	4	6	11	5	26	61	0.469		2.346	
5	4	9	11	1	1	26	92	0.708		3.538	
6	0	1	0	0	7	8	11	0.275		1.375	

Figure 4.69b: Improving the reliability of planning

Correlations

			Improve project planner's abilities	Improve/develop the quality of material	Employ specialist teams	Improve/develop the quality of labour	Learn from previous works and projects	Other: Please specify
Kendall's tau_b	Improve project planner's abilities	Correlation Coefficient	1.000	.072	-.010	-.141	.144	-.081
		Sig. (2-tailed)	.	.685	.954	.403	.398	.819
		N	28	23	23	26	26	8
	Improve/develop the quality of material	Correlation Coefficient	.072	1.000	-.021	-.011	-.134	.
		Sig. (2-tailed)	.685	.	.907	.952	.459	.
		N	23	23	23	23	23	7
	Employ specialist teams	Correlation Coefficient	-.010	-.021	1.000	.421*	.005	.
		Sig. (2-tailed)	.954	.907	.	.020	.976	.
		N	23	23	23	23	23	7
	Improve/develop the quality of labour	Correlation Coefficient	-.141	-.011	.421*	1.000	-.111	.
		Sig. (2-tailed)	.403	.952	.020	.	.517	.
		N	26	23	23	26	26	7
	Learn from previous works and projects	Correlation Coefficient	.144	-.134	.005	-.111	1.000	.
		Sig. (2-tailed)	.398	.459	.976	.517	.	.
		N	26	23	23	26	26	7
	Other: Please specify	Correlation Coefficient	-.081	.	.	.	.	1.000
		Sig. (2-tailed)	.819	.	.	.	.	.
		N	8	7	7	7	7	8
Spearman's rho	Improve project planner's abilities	Correlation Coefficient	1.000	.048	-.019	-.173	.190	-.087
		Sig. (2-tailed)	.	.829	.933	.398	.352	.838
		N	28	23	23	26	26	8
	Improve/develop the quality of material	Correlation Coefficient	.048	1.000	-.025	-.024	-.158	.
		Sig. (2-tailed)	.829	.	.909	.912	.470	.
		N	23	23	23	23	23	7
	Employ specialist teams	Correlation Coefficient	-.019	-.025	1.000	.488*	-.026	.
		Sig. (2-tailed)	.933	.909	.	.018	.906	.
		N	23	23	23	23	23	7
	Improve/develop the quality of labour	Correlation Coefficient	-.173	-.024	.488*	1.000	-.127	.
		Sig. (2-tailed)	.398	.912	.018	.	.537	.
		N	26	23	23	26	26	7
	Learn from previous works and projects	Correlation Coefficient	.190	-.158	-.026	-.127	1.000	.
		Sig. (2-tailed)	.352	.470	.906	.537	.	.
		N	26	23	23	26	26	7
	Other: Please specify	Correlation Coefficient	-.087	.	.	.	.	1.000
		Sig. (2-tailed)	.838	.	.	.	.	.
		N	8	7	7	7	7	8

*. Correlation is significant at the 0.05 level (2-tailed).

Ranks

	Mean Rank
Improve project planner's abilities	5.00
Improve/develop the quality of material	3.00
Employ specialist teams	5.43
Improve/develop the quality of labour	2.57
Learn from previous works and projects	4.00
Other: Please specify	1.00

Test Statistics

N	7
Kendall's W[a]	.776
Chi-Square	27.163
df	5
Asymp. Sig.	.000

a. Kendall's Coefficient of Concordance

Descriptive Statistics

	N	Mean	Std. Deviation
Improve project planner's abilities	28	4.3214	1.30678
Improve/develop the quality of material	23	2.3478	1.40158
Employ specialist teams	23	4.2609	1.32175
Improve/develop the quality of labour	26	2.3462	.97744
Learn from previous works and projects	26	3.5385	.94787
Other: Please specify	8	1.3750	1.06066
Valid N (listwise)	7		

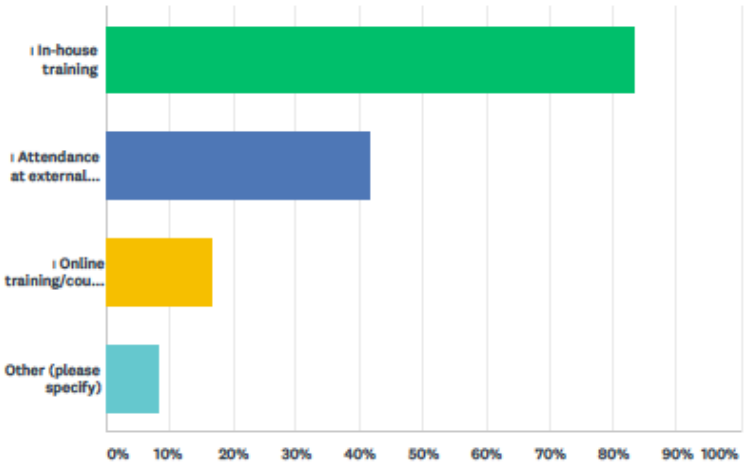
Figure 4.69c: Improving the reliability of planning

From Figure 4.69, it can seen that 'improve/develop the quality of material' ranks highest and 'improve project planner's abilities' ranks lowest.

This question was further analysed in Round 2 of the questionnaires and interviews in the UK.

Theme 16: Question 54 – Training (continuous learning and training)

Q54 – If you use the Last Planner System, what sort of training has your staff undertaken? (12 answered, 20 skipped).



ANSWER CHOICES	RESPONSES	
In-house training	83.33%	10
Attendance at external workshops courses	41.67%	5
Online training/courses	16.67%	2
Other (please specify)	8.33%	1
Total Respondents: 12		

#	OTHER (PLEASE SPECIFY)
1	ANY OR ALL OF THE ABOVE ARE ADEQUATE PROVIDED THEY ARE DONE WELL

Figure 4.70: Training undertaken by staff

From Figure 4.70, it can be seen that in-house training ranks highest and online training/courses rank lowest.

Theme 17: Questions 55 to 58 – Inhibiting Factors and Mitigating Measures

This section focuses on identifying the top factors inhibiting the project control effort of construction project practitioners.

Based on the following list of the most important/commonly identified inhibiting factors, please answer the following questions. The following is a list of identified project cost and time control inhibiting factors and their classification.

Q55 – Please rate the level of importance for each of the following factors in affecting your ability to effectively control the time of your construction projects (21 answered, 11 skipped).

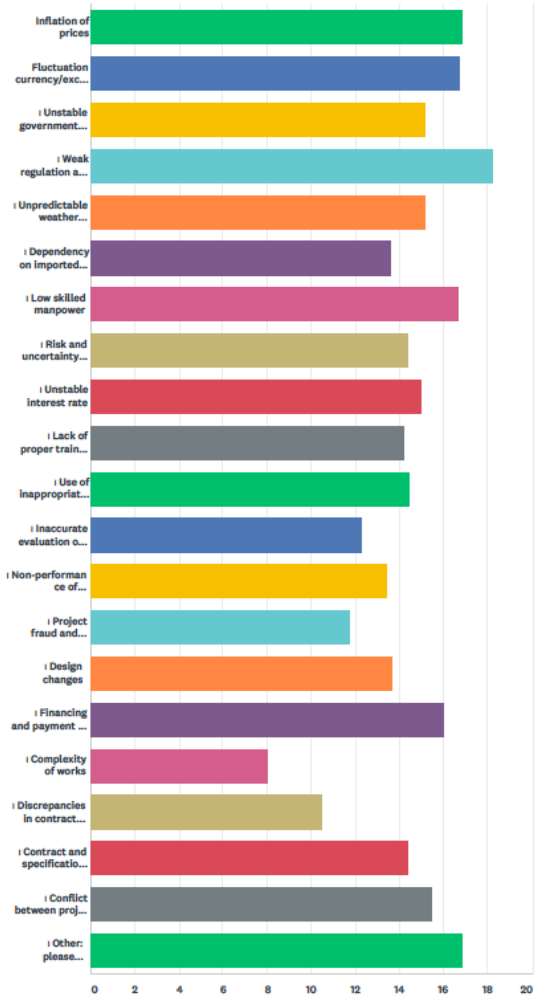


Figure 4.71a: Importance of factors in time control

Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII		Item Mean		
1	2	2	1	2	0	7	25	0.714		3.571		Q55
2	0	0	0	1	1	2	3	0.300		1.500		
3	0	0	2	0	1	3	7	0.467		2.333		
4	2	2	3	2	0	9	31	0.689		3.444		
5	0	2	0	0	1	3	9	0.600		3.000		
6	0	0	0	1	0	1	2	0.400		2.000		
7	2	1	2	0	5	10	25	0.500		2.500		
8	0	0	3	1	1	5	12	0.480		2.400		
9	0	2	0	1	0	3	10	0.667		3.333		
10	6	2	0	1	0	9	40	0.889		4.444		
11	1	0	0	1	1	3	8	0.533		2.667		
12	3	2	2	0	1	8	30	0.750		3.750		
13	0	2	1	2	1	6	16	0.533		2.667		
14	0	1	0	0	0	1	4	0.800		4.000		
15	4	0	2	1	1	8	29	0.725		3.625		
16	0	2	1	2	2	7	17	0.486		2.429		
17	0	0	0	0	0	0	0	#DIV/0!		#DIV/0!		
18	0	0	0	0	1	1	1	0.200		1.000		
19	0	1	0	3	0	4	10	0.500		2.500		
20	0	1	4	2	1	8	21	0.525		2.625		
21	0	0	0	0	3	3	3	0.200		1.000		

Figure 4.71b: Importance of factors in time control

Descriptive Statistics

	N	Mean	Std. Deviation
Inflation of prices	11	5.1818	2.75021
Fluctuation currency/exchange rate	4	5.2500	4.34933
Unstable government policies	6	6.8333	6.17792
Weak regulation and control	10	3.8000	1.54919
Unpredictable weather conditions	7	6.8571	4.18045
Dependency on imported materials	5	8.4000	4.72229
Low skilled manpower	14	5.2857	5.26861
Risk and uncertainty associated with projects	8	7.6250	7.26906
Unstable interest rate	5	7.0000	5.19615
Lack of proper training and experience of PM	15	7.8000	5.30768
Use of inappropriate software	9	7.5556	5.41089
Inaccurate evaluation of projects time/duration	14	9.7143	7.77005
Non-performance of subcontractors and nominated suppliers	11	8.5455	7.01945
Project fraud and corruption	4	10.2500	6.75154
Design changes	14	8.3571	6.58211
Financing and payment for completed works	11	6.0000	5.47723
Complexity of works	5	14.0000	3.39116
Discrepancies in contract documentation	6	11.5000	5.54076
Contract and specification interpretation disagreement	10	7.6000	5.75809
Conflict between project parties	14	6.5000	5.76128
Other: please include/add and rate other factors that you think should be among the factors put forward to them.	5	5.2000	6.94262
Valid N (listwise)	3		

Test Statistics

N	3
Kendall's W[a]	.524
Chi-Square	31.446
df	20
Asymp. Sig.	.050

a. Kendall's Coefficient of Concordance

Figure 4.71c: Importance of factors in time control

From Figure 4.71 it can be seen that weak regulation and control ranks highest and complexity of works ranks lowest.

Olawale and Sun (2010) conducted a survey and identified, classified, and ranked the factors inhibiting project cost and time control in the UK.

Q56 – Please rate the level of importance for each of the following factors in affecting your ability to effectively control the cost of your construction projects (20 answered, 12 skipped).

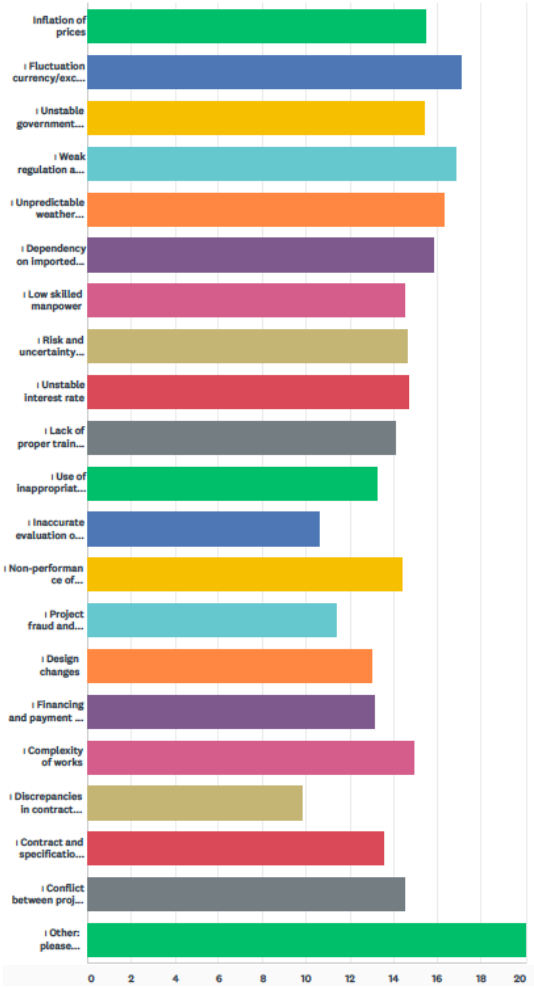


Figure 4.72a: Importance of factors in cost control

Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII	Item Mean	
1	7	1	2	1	1	12	48	0.800	4.000	Q56
2	1	2	0	1	1	5	16	0.640	3.200	
3	1	0	0	0	1	2	6	0.600	3.000	
4	0	0	3	1	1	5	12	0.480	2.400	
5	1	0	0	0	1	2	6	0.600	3.000	
6	0	2	0	1	0	3	10	0.667	3.333	
7	0	2	0	0	1	3	9	0.600	3.000	
8	1	0	1	0	1	3	9	0.600	3.000	
9	1	4	0	1	1	7	24	0.686	3.429	
10	4	1	4	0	0	9	36	0.800	4.000	
11	0	2	1	0	2	5	13	0.520	2.600	
12	1	0	3	1	0	5	16	0.640	3.200	
13	0	1	0	3	1	5	11	0.440	2.200	
14	0	0	1	1	0	2	5	0.500	2.500	
15	1	0	2	2	1	6	16	0.533	2.667	
16	0	1	2	2	0	5	14	0.560	2.800	
17	1	0	0	3	0	4	11	0.550	2.750	
18	0	1	0	0	0	1	4	0.800	4.000	
19	1	0	1	1	1	4	11	0.550	2.750	
20	0	3	0	1	2	6	16	0.533	2.667	
21	0	0	0	0	4	4	4	0.200	1.000	

Figure 4.72b: Importance of factors in cost control

Descriptive Statistics

	N	Mean	Std. Deviation
Inflation of prices	17	6.5294	4.81037
Fluctuation currency/exchange rate	8	4.8750	2.85044
Unstable government policies	5	6.6000	4.33590
Weak regulation and control	8	5.1250	3.97986
Unpredictable weather conditions	6	5.6667	2.58199
Dependency on imported materials	6	6.1667	3.86868
Low skilled manpower	8	7.5000	4.20883
Risk and uncertainty associated with projects	8	7.3750	5.44944
Unstable interest rate	12	7.3333	5.92887
Lack of proper training and experience of PM	15	7.9333	5.84889
Use of inappropriate software	12	8.7500	7.21268
Inaccurate evaluation of projects time/duration	11	11.3636	8.51202
Non-performance of subcontractors and nominated suppliers	8	7.6250	7.53918
Project fraud and corruption	5	10.6000	7.50333
Design changes	12	9.0000	7.33609
Financing and payment for completed works	11	8.9091	6.36325
Complexity of works	8	7.1250	5.51459
Discrepancies in contract documentation	5	12.2000	4.81664
Contract and specification interpretation disagreement	8	8.5000	6.50275
Conflict between project parties	10	7.5000	6.77003
Other: please include/add and rate other factors that you think should be among the factors put forward to them.	5	2.0000	2.23607
Valid N (listwise)	4		

Test Statistics

N	4
Kendall's W[a]	.555
Chi-Square	44.429
df	20
Asymp. Sig.	.001

a. Kendall's Coefficient of Concordance

Figure 4.72c: Importance of factors in cost control

From Figure 4.72 it can be seen that fluctuation currency/exchange rate ranks highest and discrepancies in contract documentation rank lowest.

Q57 – Most researchers often mention that there are problems faced by construction projects which should be eliminated in order to achieve project targets of cost, time, and quality. The following is a list of the main problems and challenges which exist in the construction industry. From the most important to the least important, please can you rank/order the following problems faced by construction industry? Please also include other main problems that exist and affect the construction industry (22 answered, 10 skipped).

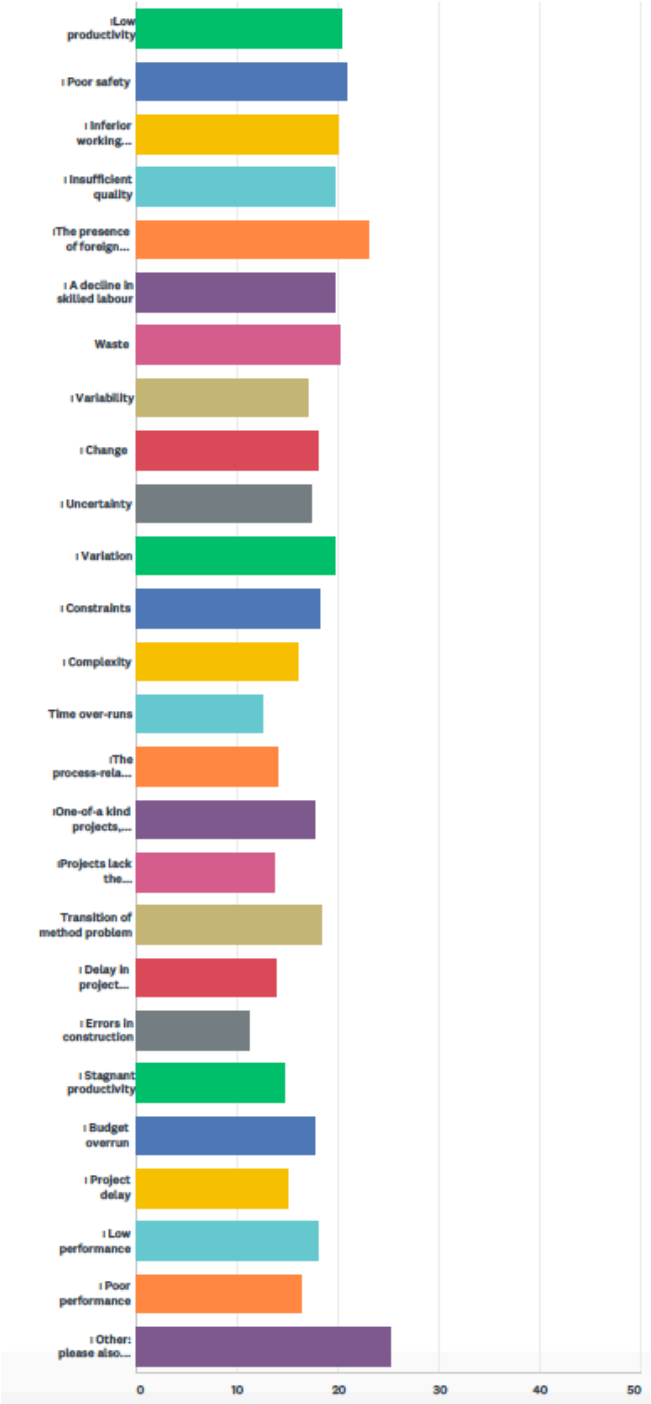


Figure 4.73a: Problems faced by construction projects

Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII		Item Mean		
1	2	2	0	1	2	7	22	0.629		3.143		Q57
2	1	0	1	1	0	3	10	0.667		3.333		
3	2	1	0	0	0	3	14	0.933		4.667		
4	0	0	5	1	2	8	19	0.475		2.375		
5	0	1	2	0	0	3	10	0.667		3.333		
6	1	2	1	1	1	6	19	0.633		3.167		
7	1	0	2	4	3	10	22	0.440		2.200		
8	0	2	0	0	1	3	9	0.600		3.000		
9	1	1	1	1	0	4	14	0.700		3.500		
10	2	0	0	1	1	4	13	0.650		3.250		
11	0	0	1	4	1	6	12	0.400		2.000		
12	0	1	1	0	0	2	7	0.700		3.500		
13	0	0	1	0	0	1	3	0.600		3.000		
14	1	1	0	0	0	2	9	0.900		4.500		
15	2	0	0	0	1	3	11	0.733		3.667		
16	0	0	1	1	0	2	5	0.500		2.500		
17	1	1	0	0	0	2	9	0.900		4.500		
18	0	0	0	3	0	3	6	0.400		2.000		
19	3	1	0	1	0	5	21	0.840		4.200		
20	0	0	0	0	0	0	0	#DIV/0!		#DIV/0!		
21	0	1	0	0	0	1	4	0.800		4.000		
22	2	4	1	0	1	8	30	0.750		3.750		
23	1	1	1	0	0	3	12	0.800		4.000		
24	1	1	2	1	2	7	19	0.543		2.714		
25	0	2	2	0	0	4	14	0.700		3.500		
26	0	0	0	0	5	5	5	0.200		1.000		

Figure 4.73b: Problems faced by construction projects

Ranks

	Mean Rank
Low productivity	10.25
Poor safety	7.25
Inferior working conditions	7.75
Insufficient quality	17.50
The presence of foreign competition	4.00
A decline in skilled labour	8.25
Waste	15.50
Variability	11.75
Change	9.75
Uncertainty	13.50
Variation	12.75
Constraints	10.25
Complexity	9.75
Time over-runs	19.25
The process-related problems, waste, absence of clear indicators of quantitative parameters and a lack of documented studies	17.00
One-of-a kind projects, multi-level organisational structure, site production	10.50
Projects lack the organisation which promotes cohesive partnerships, coordination and communication between multi-disciplinary professions, flexible contractual agreements and a customer focused objective	17.25
Transition of method problem	10.25
Delay in project delivery	25.25
Errors in construction	15.00
Stagnant productivity	14.50
Budget overrun	21.25
Project delay	22.50
Low performance	20.00
Poor performance	19.00
Other: please also specify and include other main problems that exist and affect the construction industry.	1.00

Test Statistics

N	4
Kendall's W[a]	.583
Chi-Square	58.316
df	25
Asymp. Sig.	.000

a. Kendall's Coefficient of Concordance

Figure 4.73c: Problems faced by construction projects

From Figure 4.73 it can be seen that the presence of foreign competition ranks highest and errors in construction rank lowest.

Q58 – The following is a list of the significant barriers to the successful implementation of LC in the UK. Please can you rank/order from the most important to the least important? (22 answered, 10 skipped).

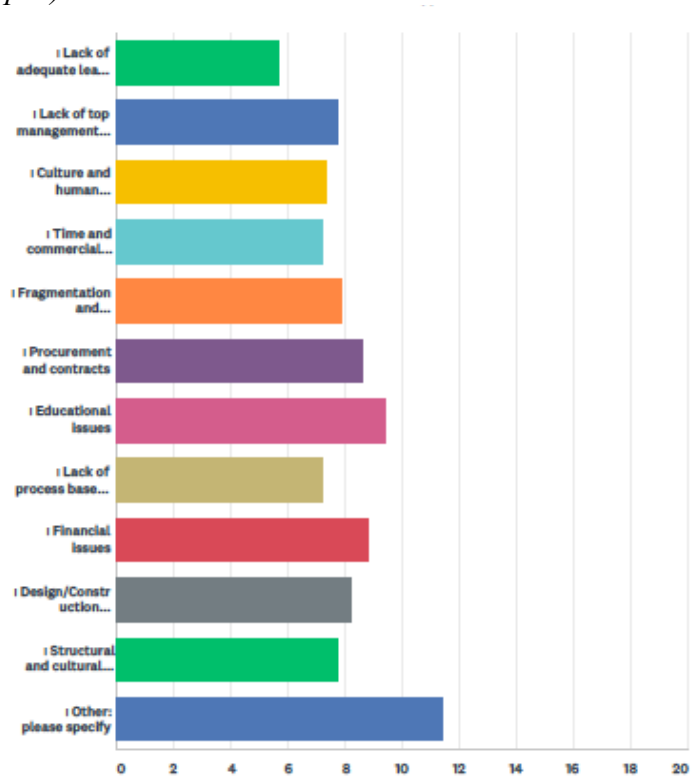


Figure 4.74a: Significant barriers to LC implementation

Item	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII	Item Mean	
1	12	1	0	0	1	14	65	0.929	4.643	Q58
2	0	2	1	2	0	5	15	0.600	3.000	
3	1	7	5	0	0	13	48	0.738	3.692	
4	1	0	1	1	2	5	12	0.480	2.400	
5	3	2	1	0	0	6	26	0.867	4.333	
6	2	2	1	1	0	6	23	0.767	3.833	
7	1	3	2	2	2	10	29	0.580	2.900	
8	0	3	4	3	0	10	30	0.600	3.000	
9	0	0	3	3	1	7	16	0.457	2.286	
10	1	0	1	5	1	8	19	0.475	2.375	
11	0	1	1	3	5	10	18	0.360	1.800	
12	0	0	0	0	8	8	8	0.200	1.000	

Figure 4.74b: Significant barriers to LC implementation

Ranks

	Mean Rank
Lack of adequate lean awareness/understanding	12.00
Lack of top management commitment	5.38
Culture and human attitudinal issues	8.75
Time and commercial pressure	7.75
Fragmentation and subcontracting	5.13
Procurement and contracts	4.38
Educational issues	4.25
Lack of process based PMSs	8.88
Financial issues	4.25
Design/Construction dichotomy	6.88
Structural and cultural barriers	9.38
Other: please specify	1.00

Test Statistics

N	8
Kendall's W[a]	.692
Chi-Square	60.904
df	11
Asymp. Sig.	.000

a. Kendall's Coefficient of Concordance

Descriptive Statistics

	N	Mean	Std. Deviation
Lack of adequate lean awareness/understanding	22	7.3182	3.72106
Lack of top management commitment	9	5.2222	3.03223
Culture and human attitudinal issues	21	5.6667	2.98887
Time and commercial pressure	12	5.7500	3.25087
Fragmentation and subcontracting	8	5.1250	1.64208
Procurement and contracts	8	4.3750	1.40789
Educational issues	12	3.5833	2.06522
Lack of process based PMSs	17	5.7647	3.56247
Financial issues	11	4.1818	2.78633
Design/Construction dichotomy	14	4.7857	3.11766
Structural and cultural barriers	19	5.2632	3.94183
Other: please specify	9	1.5556	1.66667
Valid N (listwise)	8		

Figure 4.74c: Significant barriers to LC implementation

From Figure 4.74 it can be seen that educational issues rank highest and a lack of adequate lean awareness/understanding rank lowest.

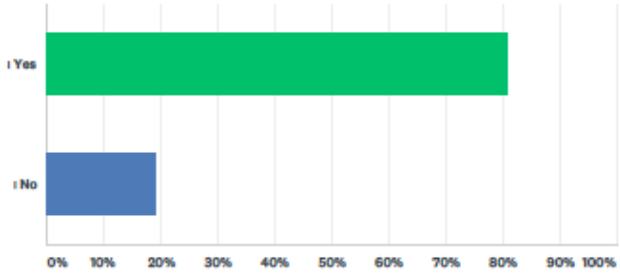
Sarhan and Fox (2013) conducted a questionnaire survey on barriers to implementing LC in the UK construction industry, and the survey results are as follows:

1. Fragmentation and subcontracting (both developed and developing nations);
2. Procurement and contracts;
3. Culture and human attitudinal issues;
4. Financial issues;
5. Lack of top management commitment and support;
6. Design/construction dichotomy;
7. Lack of adequate lean awareness/understanding;
8. Educational issues; and
9. Lack of customer-focused and process-based performance measurement systems.

This question was further analysed in Round 2 of the questionnaires and interviews in the UK.

Theme 18: Question 59 – Earned Value Method

Q59 – The earned value method (EVM) is considered an advanced project control technique that provides a quantitative measure of work performance. At the assignment level, do you measure earned value or cost performance? (21 answered, 11 skipped).



ANSWER CHOICES	RESPONSES	
Yes	80.95%	17
No	19.05%	4
TOTAL		21

Figure 4.75: Earned value or cost performance measurement

Figure 4.75 shows that 81% of the respondents measure earned value at the assignment level.

Theme 19: Questions 60 to 62 – Any other comments and associated administration

Q60 – Any other comments? (3 answered, 29 skipped).

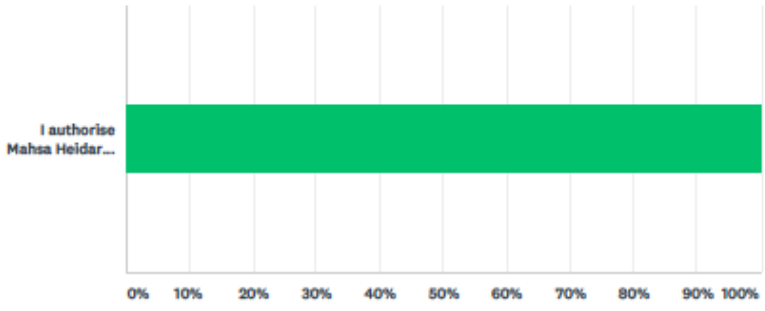
Regarding response to question 53: other: please mention: quality control of everything – materials and construction. Difficult to choose. With Q50. Significantly less waste (Provided waste is defined in the broadest of terms). For
Q53. Improve project planner's abilities training in the techniques and the required cultural changes. Other: please specify: Training in the techniques and the required cultural changes in the relationships between individuals and contracting parties.
With Question 58. The way Lean Six Sigma is viewed by the UK industry.

*Q61 – **The comment box:** Please complete the consent form provided on the intro page by writing your answers in the comment box below.*

Responses: My experience in industry is from a couple of decades ago. IT and management systems have moved a long way since then.

*Q62 – **The consent form:** Please complete the consent form below. Please answer this question regarding the consent form provided in question. (30 answered, 2 skipped).*

Figure 4.76 shows that all of the respondents (100%) completed the consent form.



ANSWER CHOICES	RESPONSES	
I authorise Mahsa Heidar Barghi PhD researcher of/at the University of Birmingham to use my answer for the purpose of her research.	100.00%	30
TOTAL		30

Figure 4.76: The consent form

4.7.5 Discussion

After identifying most of the main and common factors inhibiting project control in practice that often lead to project cost and time overruns, interviews were carried out to develop mitigating measures to help project managers better control their projects.

A list of mitigating measures was developed for the top inhibiting factors, classified as: A) preventive, B) predictive, C) corrective, D) organisational measures, and E) etc. They can be used as a checklist of good practice (see Chapter 5).

The author had an interview with Dr Ballard, prior to her PhD studies, regarding the implementation and challenges of LC and LPS. The author had an interview with a Highways Agency (National Highways) engineer, Mr Andrew Wingrove (2016), who introduced the lean project tracker and case studies which the author read through through the link that he sent via email. According to another interviewee, an engineer from Highways England (National Highways), measurement of cost is made up by saving time, a methodology that is the cheapest way of doing something and using materials. Time is critical and is the most important factor to save cost, followed by quality, sustainability, and safety. Additionally, through elimination of risk, it is possible to save money. According to one interviewee, in a lean approach, consultation is done first; from the start, risks are known and reduced, and money is saved. Also, collaboration with all the relevant parties, all the time, in any geotechnical process, is beneficial. Lean is also achievable using value management and VE.

Sarhan and Fox (2012) conducted a study of the trends in and challenges to developing a lean culture among UK construction organisations, using a questionnaire survey in the UK. The study targeted practitioners in the UK construction industry. The survey results regarding techniques practised to help construction organisations to improve their collaborative relationships are as follows:

- Collaboration techniques;
- Long-term contractual agreements, e.g. partnering; document management systems;
- Cross-functional teams;
- Collaborative planning schedules (e.g. with subcontractors or suppliers);
- Project information systems;
- Integrated Project Delivery (IPD);

- Lean Project Delivery System (LPDS); and
- Implement all the above.

In this research, interviews were conducted through different methods such as face to face, telephone, email, and Skype.

The Highways England Lean Project Tracker, Lean Maturity Assessment (HELMA) matrix is a project decision matrix for the purpose of reporting progress on Lean Improvement Projects.

In addition to finding out the status of cost and time control practice and ascertaining existing overrun problems still besetting construction projects, the questionnaire survey sought to identify the most important factors that inhibit the project control efforts of construction project practitioners.

For development of mitigating measures, in the research presented herein the author has developed predictive measures which use tools or techniques that can predict future problems, as shown in Tables 4.9 to 4.16 and the Matrix Tables.

The idea for developing the measurement and control methods stemmed from the experts' answers to Q39–46 (which can be seen in Figures 4.9 to 4.12). The results from the waste questions (Q47–49) have been used to develop the matrix of waste management as shown. Development of mitigating measures has been set out as the descriptions and explanations shown in Table 4.2. This stems from Q55–58.

4.8 Lean Construction Principles and Techniques Relevant to Construction Issues

From the evaluation above (see Section 4.7.5), to achieve construction excellence, the author identified the construction issues and challenges and the relevant tools and techniques that can be used as drivers and considered to be relevant in minimising the issues, presented below in Tables 4.9 to 4.12. This provides a guide to further investigate the relevance of LT to construction issues.

Bashir (2013) conducted similar work regarding safety issues in the construction industry and this was the inspiration for the details set out in Tables 4.9 to 4.14.

Salem et al. (2006) proposed a new 'lean assessment tool' to quantify the results of lean implementations, which evaluates six lean construction elements: Last Planner, increased visualisation, huddle meetings, first-run studies, 5Ss, and fail safe for quality.

Sarhan and Fox (2012) set in place fundamental techniques to help construction organisations to achieve the lean approach as follows:

- Workplace Organisation - Create a safe and good workplace environment to complete the job;
- Standardised Work - Identify best method to achieve quality, cost, time, etc., safely and consistently;
- Data Analysis - Set targets, monitor and improve;
- Problem Solving - Identify root causes of problems;
- Collaborative Planning;
- Visual Management - Create clear process-oriented performance information to identify problems before they occur;
- Process mapping - Identify who does what, when, why, and how;
- Work Sequence Analysis - Identify waste and risks, and Consider logistics; and
- Implement all the fundamental techniques mentioned above.

The results from the questionnaire were used to develop the Tables of Lean Techniques relevant to Time, Cost, Quality, and Sustainability issues and development of the Matrix Tables, and these are all related to each other.

Table 4.9 Lean techniques relevant to Time issues

Time Issue (Time overruns)	**Relevant Lean Construction Techniques (L)**	**Lean Construction Tool**
Ineffective and Poor planning and control	Weekly work planning	Last Planner System
	Critical task planning	First run studies
	Process mapping	
Design changes Inadequate planning	Collaborative planning	
Site congestion Poor site management	Coordinating workers and simultaneous activities	Last Planner System
	Materials and plants organization	5S (House-keeping)
Changes in site conditions	Clean workplace	5S
Lack of site awareness Lack of experience of project location Lack of experience of project type	Daily huddle meetings	Daily huddle meetings
Excessive stress Poor labour productivity	Workers empowerment in assignment scheduling	Last Planner System
Skilled labour shortage (Project environment factor)	Correlating work methods with workers' skills	Last Planner System
Lack of knowledge to read work statements Mistakes and discrepancies in design documents	Work methods illustration	First run studies, Increased visualization, Five S's, Last planner, fail safe for quality
Non-compliance with Procedures	Work methods illustration	First run studies
Human/ Judgement error	Safety signs and labels	Increased visualization
Changes initiated by designers	Visibility improvement	Increased visualization
	Visual safety borders and demarcation	Increased visualization

Table 4.9 Lean techniques relevant to Time issues (continued)

Poor supervision, Poor Team effort Poor contract management Subcontractors and nominated suppliers	Visual inspection Standardization Integrated supply chain Work methods illustration	Error-proofing, Fail safe for quality ((poka-yoke) devices), 5S, Increased visualization, First-run studies
Poor communication Late deliveries	Workers' involvement in DH meetings	Daily huddle meetings, Last Planner, Fail safe for quality, 5S, Increased visualization, First-run studies
	Safety signs and labels	Increased visualisation
Physical and mental inability	Correlating tasks with workers' ability	Last Planner System
Untidy site	Clean workplace	5S (House-keeping)
Site hazard (eg dust, noise)	Clean workplace	5S (House-keeping)
Inclement weather	Offsite fabrication	
Falling objects	Materials and plants organization	5S (House-keeping)
Organisational pressure Client requirements	workers empowerment in assigning scheduling	Last Planner System
Tripping	Visibility improvement	Increased visualization
Risk identification and reduction	Pre-task hazard analysis	Last Planner System
	Daily huddle meetings	Daily huddle meetings
	Collaborative planning	
	Integrated supply chain	
	Standardisation	
Lack of safety awareness	Dily huddle meetings	
	Collaborative planning	
High risk activities	Offsite fabrication	

Table 4.9 Lean techniques relevant to Time issues (continued)

Lack of motivation	Workers involvement in task planning	LPS
Poor work methods	Collaborative planning	
	Integrated supply chain	
Poor site management Delays	Weekly work planning	LPS
Procedural issues		Just in time Standardization
(Project environment factors): Lack of project funding Financing and payment of completed works Shortage of materials / material shortages Imported materials and plant items Inaccuracy of material estimate	 Offsite fabrication, Integrated supply chain Integrated supply chain, Visual inspection, Critical task planning, process mapping, collaborative planning Offsite fabrication, Integrated supply chain Integrated supply chain, Visual inspection, Critical task planning, process mapping, collaborative planning, materials and plant organization, clean workplace Visual inspection, collaborative planning	 Just in time, Standardization Just in time, Standardization Just in time, Standardization

Table 4.10 Lean techniques relevant to Cost issues

Cost Issue (cost overruns)	**Relevant Lean Construction Techniques (L)**	**Lean Construction Tool**
Ineffective and Poor control	Weekly work planning	Last Planner System
	Critical task planning	First run studies
	Process mapping	
Design changes Delays in design information Long waiting time for approval of drawings Problems in planning and design as main causes of change orders	Collaborative planning	
Site congestion Poor site management	Coordinating workers and simultaneous activities	Last Planner System
	Materials and plants organization	5S (House-keeping)
Site conditions	Clean workplace	5S
Lack of site awareness Lack of experience of project location Lack of experience of project type	Daily huddle meetings	Daily huddle meetings
Lack of knowledge to read work statements Mistakes and discrepancies in design documents	Work methods illustration	First run studies, Increased visualization, Five S's, Last planner, fail safe for quality
Non-compliance with Procedures	Work methods illustration	First run studies
Human/ Judgement error	Safety signs and labels	Increased visualization
Changes initiated by designers	Visibility improvement	Increased visualization

Table 4.10 Lean techniques relevant to Cost issues (continued)

	Visual safety borders and demarcation	Increased visualization
Poor supervision, Poor Team effort Poor contract management Subcontractors and nominated suppliers Poor site management and supervision	Visual inspection	Error-proofing, Fail safe for quality ((poka-yoke) devices), 5S, Increased visualization, First-run studies
Poor communication Late deliveries	Workers' involvement in DH meetings	Daily huddle meetings, Last Planner, Fail safe for quality, 5S, Increased visualization, First-run studies
	Safety signs and labels	Increased visualisation
Changes in site conditions Weather	Clean workplace	5S (House-keeping)
	Offsite fabrication	
Organisational pressure Client requirements	workers empowerment in assigning scheduling	Last Planner System
High risk activities	Offsite fabrication	
Poor work methods Inaccurate estimates Additional work Inaccurate quantity take-off	Collaborative planning Integrated supply chain JIT	
Poor site management Delays	Weekly work planning	LPS
Procedural issues		Just in time

Table 4.10 Lean techniques relevant to Cost issues (continued)

(Project environment factors):		
Financing and payment of completed works	Work methods illustration, Collaborative planning, Integrated supply chain, process mapping	
materials shortage	Integrated supply chain, offsite fabrication	Just in time
Imported materials and plant items	Collaborative planning, Integrated supply chain, visual inspection, materials and plant organization, critical task planning, process mapping	
Price fluctuation		Standardization
Materials cost increased by inflation	Work methods illustration	Standardization
Economic conditions		Standardization

Table 4.11 Lean techniques relevant to Quality issues

Quality Issue	**Relevant Lean Construction Techniques (L)**	**Lean Construction Tool**
Ineffective and Poor planning and control	Weekly work planning	Last Planner System
	Critical task planning	First run studies
	Process mapping	
	Collaborative planning	
	Quality control and inspection: Quality control implemented in construction: The Specifications and contract drawings, Visual quality checks and Quantifable quality checks Quality assurance Total quality management (TQM) Quality management systems	Quality control Zero defects Total quality management (TQM) Continuous Process Improvement Reengineering Quality Assignments
Site congestion Poor site management Changes in site conditions Site conditions	Coordinating workers and simultaneous activities	Last Planner System
	Materials and plants organization	5S (House-keeping)
	Clean workplace	5S
	Quality control and inspection: Visual quality checks and Quantifiable quality checks	Quality control Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments
Excessive stress Poor labour productivity Skilled labour shortage (Project environment factor)	Workers empowerment in assignment scheduling	Last Planner System
	Correlating work methods with workers' skills Quality assurance	Last Planner System Quality control

Table 4.11 Lean techniques relevant to Quality issues (continued)

	Total quality management (TQM) Quality management systems	Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments
Lack of knowledge to read work statements Mistakes and discrepancies in design documents	Work methods illustration Quality control and inspection: Visual quality checks and Quantifiable quality checks	First run studies, Increased visualization, Five S's, Last planner, fail safe for quality Quality control Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments
Non-compliance with Procedures	Work methods illustration Quality assurance	First run studies Quality control Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments
Human/ Judgement error		Increased visualization
	Visibility improvement	
	Quality control and inspection Quality assurance Quality management systems	Quality control Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments

Table 4.11 Lean techniques relevant to Quality issues (continued)

Poor supervision, Poor Team effort Poor contract management Poor contract management Subcontractors and nominated suppliers Subcontractors and nominated suppliers Poor site management and supervision	Visual inspection Quality control and inspection Quality assurance Total quality management (TQM) Quality management systems	Error-proofing, Fail safe for quality ((poka-yoke) devices), 5S, Increased visualization, First-run studies Quality control Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments
Physical and mental inability	Correlating tasks with workers' ability Quality control and inspection Quality assurance Total quality management (TQM) Quality management systems	Last Planner System Quality control Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments
Untidy site	Clean workplace Quality assurance Quality management systems	5S (House-keeping) Quality control Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments
Site hazard (eg dust, noise) Inclement weather Site conditions	Clean workplace Offsite fabrication Quality assurance Quality management systems	5S (House-keeping) Quality control Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering

Table 4.11 Lean techniques relevant to Quality issues (continued)

		Quality Assignments Lean Production
	Materials and plants organization Quality assurance Quality management systems	5S (House-keeping) Quality control Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments
Organisational pressure Client requirements	workers empowerment in assigning scheduling Quality assurance Quality management systems	Last Planner System Quality control Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments
Tripping	Visibility improvement Quality assurance Quality management systems	Increased visualization Quality control Zero defects Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments
High risk activities	Offsite fabrication	Lean Production
Procedural issues	Quality control and inspection Quality assurance Total quality management (TQM)	Just in time Quality control Zero defects

Table 4.11 Lean techniques relevant to Quality issues (continued)

	Quality management systems	Continuous Process Improvement Total quality management (TQM) Reengineering Quality Assignments Lean Production

Table 4.12 Lean techniques relevant to Sustainability issues

Sustainability issue	Relevant Technique
	Sustainable indicators and benchmark Sustainable assessment

A list of mitigating measures has been developed for the top inhibiting factors. Table 4.13 shows a summary of the application of LT across two sectors. Lean drivers are factors that lead organisations in different sectors to engage in Lean practice and are the organisation's purpose in applying Lean principles and techniques.

As shown in Table 4.13, these drivers vary across the sectors. According to Bashir et al. (2013), the factors that drive UK contracting organisations into Lean practice are cost reduction benefits, improved efficiency, improved quality of products and services, time reduction benefits, increased revenues, and client satisfaction.

Table 4.13 Lean Practice across different sectors

Sectors	Lean concepts applied	Lean Drivers	References
Construction	Last Planner System, Increased visualization, the 5S, Errorproofing, First run studies and Daily huddle meetings	Decline in profit margin, increased competition, low customer satisfaction, cost overrun, time overrun, elimination of non-value adding activities	Egan (1998); Abdelhamid and Salem (2004); Salem et al., (2005)
Processing	Just-in-time, kanban, total production maintenance, total quality management, 5S, production smoothing, set up reduction and cellular manufacturing	Demand for improvement activities, competition	Abdullah and Raigopal (2003); Abdelmalek and Raigopal (2005)

Khan et al. (2011) developed a framework for lean product development enablers, through the Design concepts matrix and Design structures functional plan tools.

Table 4.14 sets out the proposed framework for LC development enablers with Construction concepts matrix and Construction structures functional plan tools.

Table 4.14 Proposed framework for lean construction development enablers

Core Enablers	Techniques	Tools
Set-Based concurrent Engineering	Multiple alternatives (designed) Delaying specification	*Construction concepts matrix *Construction structures functional plan

4.9 Development of Time and Cost Matrix

The next stage is to demonstrate use of the tools that have been developed on a real project. To do this, a Time and Cost Matrix has been developed to identify the interactions and relationships and those that need managing to ensure a successful project.

Tables 4.9 and 4.10 above have been developed into an interaction matrix (see Tables 4.15 and 4.16) to demonstrate more clearly the potential relationships between the mentioned construction issues and LC techniques. The matrix shows areas of potential interaction between LC techniques, and construction site issues. The potential interactions are shown by the point of intersection of these factors. As shown in the matrix, for example, 'process mapping' could be used to reduce Time issues caused by: Design changes, Financing and payment of completed works, Inadequate planning, and Imported materials and plant items; it could also be used to reduce Cost issues caused by: Design changes, Problems in planning and design as main causes of change orders, Imported materials and plant items, Financing and payment of completed works, Delays in design information, and Long waiting time for approval of drawings. Similarly, 'workers empowerment in assignment scheduling and correlating work methods with workers skills' could potentially reduce time issues caused by: Poor labour productivity and skilled labour shortage; also, regarding the Cost issues, it could potentially reduce issues caused by Client requirements, Site conditions, and Poor site management and supervision. Employee Empowerment (EMPR) is the culture established in a participative organisation where employees are cross-trained and responsible for improvement suggestions, decision making, and quality output (Fullerton et al., 2013).

Table 4.15 Possible Interaction Matrix of Lean Construction Techniques and Time issues

	Workers empowerment in assignment scheduling	Correlating work methods with workers' skills	Just in time	Standardisation	Offsite fabrication	Integrated supply chain	Visual inspection	Work methods illustration	Weekly work planning	Critical task planning	Process mapping	Collaborative planning	Coordinating workers and simultaneous activities	Materials and plants organization	Clean workplace	Daily huddle meetings	hazard analysis	Safety signs	Visibility improvement	[illegible] meetings
Time issues	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
T1. Poor labour productivity	R	R						R					R			R				R
T2. Lack of project funding / Shortage of materials			R	R	R	R														
T3. Poor contract management							R						R							R
T4. Design changes									R	R	R	R	R							
T5. Inaccuracy of material estimate			R	R			R					R								
T6. Skilled labour shortage	R	R						R					R							R
T7. Financing and payment of completed works						R	R			R	R	R								
T8. Changes in site conditions													R	R	R		R	R		R
T9. Inclement weather					R										R		R	R	R	
T10. Inadequate planning									R	R	R	R				R				
T11. Subcontractors and nominated suppliers				R		R	R	R					R							R
T12. Imported materials and plant items						R	R			R	R	R		R	R					

Note: Interactions with label R are based on valid conclusions (results and answers to the questionnaires).

Table 4.16 Possible Interaction Matrix of Lean Construction Techniques and Cost issues

	Work methods illustration	Collaborative planning	Integrated supply chain	Workers involvement in DH meetings	Just in time	Clean workplace	Offsite fabrication	Visual inspection	Work methods illustration	Standardization	Workers empowerment in assignment scheduling	Coordinating workers and simultaneous activities	Materials and plants organization	Weekly work planning	Critical task planning	Process mapping	Safety signs and labels	Visibility improvement	Visual safety borders and demarcation	Daily huddle meetings
Cost issues	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
C1. Inaccurate quantity take-off	R	R	R		R															
C2. Late deliveries				R																
C3. Additional work		R	R		R															
C4. Weather						R	R													
C5. Poor contract management								R												
C6. Mistakes and discrepancies in design documents / Materials cost increased by inflation									R	R										
C7. materials shortage			R		R		R			R										
C8. Economic conditions										R										
C9. Client requirements											R									
C10. Site conditions						R						R	R							
C11. Poor site management						R		R				R	R							

Table 4.16 Possible Interaction Matrix of Lean Construction Techniques and Cost issues (continued)

and supervision																				
C12. Design changes		R												R	R	R				
C13. Inaccurate estimates		R	R		R															
C14. Problems in planning and design as main causes of change orders		R												R	R	R				
C15. Imported materials and plant items		R	R			R		R					R		R	R				
C16. Delays														R						
C17. Subcontractors and nominated suppliers								R												
C18. Price fluctuation										R										
C19. Financing and payment of completed works	R	R	R													R				
C20. Delays in design information		R												R	R	R				
C21. Changes initiated by designers																	R	R	R	
C22. Lack of experience of project type																				R
C23. Long waiting time for approval of drawings		R												R	R	R				
C24. Changes in site conditions						R	R													
C25. Lack of experience of project location																				R

4.10 Proposed Sustainability Checkpoints to the RIBA Outline Plan of Work

This part has been updated and developed after the Sustainability Checkpoints were included in the Green Overlay to the RIBA Outline Plan of Work. The proposed Sustainability Checkpoints are selectable in a practice- or project-specific Plan of Work; (see Table 4.17).

Table 4.17 Proposed Sustainability Checkpoints to the RIBA Outline Plan of Work

In RIBA Work Stage, the Construction Stage include: Mobilisation (J) Stage; and Construction to Practical Completion (K) Stage. At Mobilisation stage (J), key tasks and their sustainability checkpoints are described as follows. First key task includes: Letting the building contract, appointing the contractor. The Sustainability Checkpoint is: Site Waste Management Plan (SWMP) passed to contractor. In the Supplementary Guidance it is also mention that "Review potential knock-on implications of value engineering on performance and sustainability targets."
The impact of Value Engineering in construction projects is very important. The aim of Value Engineering is to enhance and increase value, at the same time as reducing cost and in a perfect world to attain the maximum function, while running/functioning on the lowest cost. The impact that VE has brought in construction projects is valuable, advantageous and long-lasting. Value = Function / Cost. More for less: VE offer and present to construct and create more product for fewer cost. Function is the main concern of VE. VE is a full-time, productive and structured method to the success of requisite function at the least cost. Example: Function of a house is to make home. VE is not a cost cutting. value engineering increase profit and result in satisfaction of clients. Implementation of VE will improve engineering process and construction methods; Save Money; Reduce Time; and Improve Quality.
Secondly, there is the key task of issuing of information to the contractor. Sustainability checkpoint is: Design stage sustainability assessment certified.
Third and finally, there is a key task of arranging site hand over to the contractor. Sustainability checkpoint is: Construction sustainability procedures developed with contractor; and Review of commissioning and handover programme.
At Construction to Practical Completion stage (K), key tasks and their sustainability checkpoints are described as follows. First key task is: Administration of the building contract to practical completion. The sustainability checkpoint is: Contractor's interim testing and monitoring of construction reviewed and observed, particularly airtightness and continuity of insulation.
Second key task is: Provision to the contractor of further information as and when reasonably required. Sustainability checkpoint is: Implications of changes to specification or design reviewed against agreed sustainability criteria.
Third key task is: Review of information provided by contractors and specialists. Sustainability check point is: Non-technical user guide completed, and aftercare service set up.
Fourth and finally, there is a key task of Assist with preparation for commissioning, training, handover, future monitoring and maintenance. Sustainability checkpoint is: Assistance with collating as-built information for post-construction sustainability certification.
By application of lean construction and value engineering, speed of on-site construction will increase and rent of facilities together with Site preliminaries decreased, there is a quicker return on saving and investment, and the building programme is more predictable which means there is little possibility and risk of over runs. Modular construction is able to bring significant and great advantages/benefits and profits in the construction process and can decrease or lessen several common problems, which may become upon. There are lots of limitations and barriers to the Implementation of these creative methods.

Table 4.17 Proposed Sustainability Checkpoints to the RIBA Outline Plan of Work (continued)

At the same time Lean Construction and VE are too complex and too simple and this is the difficulty with LC and VE philosophy/discipline. There are refusal and unwillingness to vary or change the accepted conventional norm (break the norms). Lean Construction cannot be exercised where there are limitations to freedom/choice to vary and to change. It will produce onward the full profits of variation, if there is choice/freedom to change. LC and VE cannot predict all the troubles that will happen in construction.

4.11 Concluding remarks

This chapter presents a new proposed model that contains a set of lean methods and techniques to support the application of lean principles in construction project practice and, via this, a method to more consistently achieve the full benefits that LC approaches can offer.

The adaptations of lean principles with enablers in the proposed model have been identified and assessed; a combination of different lean methods and techniques as the major enablers have been taken into consideration in the construction process. This proposed model has then been integrated and incorporated into the RIBA Plan of Work, to implement lean methods and techniques to the construction activities, as this has proved to be the most effective way to implement changes associated with the proposed LC model. The measurement and control methods, also presented in this chapter, have been developed to control and manage cost, time, quality, and sustainability.

The adaptation of lean principles, with the identification of wastes and enablers in construction process, has been evaluated. The innovative construction process models presented in this research have been developed based on the core enablers that can be used to identify and eliminate waste. The adaptation and consideration of the core enablers of the construction process model are also discussed.

The framework development in this research project consists of two parts, conceptual frameworks (see Section 4.2) and implementation frameworks (see Section 4.3). In this chapter the framework models, measurement model, matrix of waste management, survey

analysis, matrix of time and cost issues, and tables of lean techniques relevant to quality and sustainability issues have been proposed and developed. In Chapter 5, based on analysis of the results from the questionnaires and interviews (undertaken in four rounds) tested against two case studies from Iran, a modified framework and performance measurement is developed. Further, this is explained and the validated through the case studies, use of the developed performance index measurement model, and external validation, to produce an integrated framework for improving the construction process by adopting LC principles.

5 RESULTS AND DISCUSSION

5.1 Conceptual Construction Process Model

5.1.1 Second Stage of Modelling Development

In Chapter 4, the framework models, measurement model, waste management matrix, survey analysis, matrix of time and cost issues, and tables of lean techniques relevant to quality and sustainability issues are proposed and developed. In this chapter, based on analysis from the questionnaires and interviews (undertaken in four rounds) tested against two case studies from Iran, a modified framework and performance measurement is presented. Further, this is explained and validated through the case studies, the use of the developed performance index measurement model, and external validation to produce an integrated framework for improvement of the construction process by adopting LC principles.

For Round 1, information from both the UK and Iran was collected. Rounds 2, 3, and 4 related to Iran and the information was used in the application and implementation in the case studies. Additionally, Round 2 used UK sources for direct comparison with Iran, allowing a more accurate finalisation of the results and framework.

The further development of the modelling framework was based on the existing models which are described below (see Sections 5.1–5.9) and drew on the literature review (see Chapter 2).

Several models were considered for the further development of the model produced from the research presented herein, and this can be seen in this chapter (see Sections 5.1–5.9), including designing a pull system.

In this research study, the Conceptual Construction Framework with Lean Construction Implementation is proposed, as shown in Figure 5.1.

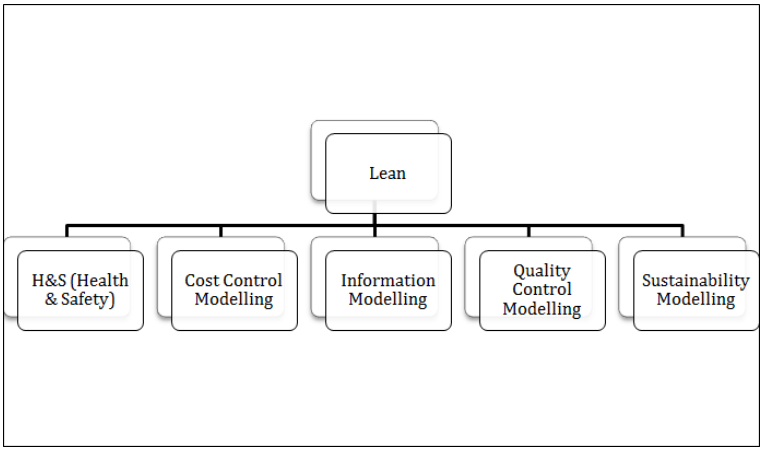


Figure 5.1: Proposed Lean Modelling Development

In developing the proposed lean framework modelling, the PDCA or Deming cycle (see Figure 5.2), a management method used for the control and continuous improvement of processes and products, was also considered and used.

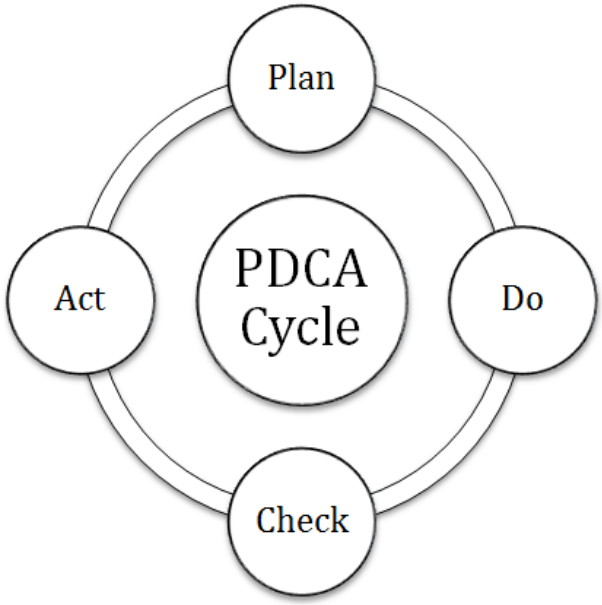


Figure 5.2: PDCA Cycle: A method of continuous improvement (Deming cycle)

Figure 5.3 shows the lean tools which were used in developing the proposed lean framework modelling (for further information please see Chapter 2, Section 2.9.1).

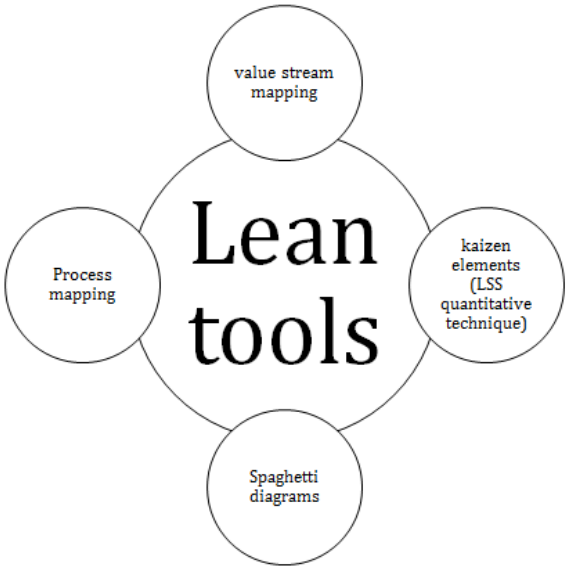


Figure 5.3: Lean tools

Survey questionnaires were used to assess stakeholders' perceptions of the tools and to both evaluate the implementation process and to examine the extent to which the tools were perceived to improve planning practice; identify benefits and barriers to tools adoption; and identify the critical success factors (CSFs). In both projects, 50 questionnaires were distributed and 20 responses were received for each.

The next section presents the outcomes for Round 1 – the results from the Iranian questionnaire.

5.2 Analysis of Round 1 of Iran Questionnaire

Sections 5.3.4–5.3.9 provide a complete description of the analysis of Round 1 of the Iran questionnaire. For ease, Table 5.1 presents a summary of the key results related to this questionnaire. The figures and tables from this round – which outline the responses given – are shown below. The details of each question can be found in Chapter 3, Section 3.2.4. In total 20, replies were gathered.

Table 5.1 Summary of Results from Round 1 questionnaire.

Question	Key data	Comments
1	The results to Question 1 show that 17 (81%) of the respondents stated they were principal contractors; only 4 (19%) of respondents stated they were subcontractors.	For Round 1, a natural bias toward principal contractors will be evident. Because some respondents chose more than one response, and chose both contractor and subcontractor, the results show 85% principal contractors and 20% subcontractors. According to an interviewee engineer, the best consultant is one who was previously worked as a contractor (K Heydarbarghi). Within this research, a good number of the respondents had experience in both sectors. To improve the implementation of LC, harmonisation between main contractors and subcontractors is a prerequisite.
2	The results to Question 2 show that 20 different roles were highlighted by respondents.	Whilst the responsibility of the 20 respondents is varied (see list below) the main position/role (which covers 16/20 respondents) was project manager/engineer. The other respondents were either a builder (1 respondent) or CEO (3 respondents) – see also results to Q3. Construction management and technology are the two key factors influencing the development of the construction industry. The respondents' roles have a direct impact on their responses.
3	15% of respondents have more than 40 years of experience and 10% have 21–40 years of experience (Figure 5.5).	This showed that there was great depth in the experience possessed by the respondents. Additionally, there is good representation throughout all experience ranges – this being key to obtaining data that is both meaningful and translatable (Olawale and Sun, 2010).
4	The majority (18 out of 20) of respondents were either working on, or had worked on, building projects, with one of these also working on landscaping.	One respondent had worked on water projects. One other respondent had worked on power transmission line projects.
5	The most frequent response (7/20 – 35%) was £11–50m.	This question sought to find the value of turnover in the companies in which respondents worked.
6	19 out of 20 (95%) respondents had between 1 and 10 live contracts at the time of undertaking the questionnaire (Figure 5.7).	1 out of 20 (5%) respondents had between 11 and 50 contracts. Smaller companies can more flexibly choose among LC methods and adapt with less effort.
7	19 out of 20 (95%) of the respondents, always apply time controls to their project; 1 respondent (5%) frequently applies time controls, and none of them (0.00%) rarely/do not apply time control techniques during projects (Figure 5.8).	The results show that most of the respondents apply time controls to their project which is an excellent response and shows that they would likely be keen and interested in the topic area and the new framework development.
8	Other techniques followed by simulation ranked as the most used technique and Gantt bar chart the least used.	Respondents were asked to rank/order the control techniques from the most important to the least important. (extremely important – 1; important – 2;

	Planning and time control techniques used for construction projects in Iran are: other techniques (score 8.40), simulation (7.71), Elemental Trend Analysis/Line of Balance (LOB) (7.5), PERT (7.42), PND (7.00), CPM (6.06), Milestone (6.06), and Gantt bar chart (5.88) (Figure 5.9).	neutral/no change – 3; unimportant – 4; extremely unimportant – 5). The popularity of these techniques might be due to their being the most established techniques in the industry, though ease of use and applicability to the construction process can also be argued as being responsible for their popularity. Other techniques used include those mentioned above. This echoes the results of Olawale and Sun (2010), who conducted a two-part UK-based survey on techniques used for: (a) project planning and time control and (b) software packages used for project planning and time control.
9	100% (20 out of 20 respondents) have used conventional/traditional time planning techniques (e.g. critical path methods, bar charts) for construction projects (Figure 5.10). Additionally, 15% (3/20) have used Lean time planning techniques such as Critical Chain programming and Last Planner.	Both modern (lean) (15%) (e.g. critical chain programming and last planner) and conventional/ traditional time planning techniques (100%) (e.g. critical path methods, bar charts) are used for construction projects in Iran. 100% (20) used conventional planning tools, and 3 also used lean approaches.
10	100% (20 out of 20) of the respondents utilised computer programs/packages when project planning (Figure 5.11).	For project planning they use computer programs and software. They structure detail plans (WWPs) from the master schedules (Questions 8–11).
11	80% of respondents said that computer software utilisation it is fully integrated in all planning levels of the company. 30% said that it is integrated partly; only one respondent (5%) said they are not using it (Figure 5.12).	The degree of computer software utilisation for the planning activity is: (Fully integrated 80%).
12	Deltek Open Plan Asta Powerproject Pertmaster	As can be seen from Figure 5.13 the use of software programs to support planning is widespread. Three clear leading applications are Deltek Open Plan, followed by Asta Powerproject and Pertmaster.
13	Respondents' assessment of the present methods of project planning are: none (0.00%): out of date; sufficient (26.32%); require upgrading/development, additional aspects need to be analysed, such as human factor (73.68%).	As can be seen from Figure 5.14, 73.68% (14/19) of the respondents said that the present methods of project planning require upgrading/development, and additional aspects, such as human factors, need to be analysed. Therefore, the application of both appropriate new technology and applying contemporary management concepts are likely to be two effective approaches to improving construction industry efficiency. One of the new management philosophies that have been considered for the UK construction industry is that of LT. LC, much like current practice, has the goal of better meeting customer needs while using less of everything, a term coined by the International Group for Lean Construction in 1993; it has been investigated by many researchers in recent years. This refers to the application of lean production principles and practices in design-construction processes to maximise value and to reduce waste.
14	The most common influencing factors that often lead to project time overruns, ranked from the most important, are: Skilled labour shortage; Poor labour productivity;	This question was asked to identify the most common factors that often lead to project time overruns in regard to the frequency of time overrun experienced.

	Inclement weather; Material shortages; Financing and payment of completed works.	
15	Most of the respondents are not aware of LPS: Yes (31.58%); No (68.42%).	Herein it is apparent that Twenty-one respondents (31.58%) mentioned that they are aware of the Last Planner Control System whilst Eight respondents (68.42%) are not.
16	Most of the respondents do nt use LPS: Yes (33.33%); No (66.67%).	Four out of 6 respondents don't use the Last Planner Systems (66.67%). Two of them (33.33%) used the LPS (Figure).
17	All of the respondents have noticed an improved cost performance index (CPI) after LPS was adopted: Yes (100%); No (0.00%).	Respondents were asked if they had seen any increase in CPI since adopting LPS. What is interesting here is that only 2 respondents answered this question. This may suggest they do not know or did not understand fully the question posed – unfortunately a 'do not know' option was not included. Of those that did respond, 100% (2 respondents) suggested they did see improvement in CPI, whereas 0.00% (0 respondent) saw no increase.
18	All of the respondents use PPC as a measurement: Yes (100%); No (0.00%).	Respondents were asked if they use PPC as a measure; once again, what is interesting to see is that only 3 of respondents answered this question. This may suggest they do not know or did not understand fully the question posed – unfortunately a 'do not know' option was not included. Of those that did respond, 100% (3 respondents) suggested they did use PPC as a measure, whereas 00.0% (0 respondent) suggested they did not.
19	More than half of the respondents would consider using LPS if not using it: Yes (53.33%); No (46.67%).	Respondents who were not using LPS were asked if they had ever considered using it (Figure 5.20). What is interesting here is that only 15 of respondents answered this question. Of those, 8 said they had considered adopting LPS, whilst 7 had not. When asked for further details, 2 respondents said they were not familiar with LPS. Although there is a lack of awareness of LC by several construction companies in Iran and in several of them the LC concept is not yet known adequately, it was found that they are ready for utilising LC practices.
20	Respondents' current structure of Weekly Work Plans (WWPs) is: build it on the master schedule and form/create additional information (45%); obtain and pick out from the master schedule (75%); totally form/construct a modern work plan (0.00%).	Respondents were asked how they currently structured their WWPs. Figure showed that 45% of respondents built it on the master schedule, whilst 0% construct a modern work plan. As can be seen from Figure 5.21, 45% of the respondents mentioned that they currently structure WWPs by building them on the master schedule and creating additional information. 75% of the respondents obtained and picked out from the master schedule, whilst none adopted another approach, which they specified.
21	Preferred techniques in the planning phase to accommodate uncertainties in the last phases of work are: set up and begin the process early (29.41%); use time buffers (70.59%); use resource buffers (11.67%).	Respondents were asked for their preferred technique to accommodate uncertainties in the last phases of work. Figure 5.22 shows that 29.41% of respondents set up and begin the process early (fast and quickly) whilst 70.59% use time buffers.

		According to Gregory A. Howell and Lauri Koskela, project management as taught by professional societies and applied in current practice must be reformed because it is inadequate today and its performance will continue to decline as projects become more uncertain, complex, and pressed for speed, and because of a deficient definition of control. Uncertainty: significant uncertainty exists throughout a project (Howell and Laufer, 1993). Project management based on an illusion of certainty cannot be effective. Laufer (1997) has suggested practices for project managers related to identifying, reducing, and coping with uncertainty.
22	Effectiveness of using LPS (Farayand Bahrevari).	The list shows that the respondents who have used LPS in their company have achieved better project completion – on time and reduced costs, etc. Although some of them mentioned that the system is not exactly called the Last Planner System, the principles are the same. They mentioned that programme layering is the reason the company likes to use the principles. There could also be some LC-like methods in place that have been developed through logic and common sense at the companies unaware of LC. The project manager becomes an individual client-based leader of the project team, the source of decision making, and the conduit for communication.
23	According to respondents, the effectiveness of the using LPS is/was Good (100%).	As can be seen from Figure 5.23 regarding the effectiveness of using LPS, 100% (3) of the respondents reported its effectiveness as Good.
24	Regarding any shortcomings, responses were: No (58.33%); Yes (33.33%); Other (8.33%; the systems needs to be more defined and usable).	As can be seen from Figure 5.24, 33.33% (4/12) of the respondents mentioned that there are shortcomings, which require development.
25	The most important problems for production control in construction are out-of-date methods for production management/control; attitude of people; type of construction projects; other.	From Figure 5.25, it can be seen that out-of-date methods for production management/control is the most common/ important problem as stated by 66.67% (12/18) of the respondents.
26	Factors that hamper the effective control of projects are finance and payments; poor labour productivity; and shortage of materials.	According to one respondent, finance and payments, poor labour productivity, and shortage of materials are factors that hamper the effective controlling of projects. According to Howell and Koskela, contracts can be managed by controlling against outcome variance from standards. Production management, which takes care of how work gets done, requires a more active sense of control. Unfortunately, control actions applied in today's form of project management are not benign. In effect, efforts to optimise activity performance reduce project performance.
27	The extent to which LC or LPS is used for	Regarding the extent of utilisation of LC or LPS, as

	production management is: not using it = 78.57%; testing on a number of works = 7.14%; completely utilised = 7.14%; at training level = 7.14%.	can be seen from Figure 5.26, 7.14% (1/14) of the respondents are testing it on several works. Training could help them utilise LC or LPS. The results show that training is an important part of implementing LPS.
28	The impact on production management of implementing the LPS. are Not applicable (41%); Excellent (32%), Good (24%).	The results in Figure 5.27 show that 32% of the respondents said that the impact of implementing the LPS is excellent/very good, and that control and management gets better and significantly increase all over and everywhere in production.
29	To guarantee that the real work follows the plan, 80% (16/20) of the respondents arrange an expert project management group; 40% rely on the quality of the subcontractor's work; and 5% think everyone should have the commitment to follow the plan that is understandable to them.	From Figure 5.28 it can be see that 80% (16/20) of the respondents mentioned that they should arrange an expert project management group in order to guarantee that the real work on site would follow the plan and conform to it. According to Ochao (2014), the process of delivering a high-performance sustainable building has led to a more complex construction practice through the increment of specialised processes. Such complexities have affected construction sequencing and timing, leading to workflow variability and excess in the estimated construction time and cost. In this study, reducing plan variations is considered a key improvement in the delivery process of sustainable building projects. This research used LPS to develop a more reliable production planning process to reduce plan variations. The implementation of LPS resulted in a significant reduction of plan variations. As variability decreased, production performance of activities increased. Plan variations are influenced by the amount of uncertainty (Wambeke et al., 2012). For example, there may be inverse to whether materials and/or equipment are delivered at the right time, or the recurrence of rework due to inexperienced workers, or even the frequency of design errors encountered (Horman et al., 2004; Thomas and Sanvido, 2000). Plan variations not only comprise the delivery of sustainable building projects but when delays occur they are also considered to be a form of waste (Koskela, 2000; Liker, 2004).
30	45% (9/20) of respondent always apply cost control while 55% (11/20) frequently apply it.	From looking at Figure 5.29 it can be see that the application of cost control is overwhelming, with 45% (9/20) of respondents indicating that they always apply their cost control method and 55% (11/20) indicating that they frequently do so. None of the respondents indicated that they rarely or do not use cost control techniques, buttressing the importance placed on cost control by construction project practitioners in Iran. According to Sun et al. (2010), this confirms the suggestion of Sohail et al. (2002) that construction professionals seem to pay more attention to cost performance of projects than time performance.

31	PERT/Cost Leading parameter method Value engineering Unit costing and earned value analysis Standard costing	From Figure 5.30 it can be seen that PERT/COST ranks as the most used technique and project cost-value reconciliation as the lowest. The three clear leading applications are PERT/COST, the leading parameter method, and value engineering. Several other techniques, such as unit costing and earned value analysis, and standard costing have also been used. Olawale and Sun (2010) conducted a survey on techniques and software packages used for project cost control in the UK.
32	COINS Bespoke/in-house systems Asta Powerproject Project costing system (PCS) Primavera SureTrak	From Figure 5.31 it can be seen that the cost control software programs used are COINS, bespoke/in-house systems, Asta Powerproject, PCS, and Primavera SureTrak.
33	Site conditions (Score 26.67); weather (26.67); lack of experience of project type (26.50); imported materials and plant items (26.00); and additional works (26.00) were the most common factors identified as often causing project cost overruns.	From Figure 5.32 it can be seen that site conditions ranks highest. Despite the wide application of cost and time control techniques and software, cost and time overruns are still quite common in construction projects.
34	Steps considered while doing quality management and control are Quality control and inspection (100%), quality assurance (15.79%), and quality measurement systems (15.79%).	From Figure 5.33 it can be seen that 100% (19/19) of the respondents consider quality control and inspection as a quality management and control step.
35	All of tools provided as options in the questionnaire have been used in the development of the main framework.	From Figure 5.34 it can be seen that Baldrige ranks as highest and quality control the lowest.
36	Factors leading to the problem of reduced and low quality are: variables causing cost overruns (65.00%); variations (35%) (project and client characteristics, project organisation factors); variables causing time overruns (30%); and errors/omissions in construction work (30%).	The results in Figure 5.35 show that variables causing cost overruns is the most important factor leading to the problem of reduced and low quality as chosen by 65% (13/20) of the respondents.
37	Respondents manage and control sustainability: (1) by sustainability assessment and (2) use of standard materials in quality control and also use of experienced labour.	The respondents answers regarding the sustainability management and control can be seen. The impact of lean on sustainability was observed and discussed.
38	Factors respondents consider regarding sustainability are: sustainable indicators and benchmark (25.00%) and sustainable assessment (83.33%).	From Figure 5.36 it can be see that 83.33% (10/12) of the respondents consider sustainable assessment as a factor regarding sustainability. According to Ogunbiyi et al. (2014), regarding integrating lean and sustainability, Houvila and Koskela (1998) raised the potential and profitability of lean principles to promote sustainable construction and a requirement framework was presented. Ogunbiyi et al. (2014) conducted research and a questionnaire survey on the impact of LC techniques

		on sustainable construction in the UK. The following are the results: Benefits of synchronising lean and sustainability: improved corporate image, increased productivity, reduction in waste, reduction in energy consumption, improvement in sustainable innovation, improved process flow, reduction in material usage, reduced cost and lead time, improvement in health and safety, improvement in environmental quality, reduction in water usage, increased sustainable competitive advantage, increased compliance with customers' expectation, increased employee morale and commitment. Lean principles/techniques for enabling sustainability: JIT, visualisation tool, daily huddle meetings, value analysis, VSM, TQM, fail safe for quality, 5Ss, TPM, first run studies, Last Planner, CE, pull approach, kanban, kaizen, Six Sigma. Areas of linkage between LC and sustainability: waste reduction, environmental management, value maximisation, health and safety improvement, performance maximisation, design optimisation, quality improvement, resource management, energy minimisation, elimination of unnecessary process, continuous improvement, cost reduction.
39	The top 5 methods that have been used in respondents' companies for construction planning efforts are: CPM (100%); long-term planning (55%); short-term planning (45%); buffer (20%); LPS (10%) (refer to Figures 4.8, 4.9, and 5.67).	As can be seen from Figure 5.37, CPM (100%), long-term planning (55%), and short-term planning (45%) are three clear leading methods used for planning.
40	The top 4 methods that have been used in respondents' companies for implementation are: other (70%); LPS (20%); LSS (20%); and Six Sigma (10%) (see also Figures 4.10 and 5.68).	As can be seen from Figure 5.38, other (70%) followed by LPS (20%), LSS (20%), and Six Sigma (10%) are the four clear leading methods used for implementation. The breakdown of 'other' are as follows: experimental controlling method (experimental control); traditional way and methods are used; based on experiment).
41	Methods that have been used in respondents' companies for monitoring/control are: commitment-based planning (90%) other (20%: traditional control methods such as visual control; only by control of maps and eye and lab control); and LPS (10%) (see also Figures 4.11 and 5.69).	As can be seen from Figure 5.39, commitment-based planning (90%), other methods (20%), and LPS (10%) are the three clear leading methods used for monitoring and control.
42	Respondents review their construction process by PPC (100%) and other methods (7.14%: also financial control) (see also Figures 4.12 and 5.70).	As can be seen from Figure 5.40, PPC (100%) is the clear leading method used for review.
43	Most respondents measure the reasons for failure of the project process: Yes (87.50%); No (12.50%).	From the results for this question it appears that 87.50% of the respondents measure reason for failure of the project process (Figure 5.41).
44	Most respondents use root cause analysis: Yes (87.50%); No (12.50%).	From the results for this question it appears that 87.50% of the respondents root-cause analysis (Figure 5.42).

45	At the operational level, most respondents do not measure cost performance: Yes (37.50%); No (62.50%) (Q45).	From the results for this question it appears that 37.50% of the respondents measure cost performance at the operational level (Figure 5.43).
46	In assigning tasks, most respondents do not think that shielding is essential and important: Yes (30%); No (70%) (Q46).	From the results for this question it appears that 30% of the respondents believe that in assigning tasks, shielding is essential and important (Figure 5.44).
47	Issues and operations related to waste on Iranian sites, ranked from most important are: (1) cutting of reinforcement (score 4.44); (2) wrong or improper welding; (3.a) improper excavation (total 17); 3.b general waste (total 18) (3.a = 3.b, the same score); (4) pouring concrete.	From Figure 5.45 cutting of reinforcement ranks as highest and pouring concrete the lowest.
48	The top 5 identified areas of waste and value-loss found on site are ground preparation (score 7.92), soil condition (7.00), weather conditions (rain, snow, etc., 6.91), material handling (6.71), and breakdown of equipment (6.50).	From Figure 5.46 it can be seen that other followed by ground preparation ranks as highest and maintenance (repairs) the lowest. According to Abdulmalek et al. (2007), TPS or Lean Manufacturing focuses on pinpointing the major sources of waste, and then using tools such as JIT, production smoothing, setup reduction, and others to eliminate the waste. The most common lean tools are: JIT, kanbans, TPM, TQM, 5Ss. VSM: A value stream is a collection of all actions (value-added) that are required to bring a product (or a group of products that use the same resources) through the main flows, starting with raw material and ending with the customer (Rotherham and Shook, 1999). These actions consider the flow of both information and materials within the overall supply chain. The ultimate goal of VSM is to identify all types of waste in the value stream and to take steps to try and eliminate these (Rotherham and Shook, 1999). According to Salem et al. (2006), the combined effect of on-site, one-of-a-kind, and complex production is uncertainty. 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.
49	From the most to least important, the types of waste which are most relevant to the activities during the construction phase are: overproduction (score 21.75), excess inventory (21.67), over-processing (21.60), poor level of commitment to quality improvement (20.60), and construction defects (20.50).	From Figure 5.47 it can be seen that overproduction ranks highest. In order to reduce waste, the improvement should be focused on eliminating non-value-adding or flow activities and making conversion or value-adding activities more efficient. Waste in production process comes in many forms, for example Ohno's seven wastes (Ohno, 1998): (1) The waste of overproduction of goods not needed (producing more or doing more than is needed);

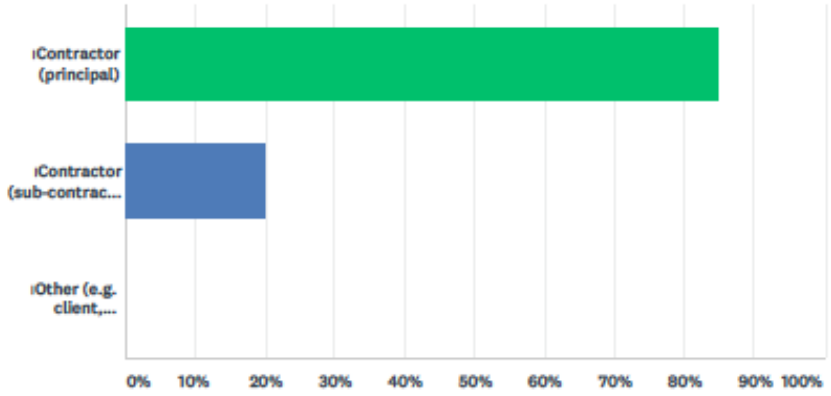
		(2) Waiting by employees for a procedure; (3) Unnecessary motions; (4) Transporting (or conveyance); (5) Overprocessing (or inappropriate processing); (6) Unnecessary inventory; and (7) Defects in products that must be corrected. Womack and Jones (1996) added to this list 'goods and services that do not meet customer needs'. Terry and Smith (2011) also suggested that skills misuse could also be considered as waste. Waste in construction impacts in many ways, not least regarding (Koskela et al. (2013): (1) Quality costs; (2) External quality cost during facility use; (3) Lack of constructability (4) Variation in material requirement (poor materials management); (5) Excess consumption of materials on site; (6) Working time used for non-value-adding activities on site; and (7) Lack of safety.
50	Impacts that respondents have seen on waste on site since adopting LPS are: less waste (66.67%) and neutral/no change (33.33%).	Since adopting LPS, 33.33% of the respondents mentioned they have seen neutral/no change in waste on site, while 66.67% mentioned less waste (Figure 5.48).
51	By developing and adopting new construction control, measurement, and performance methods, respondents have seen: significantly less waste (46.67%), less waste (46.67%), and neutral/no change (6.67%).	From Figure 5.49 it can be seen that 46.67% of the respondents mentioned that by developing and adopting new methods, there is significantly less waste on site.
52	By adopting the new methods, respondents say that the following wastes will be eliminated from the construction process: construction changes; unrealistic constraints of project time.	According to a respondent, through waste elimination, the problems in Question 49 would be reduced.
53	From Figure 5.50 improve/develop the quality of material ranks as highest and improve project planner's abilities the lowest.	The significance of the techniques for improving the reliability of planning are Other, Improve/develop the quality of material, Improve project planner's abilities, Improve/develop the quality of labour, learn from previous works and projects, Employ specialist teams (Q53).
54	The types of training undertaken by respondents' staff as part of the Improvement program for Iranian construction projects were: other (57.14%: all not using/not working with LPS), in-house training (42.86%), and attendance at external workshops/courses (42.86%).	From Figure 5.51 it can be seen that in-house training and attendance at external workshops/courses rank equal highest and online training/courses the lowest.
55	Factors affecting respondents' ability to effectively control the time of their construction projects are: use of inappropriate software (score 20.67); contract and specification interpretation	From Figure 5.52 use of inappropriate software ranks as highest. Olawale and Sun (2010) conducted a survey and identified factors inhibiting project cost and time

	disagreement (20.20); discrepancies in contract documentation (20.00); project fraud and corruption (20.00); and conflict between project parties (19.67).	control and classification; and ranked the factors inhibiting effective project time and cost control in the UK.
56	Factors affecting respondents' ability to effectively control the cost of their construction projects are: use of inappropriate software; complexity of works; unpredictable weather conditions; lack of proper training and experience of project manager; and project fraud and corruption.	From Figure 5.53 it can be seen that use of inappropriate software ranks as highest.
57	The problems faced by the construction industry are inferior working conditions: (score 25.00), the presence of foreign competition (26.00), constraints (25.00), complexity (25.33), transition of method problem (25.00).	From Figure 5.54 it can be seen that inferior working conditions ranks as highest.
58	The significant barriers to the successful implementation of LC in Iran are: financial issues (score 11.00); culture and human attitudinal issues (9.67); lack of process-based PMSs (9.63); time and commercial pressure (9.57); and structural and cultural barriers (9.50).	From Figure 5.55 it can be seen that a lack of top management commitment ranks as highest and procurement and contracts the lowest. Lean implementation begins with leadership commitment and is sustained with a culture of continuous improvement. Sarhan and Fox (2013) conducted a questionnaire survey on barriers to implementing LC in the UK construction industry, and found that the most common were: 1. Fragmentation and subcontracting (both developed and developing nations); 2. Procurement and contracts; 3. Culture and human attitudinal issues; 4. Financial issues; 5. Lack of top management commitment and support; 6. Design/construction dichotomy; 7. Lack of adequate lean awareness/understanding; 8. educational issues; and 9. Lack of customer-focused and process-based performance measurement systems.
59	Most of the respondents do not measure earned value or cost performance at the assignment level: Yes (38.46%), No (61.54)%.	Figure 5.56 shows that 38.46% of the respondents measure earned value at the assignment level.
60	**Any other comments** Reducing variability to improve performance and improving labour flow reliability for better productivity as lean construction principles. The results showed that there was strong support that more reliable material, information, and equipment availability contributes to better performance.	**Any other comments** The construction industry has adapted lean techniques to eliminate waste and increase profit. It was found that there is a need for behavioural changes and training for effective use of lean tools. Most of the lean construction tools, selected for the project, are either ready to use or are recommended with some modifications.
61	Consent form responses.	The comment box
62	Consent form responses.	The consent form is shown in Figure 5.57.

		By presenting one of the first comprehensive research efforts on LC in Iran, hopefully this research will help raise the awareness of LC in the country.

Theme 1: Questions 1 to 6 – General Information Questions

Q1 – What is your company class?



ANSWER CHOICES	RESPONSES	
Contractor (principal)	85.00%	17
Contractor (sub-contractor)	20.00%	4
Other (e.g. client, consultancy, government agency etc.): Please specify	0.00%	0
Total Respondents: 20		

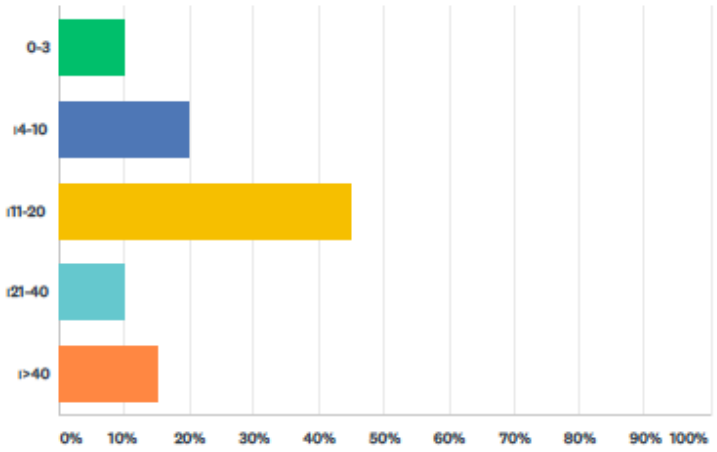
#	PLEASE SPECIFY
	There are no responses.

Figure 5.4: Respondents' company class

Q2 – What is your main responsibility/position/role?

#	RESPONSES
1	Project Manager
2	Construction manager
3	Chief Executive Officer
4	Construction manager
5	Design Engineer
6	Engineer
7	Planning Engineer
8	Civil Engineer
9	Planning Engineer
10	Planning engineer
11	Engineer
12	Builder
13	Planning Engineer
14	Design Eng. in water work projects
15	construction manager
16	CEO
17	Construction manager
18	Project Manager
19	Chief planning Engineer
20	CEO, Managing director

Q3 – How many years of experience do you have?



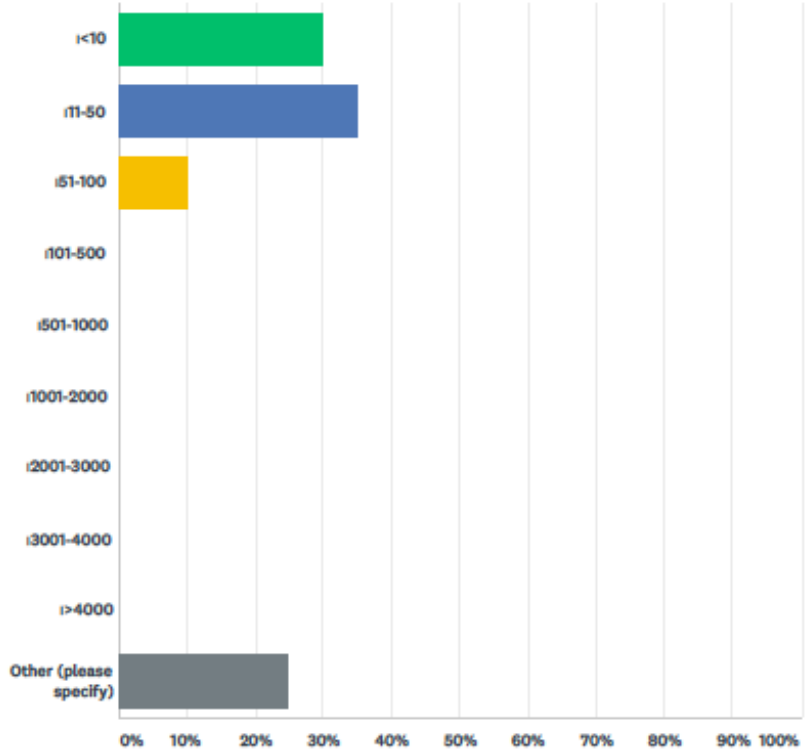
ANSWER CHOICES	RESPONSES	
0-3	10.00%	2
4-10	20.00%	4
11-20	45.00%	9
21-40	10.00%	2
>40	15.00%	3
TOTAL		20

Figure 5.5: Respondents' years of experience

Q4 – What types of project do/have you worked on?

#	RESPONSES
1	Residential buildings
2	Residential Building
3	Building
4	building
5	Building/construction/civil design
6	Building
7	Building
8	building / construction / developer
9	Building
10	Building
11	Construction
12	Building
13	building
14	Water works: Water & waste water treatment plants, Pump stations, Reverse osmosis treatment systems which includes process and civil design.
15	building
16	Power Transmission Line
17	Residential Building
18	Residential buildings
19	building and relevant mechanical & electrical works plus landscaping
20	Buildings (dwelling)

Q5 – What is your company's total turnover (£m)?

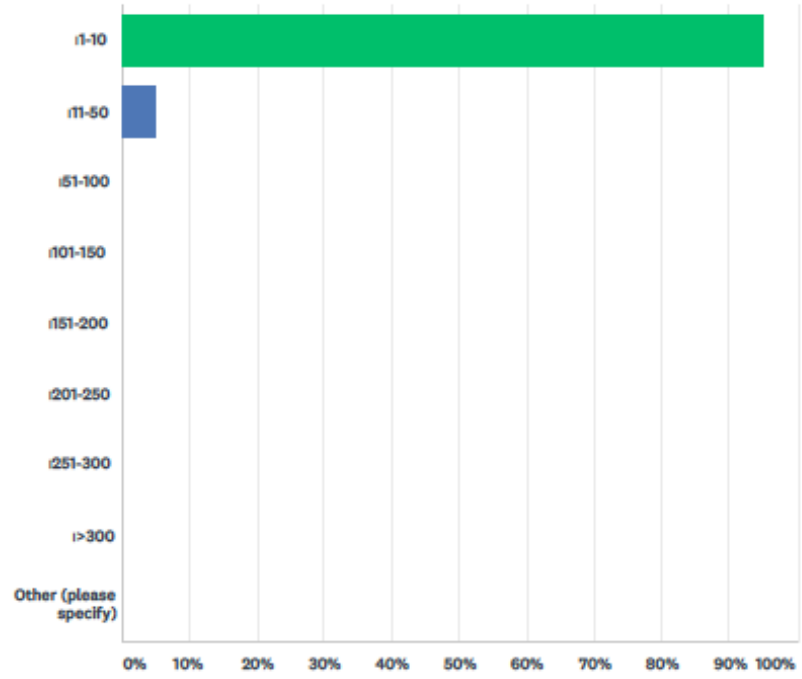


ANSWER CHOICES	RESPONSES	
<10	30.00%	6
11-50	35.00%	7
51-100	10.00%	2
101-500	0.00%	0
501-1000	0.00%	0
1001-2000	0.00%	0
2001-3000	0.00%	0
3001-4000	0.00%	0
>4000	0.00%	0
Other (please specify)	25.00%	5
TOTAL		20

Figure 5.6: Respondents' companies' total turnover

#	OTHER (PLEASE SPECIFY)
1	Iran: 1-1.5
2	Iran: <1
3	Iran: 1-1.5
4	Iran: 1-1.5
5	Iran: 1-1.5

Q6 – How many live contracts do you have?



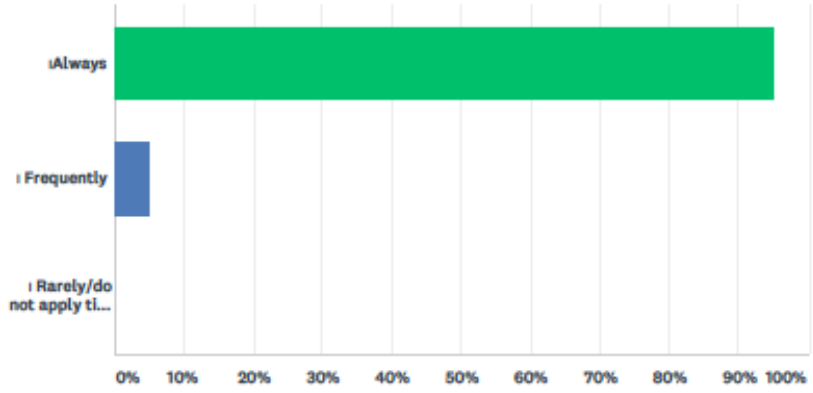
ANSWER CHOICES	RESPONSES	
1-10	95.00%	19
11-50	5.00%	1
51-100	0.00%	0
101-150	0.00%	0
151-200	0.00%	0
201-250	0.00%	0
251-300	0.00%	0
>300	0.00%	0
Other (please specify)	0.00%	0
TOTAL		20

#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 5.7: Number of live contracts

Theme 2: Question 7 – Planning and Time Control

Q7 – Do you apply time controls to your projects?

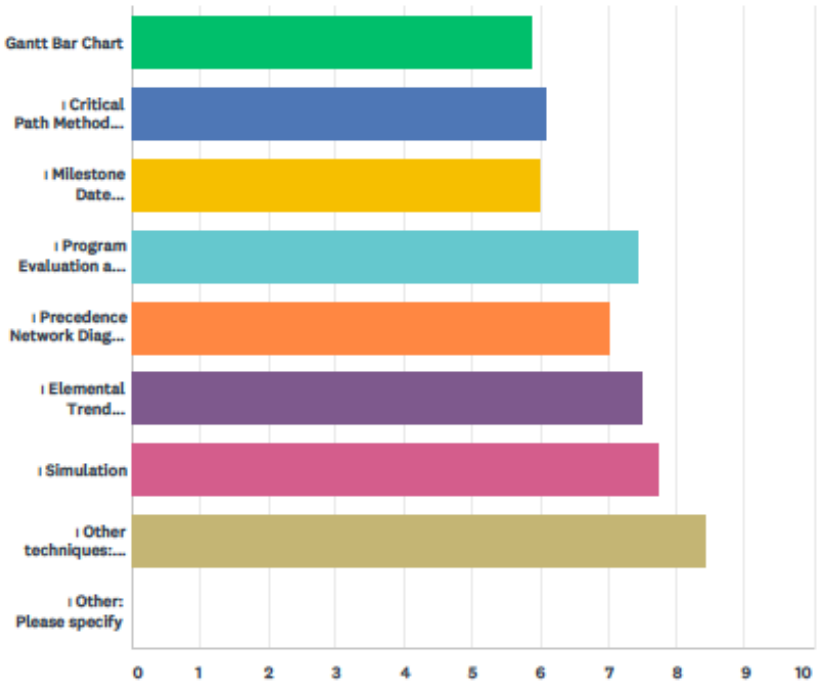


ANSWER CHOICES	RESPONSES	
Always	95.00%	19
Frequently	5.00%	1
Rarely/do not apply time control techniques during projects	0.00%	0
TOTAL		20

Figure 5.8: Application of time controls

Theme 3: Questions 8 to 13 – Time Control Techniques and Software Applications

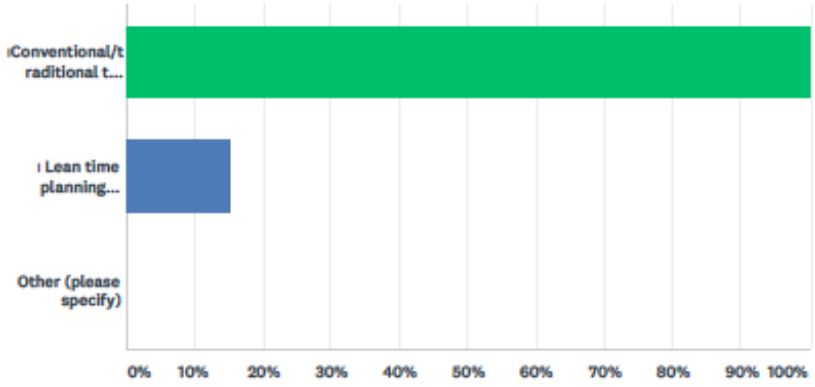
Q8– In terms of planning and time control, which of the following control techniques do you use?



	1	2	3	4	5	6	7	8	9	TOTAL	SCORE
Gantt Bar Chart	0.00% 0	5.88% 1	0.00% 0	70.59% 12	23.53% 4	0.00% 0	0.00% 0	0.00% 0	0.00% 0	17	5.88
Critical Path Method (CPM) (Critical Path Networks/Method)	11.76% 2	5.88% 1	5.88% 1	29.41% 5	47.06% 8	0.00% 0	0.00% 0	0.00% 0	0.00% 0	17	6.06
Milestone Date Programming Technique	0.00% 0	16.67% 1	16.67% 1	16.67% 1	50.00% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	6.00
Program Evaluation and Review Technique (PERT)	33.33% 4	25.00% 3	16.67% 2	0.00% 0	25.00% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	12	7.42
Precedence Network Diagram (PND)	0.00% 0	12.50% 1	75.00% 6	12.50% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	7.00
Elemental Trend Analysis/Line of Balance (LOB)	0.00% 0	50.00% 2	50.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	7.50
Simulation	14.29% 1	42.86% 3	42.86% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	7	7.71
Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	70.00% 7	10.00% 1	10.00% 1	10.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	10	8.40
Other: Please specify	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

Figure 5.9: Techniques used for project planning and time control

Q9 – What kind of planning techniques do you use for construction projects?

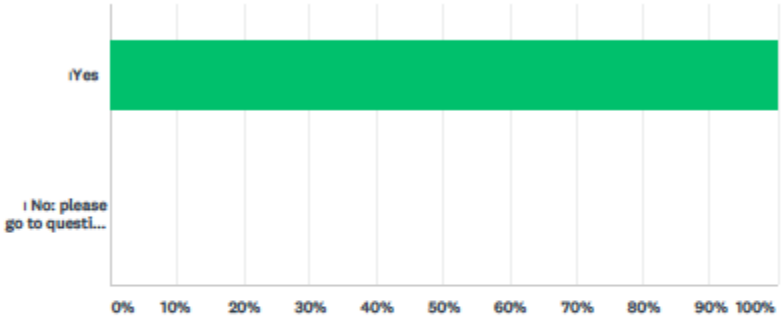


ANSWER CHOICES	RESPONSES	
Conventional/traditional time planning techniques (e.g. Critical Path Methods, Bar charts)	100.00%	20
Lean time planning techniques (e.g. Critical Chain Programming and Last Planner)	15.00%	3
Other (please specify)	0.00%	0
Total Respondents: 20		

#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 5.10: Kind of planning techniques used

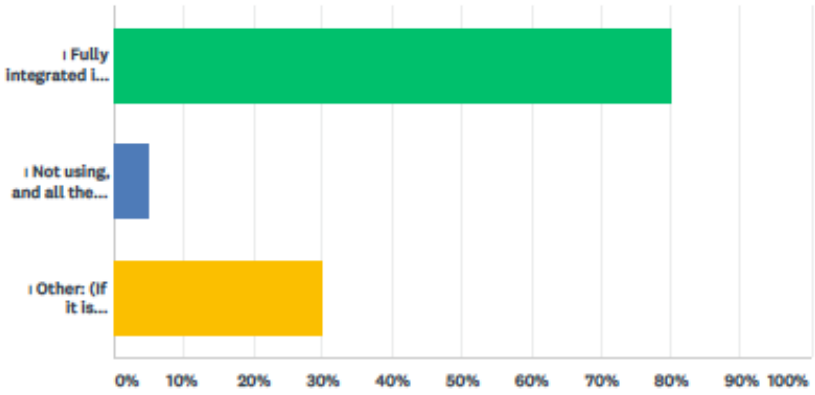
Q10 – For project planning, do you utilise computer programs/packages



ANSWER CHOICES	RESPONSES	
Yes	100.00%	20
No: please go to question 13	0.00%	0
TOTAL		20

Figure 5.11: Utilisation of computer program for project planning

Q11– For the planning activity of the company, what is the degree of computer software utilisation and/or how do you rank/assess and evaluate that?

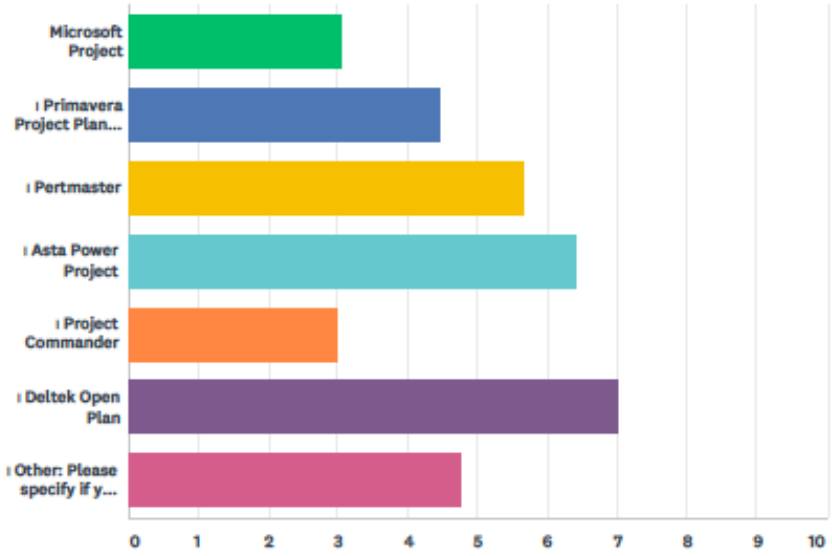


ANSWER CHOICES	RESPONSES	
Fully integrated in all planning levels	80.00%	16
Not using, and all the planning process are prepared and complete by hand	5.00%	1
Other: (If it is integrated partly, please state the part(s) which require software program utilization), Please specify	30.00%	6
Total Respondents: 20		

#	OTHER (PLEASE SPECIFY)
1	Both above choices, fully and partly, based on the type of the planning activity that is carried out.
2	Fully and partly based on the specific activity
3	It differs in different levels, it's a mixture of fully integrated and partly integrated in different levels.
4	partly
5	Partly integrated
6	80% integrated in planning levels but about 20% of activities are manually planned usually small leftover activities.

Figure 5.12: Degree of computer software utilisation for planning

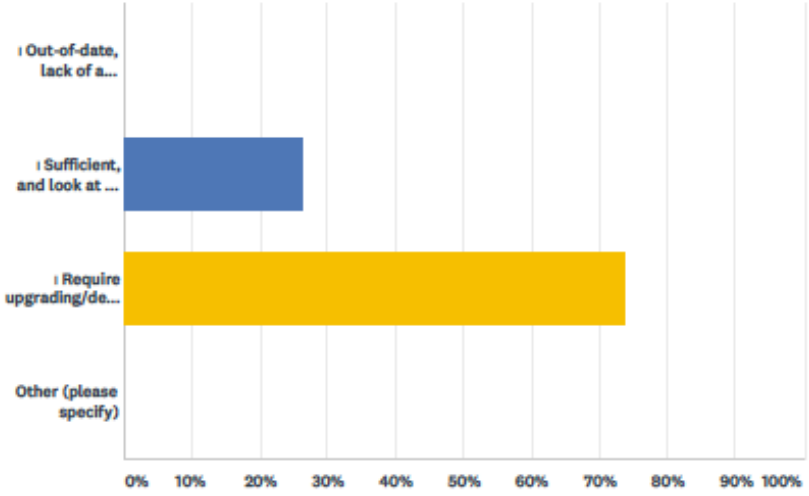
Q12 – What software programs do you use for planning and scheduling?



	1	2	3	4	5	6	7	TOTAL	SCORE
Microsoft Project	0.00% 0	0.00% 0	0.00% 0	5.00% 1	95.00% 19	0.00% 0	0.00% 0	20	3.05
Primavera Project Planner	0.00% 0	0.00% 0	54.55% 6	36.36% 4	9.09% 1	0.00% 0	0.00% 0	11	4.45
Pertmaster	0.00% 0	66.67% 6	33.33% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	9	5.67
Asta Power Project	71.43% 5	14.29% 1	0.00% 0	14.29% 1	0.00% 0	0.00% 0	0.00% 0	7	6.43
Project Commander	0.00% 0	0.00% 0	0.00% 0	50.00% 1	0.00% 0	50.00% 1	0.00% 0	2	3.00
Deltek Open Plan	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	7.00
Other: Please specify if you are using any other software packages.	25.00% 1	0.00% 0	0.00% 0	75.00% 3	0.00% 0	0.00% 0	0.00% 0	4	4.75

Figure 5.13: Software programs used for planning and scheduling

Q13 – How do you assess the present methods of project planning?



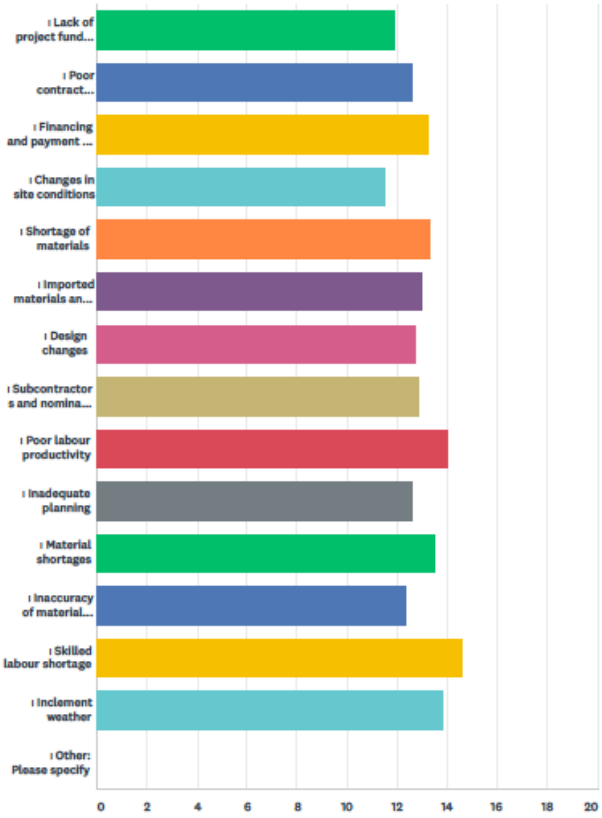
ANSWER CHOICES	RESPONSES	
Out-of-date, lack of a number of important aspects, such as human factor	0.00%	0
Sufficient, and look at the whole aspects/parts of a project	26.32%	5
Require upgrading/development, additional aspects need to be analyze, such as human factor	73.68%	14
Other (please specify)	0.00%	0
TOTAL		19

#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 5.14: Assessment of the present project planning methods

Theme 4: Question 14 – Time Overruns

Q14 – What factors lead to project time overruns?



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL	SCORE
Lack of project funding	20.00% 2	0.00% 0	0.00% 0	10.00% 1	70.00% 7	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	10	11.90
Poor contract management	0.00% 0	18.18% 2	36.36% 4	36.36% 4	9.09% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	11	12.64

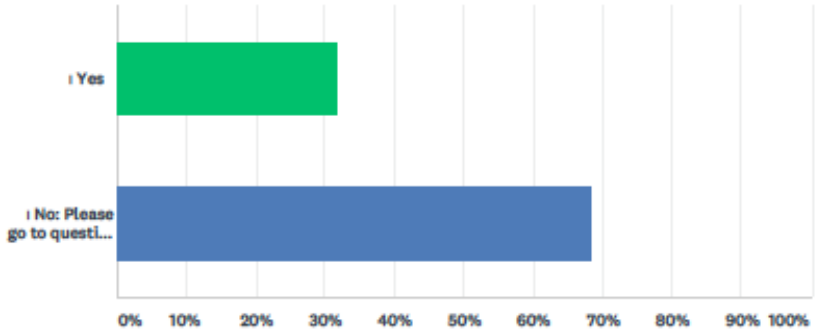
Financing and payment of completed works	37.50% 3	12.50% 1	12.50% 1	12.50% 1	25.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	13.25
Changes in site conditions	0.00% 0	0.00% 0	0.00% 0	50.00% 1	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	11.50
Shortage of materials	0.00% 0	33.33% 1	66.67% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	13.33
Imported materials and plant items	33.33% 1	0.00% 0	33.33% 1	0.00% 0	33.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	13.00
Design changes	11.11% 1	33.33% 3	11.11% 1	11.11% 1	33.33% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	9	12.78
Subcontractors and nominated suppliers	15.38% 2	30.77% 4	0.00% 0	30.77% 4	23.08% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	13	12.85
Poor labour productivity	40.00% 2	20.00% 1	40.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	14.00
Inadequate planning	9.09% 1	0.00% 0	45.45% 5	36.36% 4	9.09% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	11	12.64
Material shortages	0.00% 0	50.00% 1	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	13.50
Inaccuracy of material estimate	0.00% 0	0.00% 0	50.00% 3	33.33% 2	16.67% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	12.33
Skilled labour shortage	60.00% 6	40.00% 4	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	10	14.60
Inclement weather	20.00% 1	60.00% 3	0.00% 0	20.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	13.80
Other: Please specify	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

Figure 5.15: Factors that lead to project time overruns

Theme 5: Questions 15 to 24 – Lean Time Planning Techniques

Questions 15 to 24 were derived to establish the knowledge (and application) of respondents when it comes to the plethora of Lean time planning techniques that currently exist.

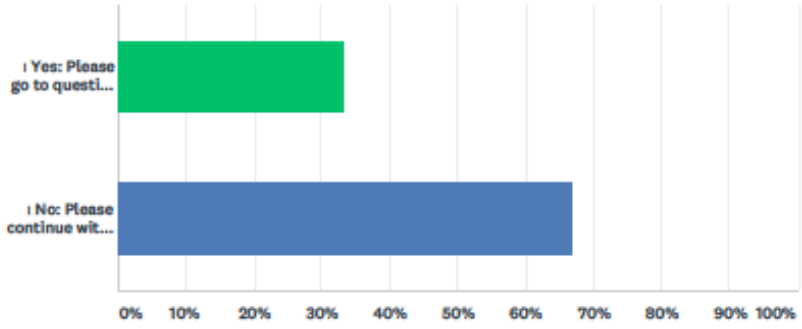
Q15 – Are you aware of the Last Planner System (LPS)?



ANSWER CHOICES	RESPONSES	
Yes	31.58%	6
No: Please go to question 19	68.42%	13
TOTAL		19

Figure 5.16: Awareness of the Last Planner System

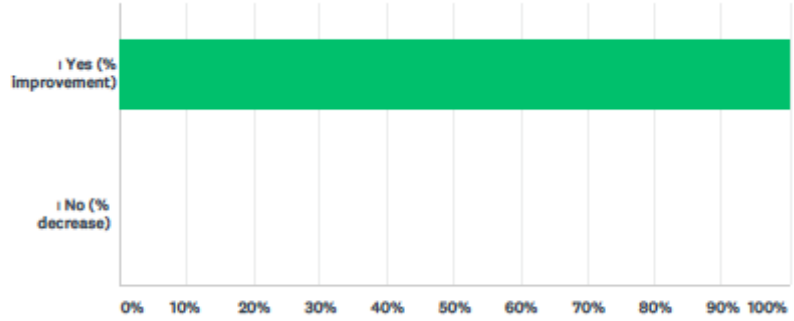
Q16 – Do you use the Last Planner System (LPS)?



ANSWER CHOICES	RESPONSES	
Yes: Please go to question 17	33.33%	2
No: Please continue with Question 20	66.67%	4
TOTAL		6

Figure 5.17: Use of the Last Planner System

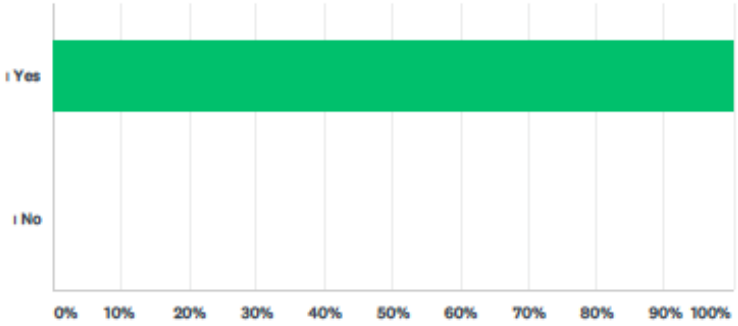
Q17 – After the Last Planner System (LPS) was adopted have you seen an improvement in Cost Performance Index (CPI)?



ANSWER CHOICES	RESPONSES	
Yes (% improvement)	100.00%	2
No (% decrease)	0.00%	0
TOTAL		2

Figure 5.18: Improvement of CPI after LPS adopted

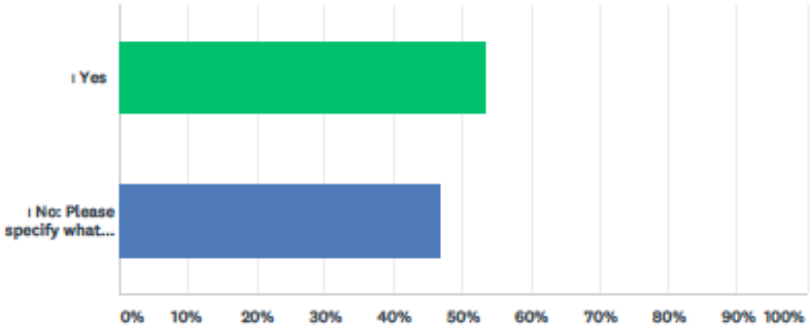
Q18 – Do you use Percent Plan Complete (PPC) as a measure?



ANSWER CHOICES	RESPONSES	
Yes	100.00%	3
No	0.00%	0
TOTAL		3

Figure 5.19: Use of PPC as a measurement

Q19 – If you are not using LPS, have you ever considered using it?

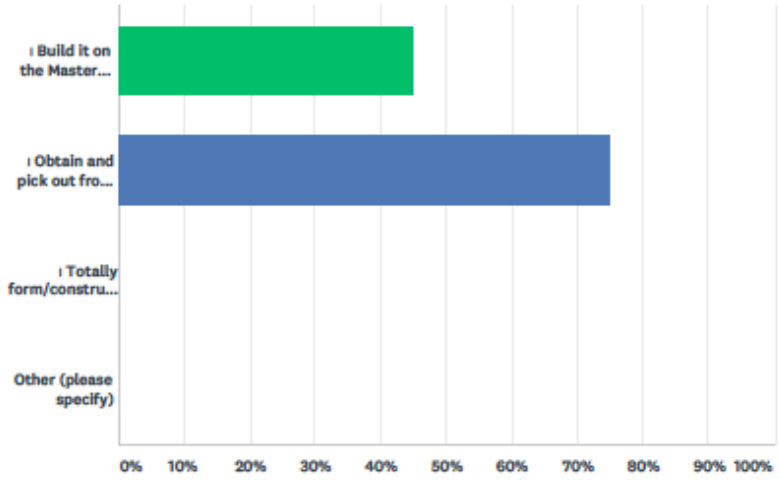


ANSWER CHOICES	RESPONSES	
Yes	53.33%	8
No: Please specify what reasons convinced you NOT to use it?	46.67%	7
TOTAL		15

#	PLEASE SPECIFY
1	Know nothing about the Last Planner System.
2	not familiar with Last Planner System.

Figure 5.20: Consideration of using LPS

Q20 – How do you currently structure Weekly Work Plans (WWPs)?

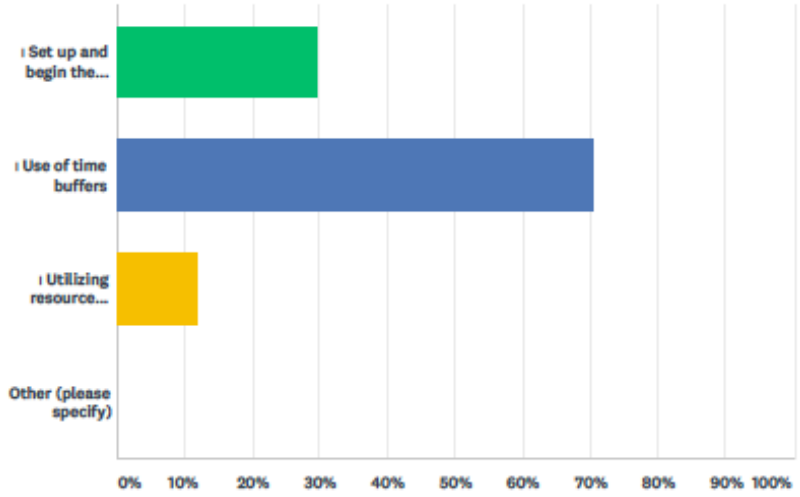


ANSWER CHOICES	RESPONSES	
Build it on the Master schedule and form/create additional information	45.00%	9
Obtain and pick out from the master schedule	75.00%	15
Totally form/construct a modern work plan	0.00%	0
Other (please specify)	0.00%	0
Total Respondents: 20		

#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 5.21: Current structure of WWPs

Q21 – In order to accommodate uncertainties in the last phases of work, which of the following is your preferred technique in the planning phase?



ANSWER CHOICES	RESPONSES	
Set up and begin the process early (fast and quickly)	29.41%	5
Use of time buffers	70.59%	12
Utilizing resource buffers	11.76%	2
Other (please specify)	0.00%	0
Total Respondents: 17		

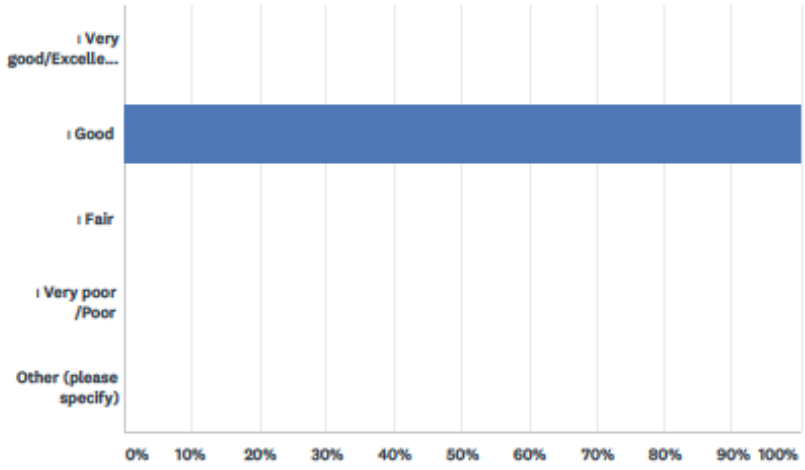
#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 5.22: Preferred technique to accommodate uncertainties in planning

*Q22 – **open ended** – If you have been using the Last Planner System, can you please say what it was that resulted in its adoption by your company? (Has it had an impact? Has it been useful? Do you find this effective?)*

#	RESPONSES
1	The system's name is not exactly known as the Last Planner System but has the same parts.
2	According to an Engineer Interviewee, ""another name" for "Lean Construction" in Iran, which is used in Farsi/Persian language as a synonym word to Lean Construction is ""FARAYAND BAHREVARI" which the English translation of each of the words separately would be as follows: FARAYAND means Process or Procedure, and BAHREVARI means Benefit or Profit. So it would be Benefitting or Profiting Process (Exploitation Process). So Benefit Process means a Procedure that brings Benefit for everyone and provide Profit for company and the work and also increase the Value and the Quality of work and the final product, and also manage and control Construction Time and Cost so that the project completed on time or earlier and within budget and also tries to reduce or eliminate Waste, and works towards Customer Satisfaction, and so in many ways it is similar to the Lean Construction philosophy. And the interviewee engineer has used the "FARAYAND BAHREVARI" in his own construction company, which brought satisfactory results for the company. ("An Iranian Engineer, Mr. Kazem Heydarbarghi, who was self employed (the owner) in Iran provided this interesting view about "FARAYAND BAHREVARI"). There are different kinds of production in Iran, which according to Interviewee Engineers, the following are some of the common examples of construction production at Iranian sites: • Aggregate production • Materials production • Construction materials • Dwelling • Building production Building and construction is a kind of production.

Q23 – If you use the Last Planner System, I'd like to explore its effectiveness. How have you measured its effectiveness? And how do you know it's been effective?

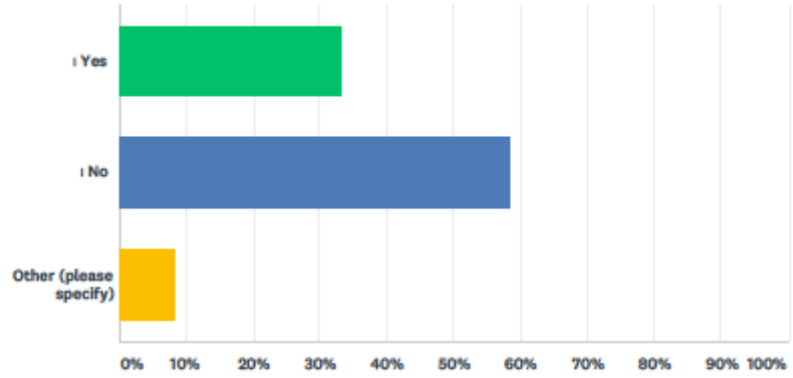


ANSWER CHOICES	RESPONSES	
Very good/Excellent	0.00%	0
Good	100.00%	3
Fair	0.00%	0
Very poor /Poor	0.00%	0
Other (please specify)	0.00%	0
TOTAL		3

#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 5.23: Effectiveness of using LPS

Q24 – Are there any shortcomings that you can tell me about?



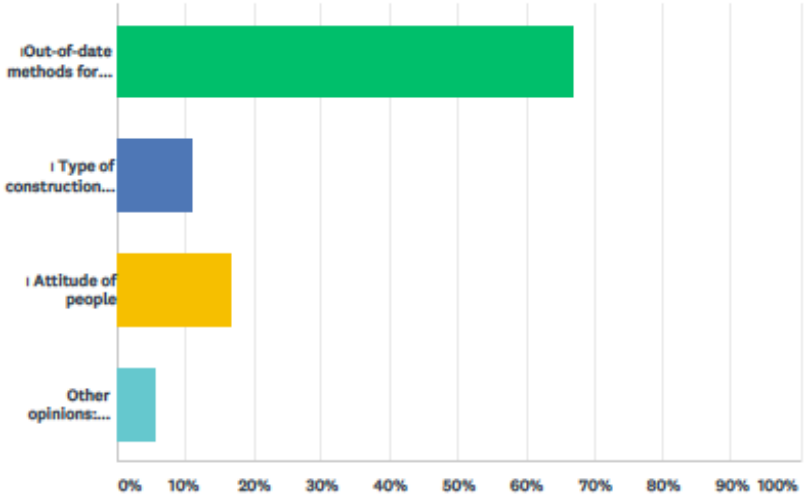
ANSWER CHOICES	RESPONSES	
Yes	33.33%	4
No	58.33%	7
Other (please specify)	8.33%	1
TOTAL		12

#	OTHER (PLEASE SPECIFY)
1	Yes, the system needs to be more defined and usable, and therefore it is a very good idea that a new developed system would be introduced that can complete and develop the current system in use.

Figure 5.24: Any shortcomings

Theme 6: Questions 25 to 28 – Production Control in Construction

Q25 – For production control/management in construction, which of the following is the common/presently most important problem?



ANSWER CHOICES	RESPONSES	
Out-of-date methods for production management/control	66.67%	12
Type of construction projects	11.11%	2
Attitude of people	16.67%	3
Other opinions: Please specify	5.56%	1
TOTAL		18

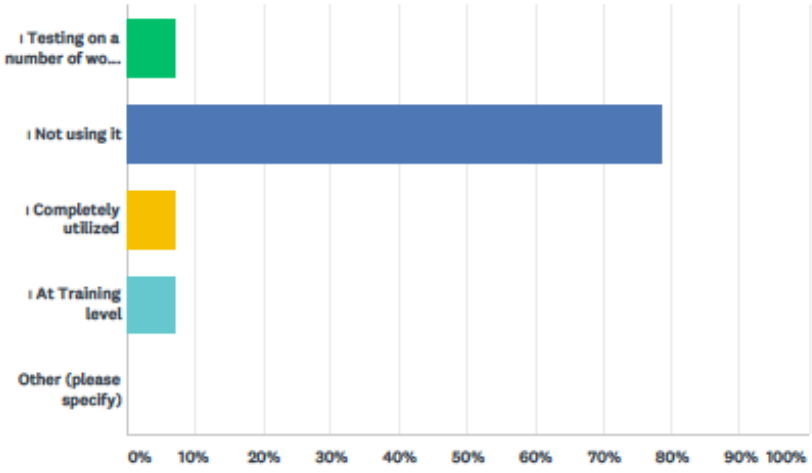
#	OTHER OPINIONS: PLEASE SPECIFY
1	Type of construction projects Attitude of people

Figure 5.25: The most important problems for production control

Q26 – Which factors hamper the effective controlling of projects?

#	RESPONSES
1	Finance and payments, poor labour productivity and shortage of materials

Q27 – For production management/control in your firm, to what extent is lean construction or The Last Planner System used?

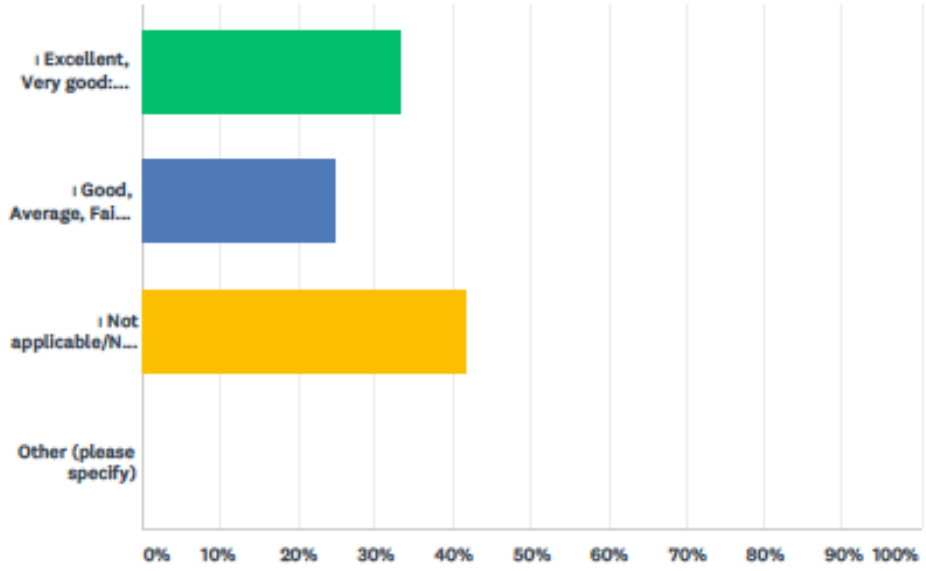


ANSWER CHOICES	RESPONSES	
Testing on a number of works	7.14%	1
Not using it	78.57%	11
Completely utilized	7.14%	1
At Training level	7.14%	1
Other (please specify)	0.00%	0
TOTAL		14

#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 5.26: Extent of utilisation of LC or LPS

Q28 – Based on your experience so far, how do you assess/evaluate the impact on production management of implementing The Last Planner System?



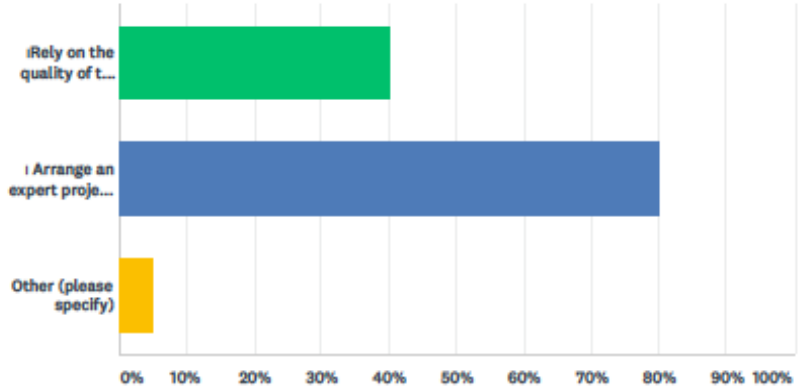
ANSWER CHOICES
Excellent, Very good: control and management gets better/increase significantly all over and everywhere in production
Good, Average, Fair: Improvement/development can be seen and is visible
Not applicable/Not working/Not practical: Does not assist to advance production control/management
Other (please specify)
TOTAL

#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 5.27: Impact of implementing LPS

Theme 7: Question 29 – Planning Reliability

Q29 – What should be done in order to guarantee that the real work on site would follow the plan and conform to it?



ANSWER CHOICES	RESPONSES	
iRely on the quality of the subcontractor's work	40.00%	8
ı Arrange an expert project management group	80.00%	16
Other (please specify)	5.00%	1
Total Respondents: 20		

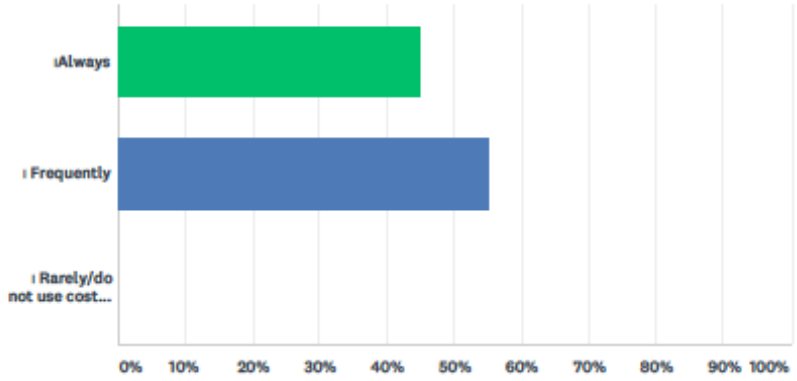
#	OTHER (PLEASE SPECIFY)
1	Everyone should have the commitment to follow the plan that is understandable by them.

Figure 5.28: Things to do to follow the plan

Theme 8: Questions 30 to 32 – Cost Management of Construction Projects

Cost Control Practices

Q30 – Do you apply cost controls to your project?

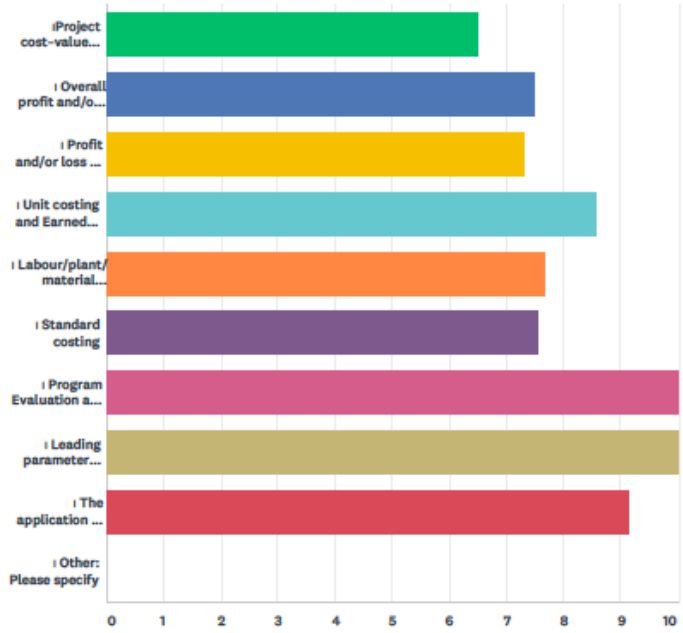


ANSWER CHOICES	RESPONSES	
Always	45.00%	9
Frequently	55.00%	11
Rarely/do not use cost control during projects	0.00%	0
TOTAL		20

Figure 5.29: Application of cost controls

Cost Control Techniques

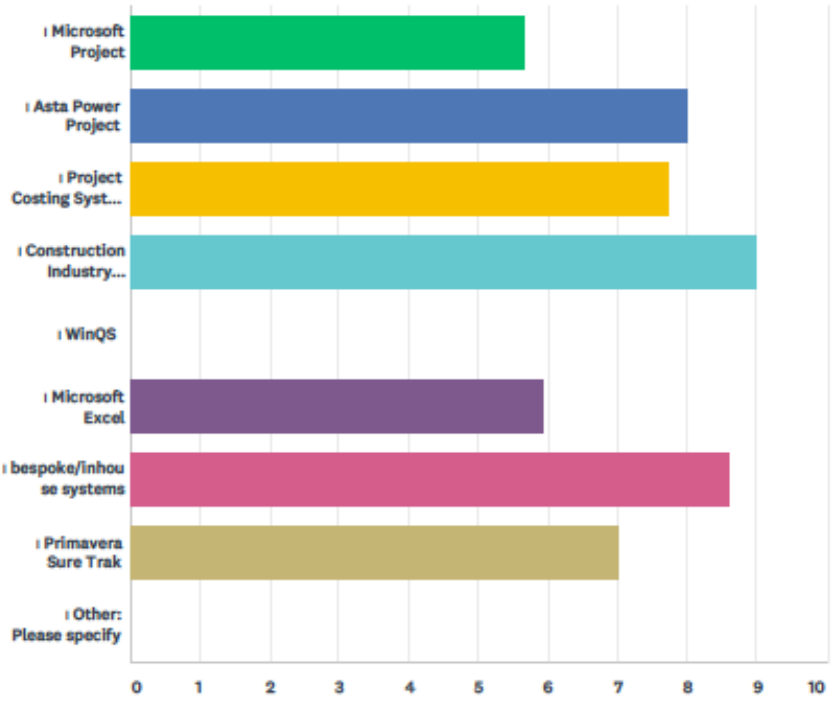
Q31 – For project cost control, which of the following control methods/techniques do you use?



	1	2	3	4	5	6	7	8	9	10	TOTAL	SCORE
Project cost–value reconciliation	0.00% 0	0.00% 0	25.00% 1	0.00% 0	75.00% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	6.50
Overall profit and/or loss	25.00% 2	0.00% 0	0.00% 0	50.00% 4	25.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	7.50
Profit and/or loss on each contract at valuation dates	20.00% 2	10.00% 1	0.00% 0	20.00% 2	50.00% 5	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	10	7.30
Unit costing and Earned value analysis	0.00% 0	64.29% 9	28.57% 4	7.14% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	14	8.57
Labour/plant/material (actual versus forecast reconciliation)	0.00% 0	25.00% 3	33.33% 4	25.00% 3	16.67% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	12	7.67
Standard costing	11.11% 1	0.00% 0	44.44% 4	22.22% 2	22.22% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	9	7.56
Program Evaluation and Review Technique (PERT/COST)	100.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	10.00
Leading parameter method	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	10.00
The application of principles of Value Engineering	57.14% 4	14.29% 1	14.29% 1	14.29% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	7	9.14
Other: Please specify	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

Figure 5.30: Cost control techniques used

Q32 – For cost control, which of the following software packages do you use?



	1	2	3	4	5	6	7	8	9	TOTAL	SCORE
Microsoft Project	0.00% 0	0.00% 0	0.00% 0	64.29% 9	35.71% 5	0.00% 0	0.00% 0	0.00% 0	0.00% 0	14	5.64
Asta Power Project	50.00% 1	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	8.00
Project Costing System (PCS)	37.50% 3	0.00% 0	62.50% 5	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	7.75
Construction Industry Software (COINS)	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	9.00
WinQS	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00
Microsoft Excel	0.00% 0	8.33% 1	16.67% 2	33.33% 4	41.67% 5	0.00% 0	0.00% 0	0.00% 0	0.00% 0	12	5.92
bespoke/inhouse systems	60.00% 3	40.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	8.60
Primavera Sure Trak	0.00% 0	54.55% 6	18.18% 2	0.00% 0	27.27% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	11	7.00
Other: Please specify	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

Figure 5.31: Software packages used for cost control

Theme 9: Question 33 – Cost Overruns

Please answer the following questions to identify the most common factors that often causes and lead to project cost overruns.

Q33 – Which of the following are among the most common influencing factors that often lead to project cost overruns?

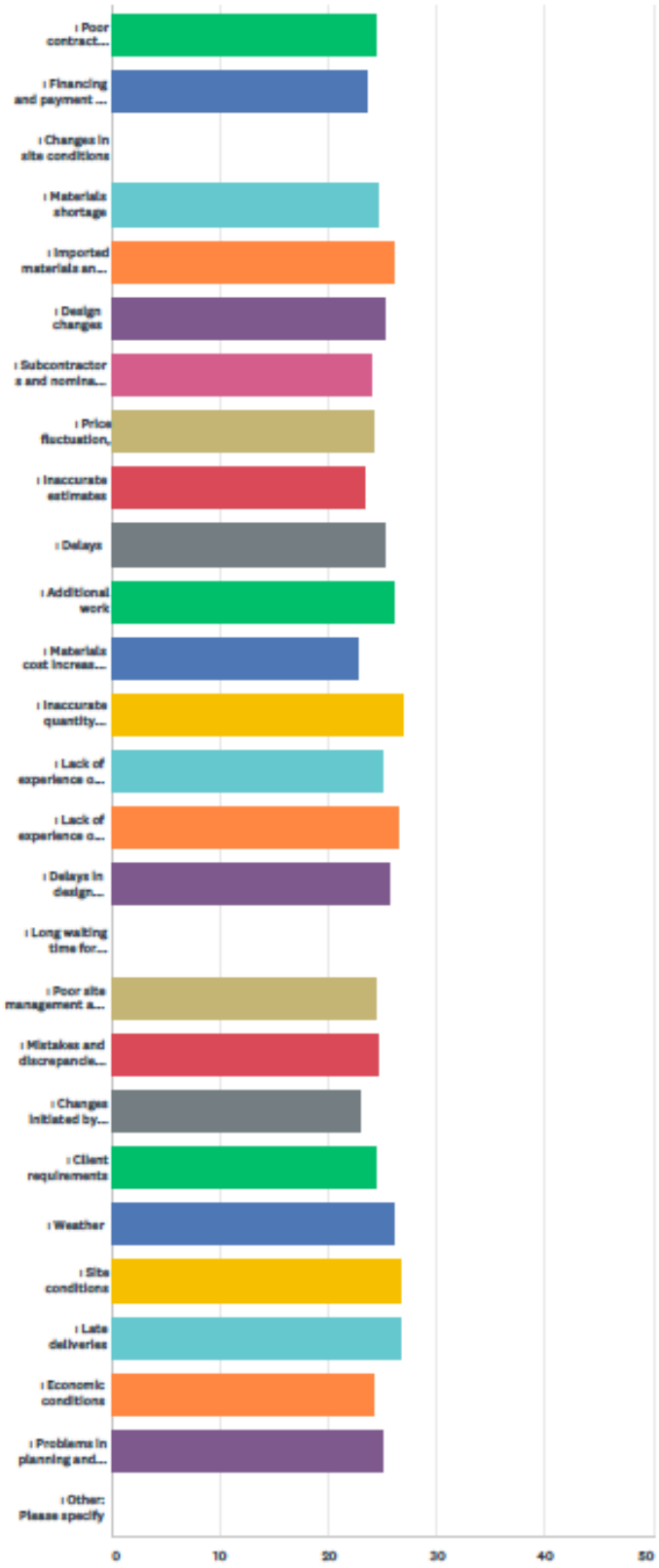
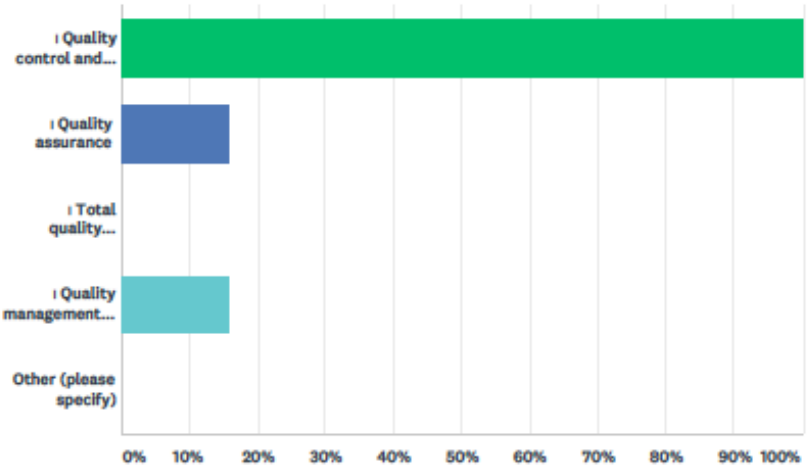


Figure 5.32: Cost overruns factors

Theme 10: Questions 34 to 36: Quality Management and Control

Q34 – Which of the following steps do you consider while doing quality management and control?

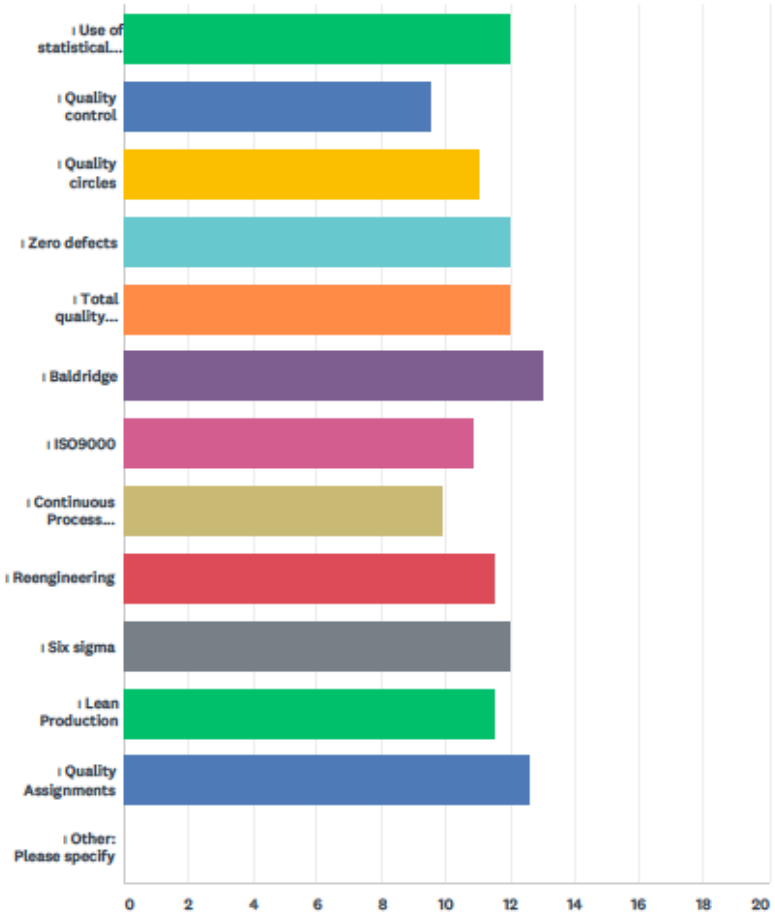


ANSWER CHOICES	RESPONSES	
Quality control and inspection: Quality control implemented in construction: The Specifications and contract drawings, Visual quality checks and Quantifable quality checks	100.00%	19
Quality assurance	15.79%	3
Total quality management (TQM)	0.00%	0
Quality management systems	15.79%	3
Other (please specify)	0.00%	0
Total Respondents: 19		

Figure 5.33: Quality management and control steps

#	OTHER (PLEASE SPECIFY)
	There are no responses.

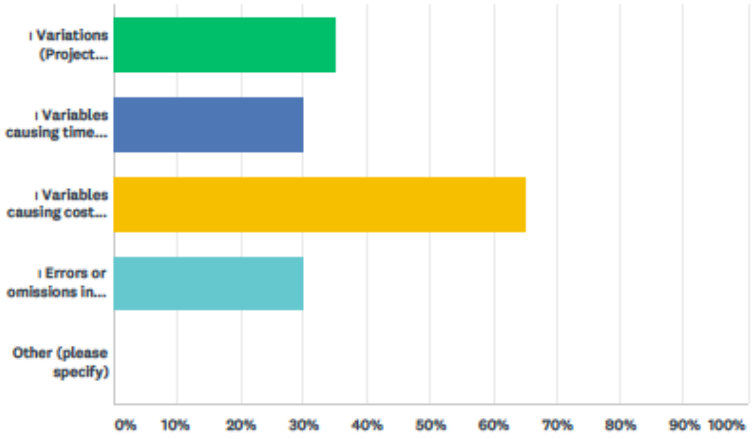
Q35 – Which of the following quality tools have you used in order to improve quality and productivity?



	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL	SCORE
Use of statistical methods/statistical process control (SPC)	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	12.00
Quality control	0.00% 0	0.00% 0	0.00% 0	53.85% 7	46.15% 6	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	13	9.54
Quality circles	0.00% 0	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	11.00
Zero defects	50.00% 1	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	12.00
Total quality management (TQM)	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	12.00
Baldridge	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	13.00
ISO9000	16.67% 1	0.00% 0	33.33% 2	50.00% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	10.83
Continuous Process Improvement	11.11% 1	11.11% 1	0.00% 0	11.11% 1	66.67% 6	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	9	9.89
Reengineering	0.00% 0	50.00% 2	50.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	11.50
Six sigma	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	12.00
Lean Production	0.00% 0	50.00% 2	50.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	11.50
Quality Assignments	71.43% 5	14.29% 1	14.29% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	7	12.57
Other: Please specify	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

Figure 5.34: Quality tools used

Q36 – Which of the following factors lead to the problem of reduced and low quality?



ANSWER CHOICES	RESPONSES	
Variations (Project charactrstics, Characteristics of client, Project organization factors)	35.00%	7
Variables causing time overruns	30.00%	6
Variables causing cost overruns	65.00%	13
Errors or omissions in construction work	30.00%	6
Other (please specify)	0.00%	0
Total Respondents: 20		

#	OTHER (PLEASE SPECIFY)
	There are no responses.

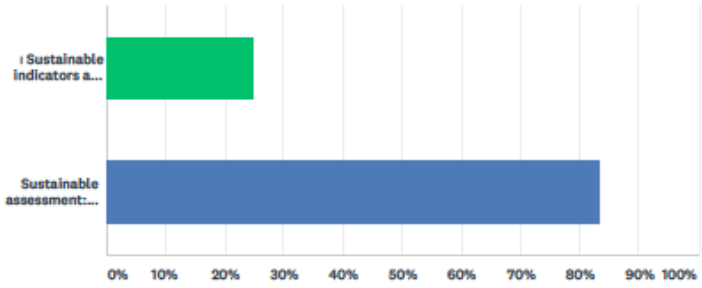
Figure 5.35: Low quality factors

Theme 11: Questions 37 to 38 – Sustainability Management and Control

Q37: Please answer the following questions regarding sustainable measurement and control. Please describe/explain how you manage and control sustainability.

#	RESPONSES
1	By sustainability assessment.
2	Use of standard materials in quality control and also use of experienced labour.

Q38 – Which of the following factors do you consider regarding sustainability?



ANSWER CHOICES	RESPONSES	
Sustainable indicators and benchmark: Please explain	25.00%	3
Sustainable assessment: Please explain	83.33%	10
Total Respondents: 12		

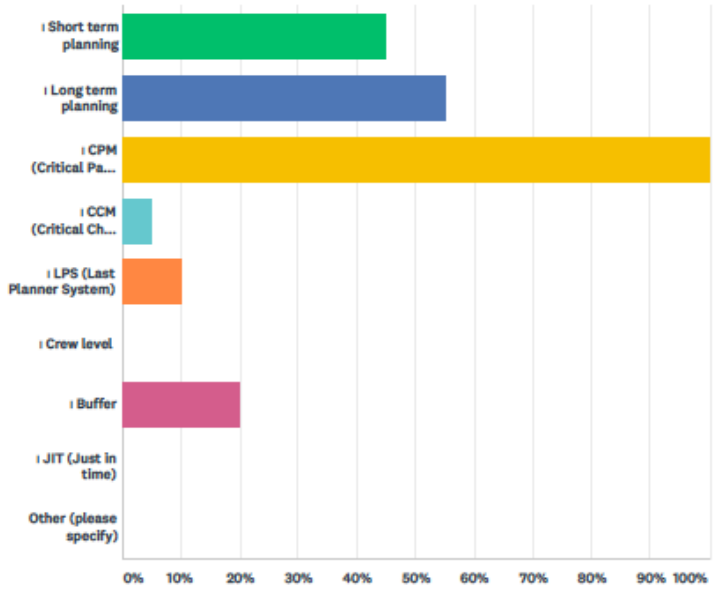
#	PLEASE EXPLAIN
	There are no responses.

Figure 5.36: Factors consider by respondents regarding sustainability

Theme 12: Questions 39 to 46 – Development of the Measurement and Control Methods

The adaptation of lean principles with identified enablers is assessed, where a combination of different lean principles and techniques will be considered as the main enablers to develop a new framework for the construction process. Please answer the following questions regarding each of the Plan, Implementation, and Monitoring/Control and Review functions.

Q39 – For construction planning efforts, which of the following methods have you used in your company?

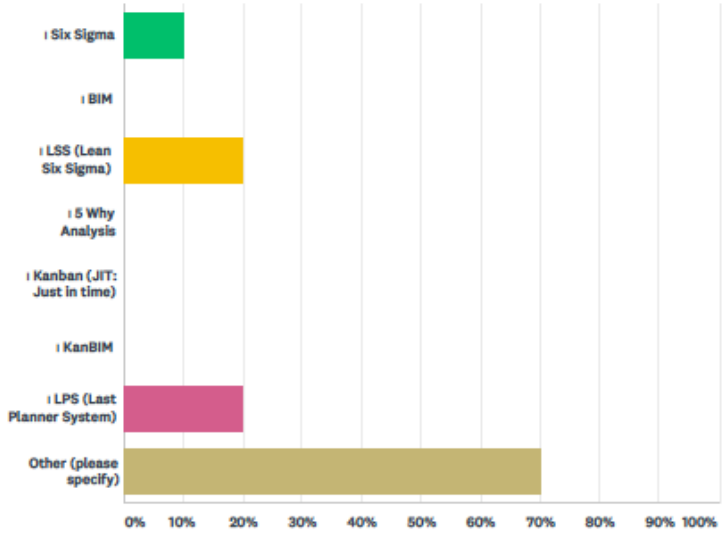


ANSWER CHOICES	RESPONSES	
Short term planning	45.00%	9
Long term planning	55.00%	11
CPM (Critical Path Method)	100.00%	20
CCM (Critical Chain Method)	5.00%	1
LPS (Last Planner System)	10.00%	2
Crew level	0.00%	0
Buffer	20.00%	4
JIT (Just in time)	0.00%	0
Other (please specify)	0.00%	0
Total Respondents: 20		

#	OTHER (PLEASE SPECIFY)
	There are no responses.

Figure 5.37: Methods used for planning

Q40 – For implementation, which of the following methods have you used in your company?

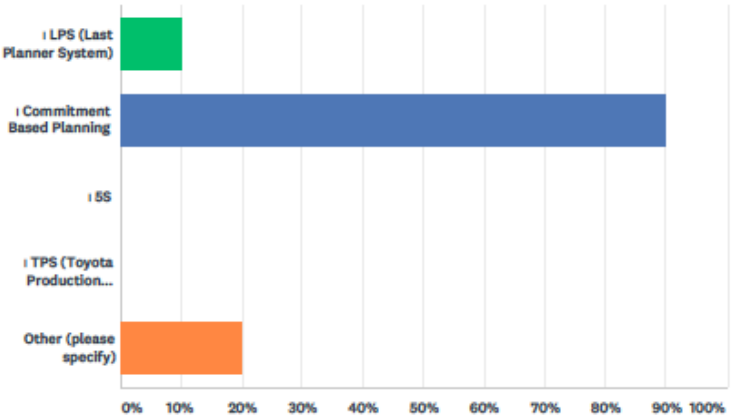


ANSWER CHOICES	RESPONSES	
Six Sigma	10.00%	1
BIM	0.00%	0
LSS (Lean Six Sigma)	20.00%	2
5 Why Analysis	0.00%	0
Kanban (JIT: Just in time)	0.00%	0
KanBIM	0.00%	0
LPS (Last Planner System)	20.00%	2
Other (please specify)	70.00%	7
Total Respondents: 10		

#	OTHER (PLEASE SPECIFY)
1	Experimental controlling method
2	Experimental control
3	Traditional way and methods are used
4	Traditional methods
5	based on experiment
6	Based on experiment
7	Experimental controlling

Figure 5.38 Methods used for implementation

Q41 – For monitoring/control, which of the following methods have you used in your company?

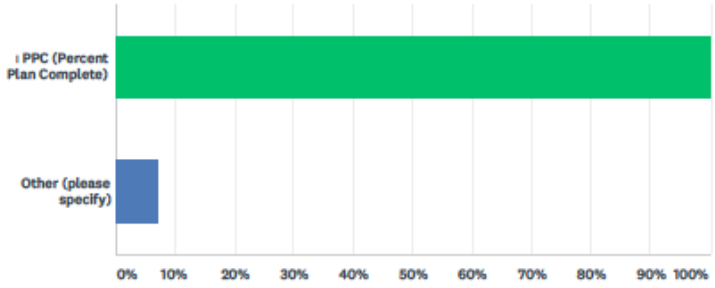


ANSWER CHOICES	RESPONSES	
LPS (Last Planner System)	10.00%	1
Commitment Based Planning	90.00%	9
5S	0.00%	0
TPS (Toyota Production System)	0.00%	0
Other (please specify)	20.00%	2
Total Respondents: 10		

#	OTHER (PLEASE SPECIFY)
1	Traditional control methods such as visual control method
2	Only by control of maps and eye and lab control

Figure 5.39: Methods used for monitoring and control

Q42 – How do you review your construction process?

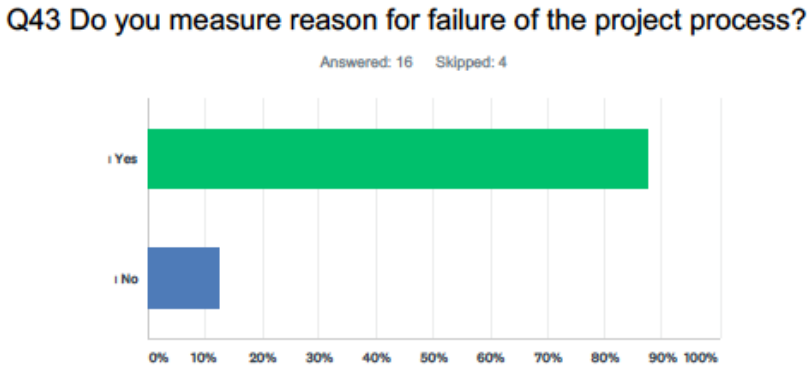


ANSWER CHOICES	RESPONSES	
PPC (Percent Plan Complete)	100.00%	14
Other (please specify)	7.14%	1
Total Respondents: 14		

#	OTHER (PLEASE SPECIFY)
1	Also Financial control,

Figure 5.40: Methods used for review

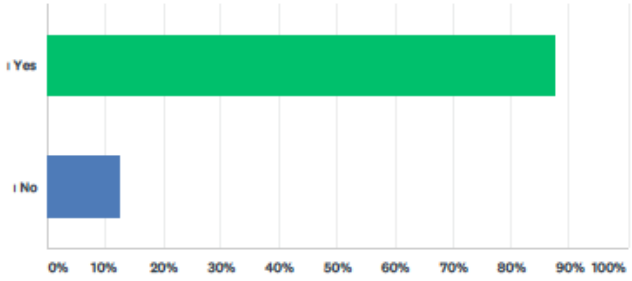
Q43 – Do you measure reasons for failure of the project process?



ANSWER CHOICES	RESPONSES	
Yes	87.50%	14
No	12.50%	2
TOTAL		16

Figure 5.41: Measurement of reasons for failure of the project

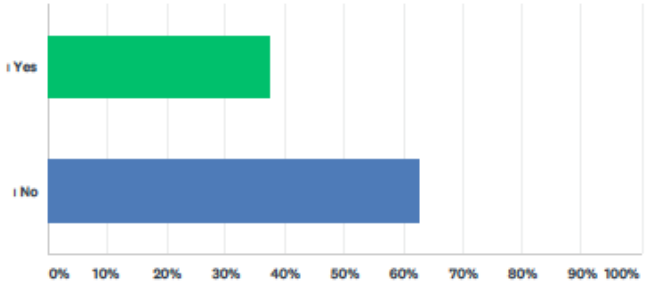
Q44 – Do you use root cause analysis?



ANSWER CHOICES	RESPONSES	
Yes	87.50%	14
No	12.50%	2
TOTAL		16

Figure 5.42: Root cause analysis

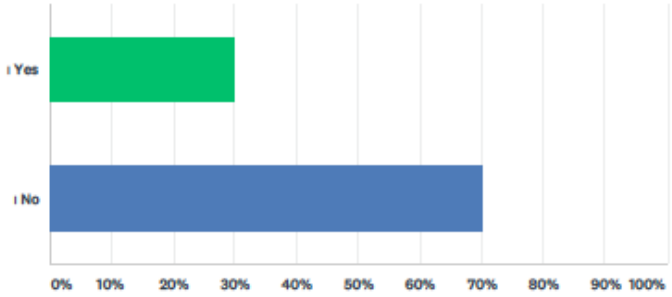
Q45 – At the operational level, do you measure cost performance?



ANSWER CHOICES	RESPONSES	
Yes	37.50%	6
No	62.50%	10
TOTAL		16

Figure 5.43: Cost performance measurement

Q46 – In assigning tasks, is shielding essential/important?



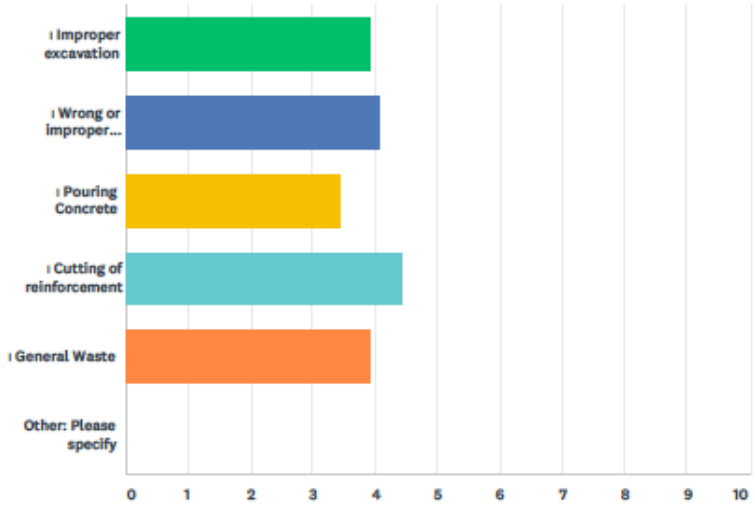
ANSWER CHOICES	RESPONSES	
Yes	30.00%	3
No	70.00%	7
TOTAL		10

Figure 5.44: Importance of shielding

Theme 13: Question 47 – Waste in the Production Process

For total improvement in lean production, the basic procedure is to recognise waste in the Process, therefore removing it. Wastes in production process could be the waste of overproduction of goods not needed, waiting by employees for procedures, unnecessary motions, transporting (or conveyance), overprocessing (or inappropriate processing), unnecessary inventory, and defects in products.

Q47 – Regarding the following issues and operations related to waste in Iranian sites, please can you rank/order from the most important to the least important?

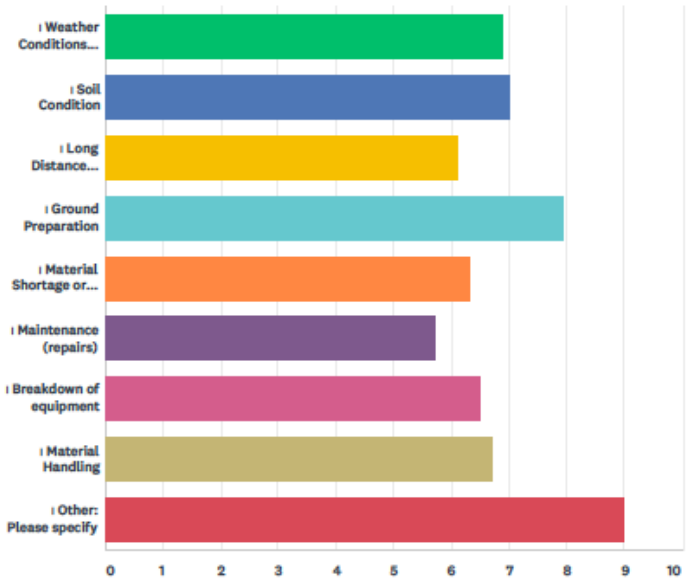


	1	2	3	4	5	6	TOTAL	SCORE
Improper excavation	29.41% 5	11.76% 2	11.76% 2	17.65% 3	29.41% 5	0.00% 0	17	3.94
Wrong or improper welding	23.53% 4	23.53% 4	11.76% 2	17.65% 3	23.53% 4	0.00% 0	17	4.06
Pouring Concrete	0.00% 0	0.00% 0	55.56% 10	33.33% 6	11.11% 2	0.00% 0	18	3.44
Cutting of reinforcement	18.75% 3	50.00% 8	0.00% 0	18.75% 3	12.50% 2	0.00% 0	16	4.44
General Waste	22.22% 4	16.67% 3	22.22% 4	11.11% 2	27.78% 5	0.00% 0	18	3.94
Other: Please specify	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

Figure 5.45: Issues and operations related to waste on site

Theme 14: Question 48 – Waste and Value-loss

Q48 – In the following, the waste and value-loss found on site are explained. Identification can be an excellent pointer and guide for the possible impact of the Lean Construction Philosophy. Please can you rank/order from the most important to the least important?



	1	2	3	4	5	6	7	8	9	TOTAL	SCORE
Weather Conditions (Rain, Snow, etc)	0.00% 0	27.27% 3	45.45% 5	18.18% 2	9.09% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	11	6.91
Soil Condition	0.00% 0	33.33% 2	33.33% 2	33.33% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	7.00
Long Distance Equipment Displacement	11.11% 1	22.22% 2	11.11% 1	0.00% 0	44.44% 4	0.00% 0	11.11% 1	0.00% 0	0.00% 0	9	6.11
Ground Preparation	53.85% 7	15.38% 2	15.38% 2	0.00% 0	15.38% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	13	7.92
Material Shortage or Deficiency	6.25% 1	6.25% 1	18.75% 3	56.25% 9	6.25% 1	6.25% 1	0.00% 0	0.00% 0	0.00% 0	16	6.31
Maintenance (repairs)	0.00% 0	18.18% 2	0.00% 0	18.18% 2	63.64% 7	0.00% 0	0.00% 0	0.00% 0	0.00% 0	11	5.73
Breakdown of equipment	30.00% 3	0.00% 0	30.00% 3	10.00% 1	20.00% 2	0.00% 0	0.00% 0	0.00% 0	10.00% 1	10	6.50
Material Handling	14.29% 1	42.86% 3	0.00% 0	28.57% 2	0.00% 0	0.00% 0	0.00% 0	14.29% 1	0.00% 0	7	6.71
Other: Please specify	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	9.00

Figure 5.46: Waste and value-loss on site

Theme 15: Questions 49 to 53 – Types of Waste

As shown in the following questions and based on the present literature, several types of waste in the construction process of construction projects are recognised, which can be eliminated by using the proposed construction process. The following waste types are the

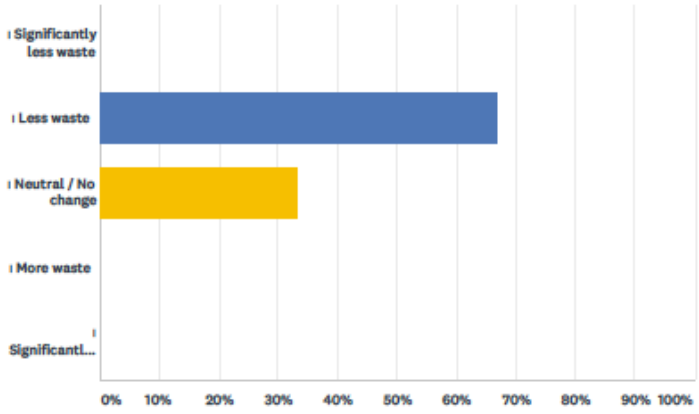
results of the literature review done by the researcher. The purpose of this study is to elaborate on construction waste.

Q49 – From the most important to the least important, please can you rank/order the following types of waste which are mostly relevant to the activities during the construction phase?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	TOTAL	SCORE
Transport	0.00% 0	0.00% 0	50.00% 1	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	19.00
Over-production	75.00% 3	25.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	21.75
Delays	0.00% 0	0.00% 0	0.00% 0	75.00% 3	25.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	18.75
Unnecessary movements	16.67% 1	0.00% 0	16.67% 1	33.33% 2	33.33% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	19.33
Over-processing	60.00% 3	40.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	21.60
Construction defects	0.00% 0	50.00% 2	50.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	20.50
Excess inventory	66.67% 2	33.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	21.67
Poor contractor briefing	0.00% 0	50.00% 1	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	20.00
Insufficient pre-construction meetings	33.33% 1	0.00% 0	33.33% 1	0.00% 0	33.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	20.00
Lack of project definition	40.00% 2	0.00% 0	0.00% 0	40.00% 2	20.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	20.00
Poor technical knowledge	0.00% 0	33.33% 1	33.33% 1	0.00% 0	33.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	19.67
Poor specification	20.00% 1	40.00% 2	0.00% 0	20.00% 1	20.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	20.20
Construction changes	0.00% 0	0.00% 0	0.00% 0	0.00% 0	100.00% 7	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	7	18.00
Insufficient and unrealistic constraints of project time	14.29% 1	14.29% 1	57.14% 4	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	14.29% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	7	19.57
Insufficient and unrealistic constraints of project cost	0.00% 0	25.00% 1	0.00% 0	50.00% 2	0.00% 0	0.00% 0	0.00% 0	25.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	18.50
Inadequate involvement of other professionals and teamwork during the construction stage	0.00% 0	33.33% 2	16.67% 1	33.33% 2	16.67% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	19.67
Lack of constructability review of construction	25.00% 2	0.00% 0	25.00% 2	25.00% 2	12.50% 1	0.00% 0	12.50% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	19.50
Poor communication between construction team	0.00% 0	0.00% 0	25.00% 1	50.00% 2	0.00% 0	25.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	18.75
Making construction decisions on cost and not value of work	16.67% 1	0.00% 0	33.33% 2	16.67% 1	33.33% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	19.50
Poor level of commitment to quality improvement	20.00% 1	20.00% 1	60.00% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	20.60
Effect of standards and construction code on quality	0.00% 0	62.50% 5	12.50% 1	25.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	20.38
Other: Please specify	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

Figure 5.47: Types of waste

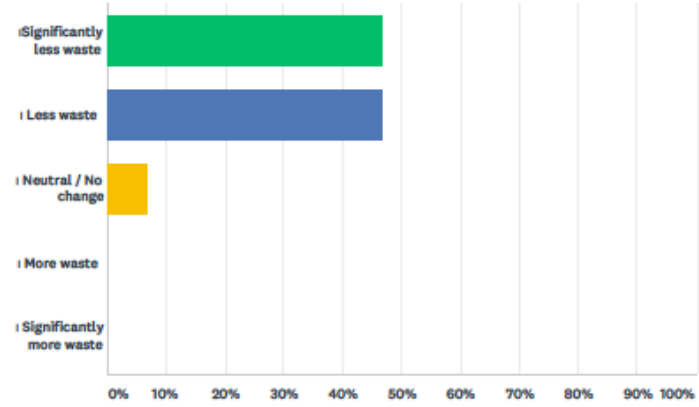
Q50 – Since adopting the Last Planner System, what impact have you seen on waste on site?



ANSWER CHOICES	RESPONSES	
Significantly less waste	0.00%	0
Less waste	66.67%	2
Neutral / No change	33.33%	1
More waste	0.00%	0
Significantly more waste	0.00%	0
TOTAL		3

Figure 5.48: Impact on waste by adopting the LPS

Q51 – By developing and adopting new construction control, measurement, and performance methods, how do you assess/evaluate the impact on waste on site?



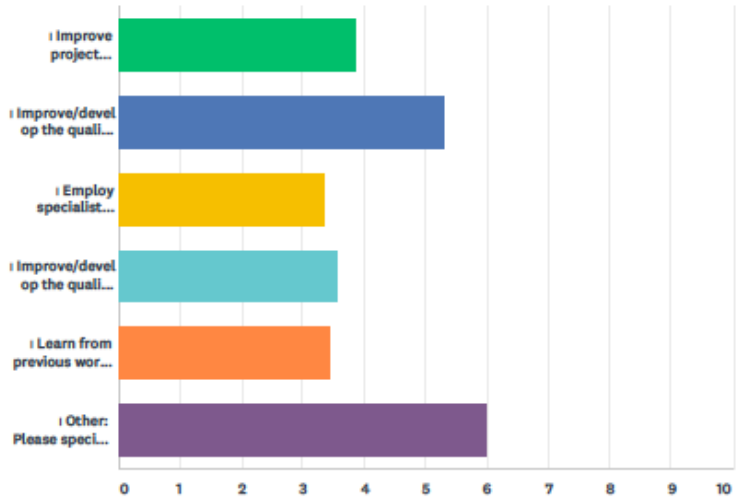
ANSWER CHOICES	RESPONSES	
Significantly less waste	46.67%	7
Less waste	46.67%	7
Neutral / No change	6.67%	1
More waste	0.00%	0
Significantly more waste	0.00%	0
TOTAL		15

Figure 5.49: Impact on waste by development of new methods

Q52 – By adopting the new methods, which of the wastes mentioned in this questionnaire do you think will be eliminated from the construction process? Please also write a list of other wastes that would be eliminated or reduced as a result of adopting the new methods and give your idea regarding the impact on construction works.

#	RESPONSES
1	construction changes; unrealistic constraints of project time.
2	Problems in Question 49. would be reduced

Q53 – For improving the reliability of planning, can you rate the significance of the following mentioned techniques?

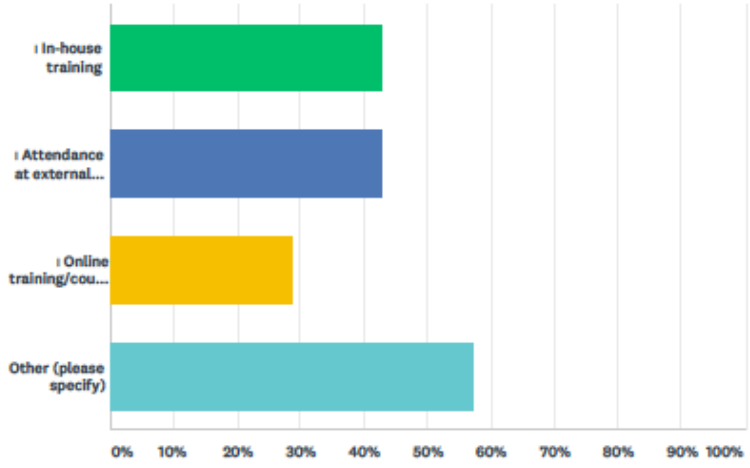


	1	2	3	4	5	6	TOTAL	SCORE
Improve project planner's abilities	20.00% 4	0.00% 0	50.00% 10	5.00% 1	25.00% 5	0.00% 0	20	3.85
Improve/develop the quality of material	52.94% 9	23.53% 4	23.53% 4	0.00% 0	0.00% 0	0.00% 0	17	5.29
Employ specialist teams	0.00% 0	25.00% 5	15.00% 3	35.00% 7	20.00% 4	5.00% 1	20	3.35
Improve/develop the quality of labour	5.56% 1	33.33% 6	11.11% 2	11.11% 2	38.89% 7	0.00% 0	18	3.56
Learn from previous works and projects	10.00% 2	15.00% 3	5.00% 1	50.00% 10	20.00% 4	0.00% 0	20	3.45
Other: Please specify	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	6.00

Figure 5.50: Improving the reliability of planning

Theme 16: Question 54 - Training (continuous learning and training)

Q54 – If you use the Last Planner System, what sort of training has your staff undertaken?



ANSWER CHOICES	RESPONSES	
In-house training	42.86%	3
Attendance at external workshops courses	42.86%	3
Online training/courses	28.57%	2
Other (please specify)	57.14%	4
Total Respondents: 7		

Figure 5.51: Training undertaken by staff

#	OTHER (PLEASE SPECIFY)
1	Not using the LPS
2	Not using the LPS
3	Not using the LPS
4	not working with LPS

Theme 17: Questions 55 to 58 – Inhibiting Factors and Mitigating Measures

This section focuses on identifying the top factors inhibiting the project control effort of construction project practitioners. Based on the following list of the most important/commonly identified inhibiting factors, please answer the following questions.

The following is a list of identified project cost and time control inhibiting factors and their classification.

Q55 – Please rate the level of importance for each of the following factors in affecting your ability to effectively control the time of your construction projects.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	TOTAL	SCORE	
Inflation of prices	0.00% 0	8.33% 1	0.00% 0	25.00% 3	58.33% 7	0.00% 0	0.00% 0	0.00% 0	8.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	12	17.17
Fluctuation currency/exchange rate	0.00% 0	0.00% 0	0.00% 0	25.00% 1	50.00% 2	0.00% 0	25.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	16.75
Unstable government policies	0.00% 0	0.00% 0	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	18.00
Weak regulation and control	0.00% 0	0.00% 0	37.50% 3	37.50% 3	12.50% 1	12.50% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	18.00
Unpredictable weather conditions	25.00% 1	25.00% 1	25.00% 1	25.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	19.50
Dependency on imported materials	50.00% 1	0.00% 0	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	19.50
Low skilled manpower	20.00% 1	0.00% 0	0.00% 0	80.00% 4	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	18.60
Risk and uncertainty associated with projects	0.00% 0	14.29% 1	71.43% 5	0.00% 0	14.29% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	7	18.86
Unstable interest rate	20.00% 1	0.00% 0	40.00% 2	40.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	19.00
Lack of proper training and experience of PM	0.00% 0	20.00% 1	20.00% 1	40.00% 2	20.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	18.40
Use of inappropriate software	66.67% 2	33.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	20.67
Inaccurate evaluation of projects time/duration	14.29% 1	0.00% 0	71.43% 5	0.00% 0	14.29% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	7	19.00
Non-performance of subcontractors and nominated suppliers	0.00% 0	50.00% 3	16.67% 1	0.00% 0	33.33% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	18.83
Project fraud and corruption	0.00% 0	100.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	20.00
Design changes	20.00% 1	40.00% 2	0.00% 0	0.00% 0	40.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	19.00
Financing and payment for completed works	33.33% 2	16.67% 1	16.67% 1	0.00% 0	16.67% 1	0.00% 0	0.00% 0	16.67% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	18.67
Complexity of works	66.67% 4	0.00% 0	0.00% 0	16.67% 1	16.67% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	19.83
Discrepancies in contract documentation	0.00% 0	100.00% 4	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	20.00
Contract and specification interpretation disagreement	40.00% 2	40.00% 2	20.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	20.20
Conflict between project parties	50.00% 3	16.67% 1	0.00% 0	16.67% 1	16.67% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	19.67
Other: please include/add and rate other factors that you think should be among the factors put forward to them.	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

Figure 5.52: Importance of factors in time control

Q56 – Please rate the level of importance for each of the following factors in affecting your ability to effectively control the cost of your construction projects.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	TOTAL	SCORE
Inflation of prices	0.00% 0	0.00% 0	0.00% 0	0.00% 0	92.31% 12	0.00% 0	0.00% 0	7.69% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	13	16.77
Fluctuation currency/exchange rate	0.00% 0	0.00% 0	11.11% 1	22.22% 2	55.56% 5	0.00% 0	0.00% 0	0.00% 0	11.11% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	9	17.00
Unstable government policies	33.33% 1	0.00% 0	0.00% 0	66.67% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	19.00
Weak regulation and control	0.00% 0	22.22% 2	11.11% 1	66.67% 6	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	9	18.56
Unpredictable weather conditions	50.00% 1	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	20.50
Dependency on imported materials	0.00% 0	50.00% 1	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	19.50
Low skilled manpower	0.00% 0	0.00% 0	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	18.00
Risk and uncertainty associated with projects	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	18.00
Unstable interest rate	20.00% 1	0.00% 0	20.00% 1	40.00% 2	20.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	18.60
Lack of proper training and experience of PM	0.00% 0	100.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	20.00
Use of inappropriate software	66.67% 2	33.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	3	20.67
Inaccurate evaluation of projects time/duration	0.00% 0	50.00% 2	25.00% 1	0.00% 0	0.00% 0	25.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	18.75
Non-performance of subcontractors and nominated suppliers	0.00% 0	11.11% 1	77.78% 7	11.11% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	9	19.00
Project fraud and corruption	0.00% 0	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	20.00
Design changes	25.00% 1	0.00% 0	0.00% 0	75.00% 3	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	18.75
Financing and payment for completed works	12.50% 1	37.50% 3	25.00% 2	0.00% 0	25.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	19.13
Complexity of works	75.00% 6	12.50% 1	0.00% 0	12.50% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	20.50
Discrepancies in contract documentation	20.00% 1	40.00% 2	40.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	19.80
Contract and specification interpretation disagreement	16.67% 1	33.33% 2	33.33% 2	16.67% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	19.50
Conflict between project parties	50.00% 2	0.00% 0	25.00% 1	25.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	19.75
Other: please include/add and rate other factors that you think should be among the factors put forward to them.	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

Figure 5.53: Importance of factors in cost control

Q57 – Most researchers often mention that there are problems faced by construction projects which should be eliminated in order to achieve project targets of cost, time, and quality.
The following is a list of the main problems and challenges which exist in the construction industry. From the most important to the least important, please can you rank/order the following problems that faced by construction industry? Please also include other main problems that exist and affect the construction industry.

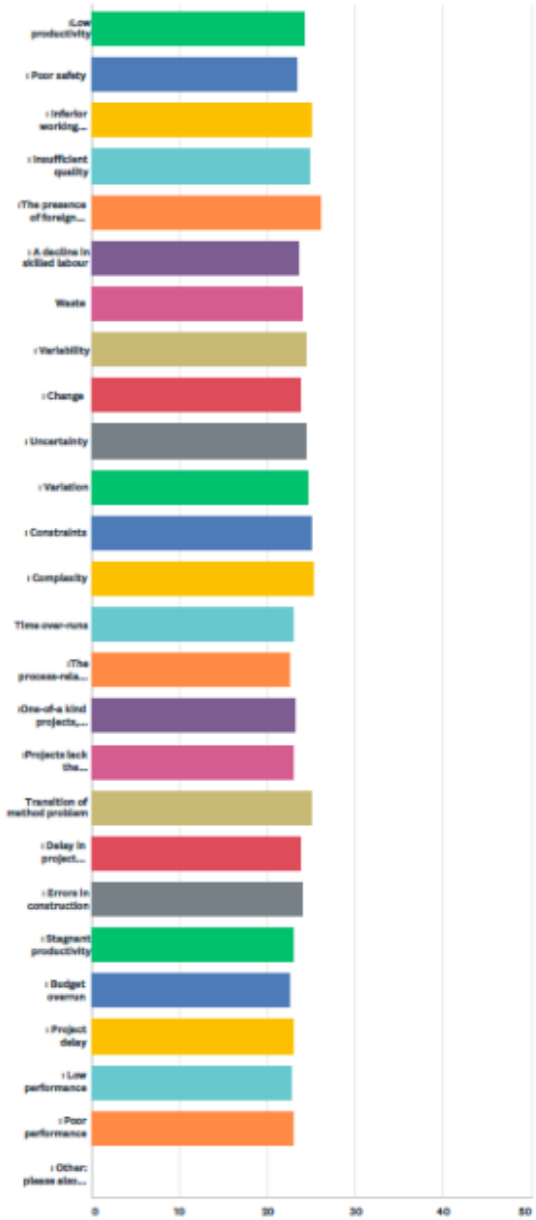
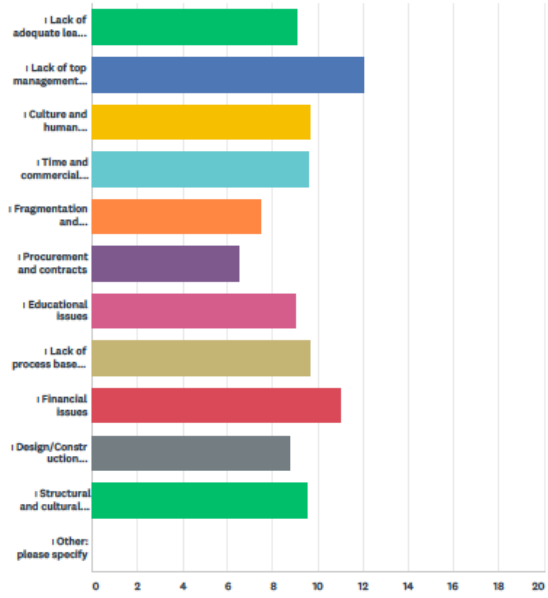


Figure 5.54: Problems faced by construction projects

Q58 – The following is a list of the significant barriers to the successful implementation of LC in the UK. Please can you rank/order from the most important to the least important?

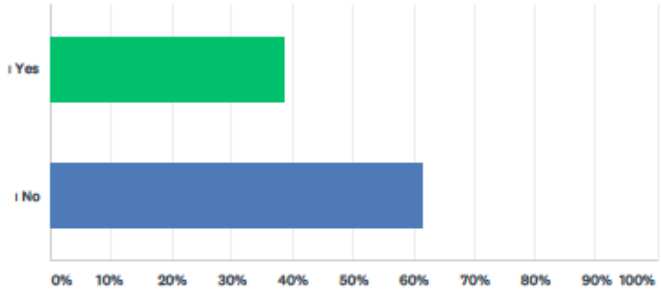


	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL	SCORE
Lack of adequate lean awareness/understanding	25.00% 3	0.00% 0	8.33% 1	16.67% 2	41.67% 5	0.00% 0	0.00% 0	8.33% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	12	9.08
Lack of top management commitment	100.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	1	12.00
Culture and human attitudinal issues	0.00% 0	33.33% 2	0.00% 0	66.67% 4	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	9.67
Time and commercial pressure	14.29% 1	28.57% 2	28.57% 2	14.29% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	14.29% 1	0.00% 0	0.00% 0	0.00% 0	7	9.57
Fragmentation and subcontracting	0.00% 0	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2	7.50
Procurement and contracts	0.00% 0	0.00% 0	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	2	6.50
Educational issues	0.00% 0	40.00% 2	0.00% 0	20.00% 1	20.00% 1	0.00% 0	20.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	9.00
Lack of process based PMSs	25.00% 2	0.00% 0	37.50% 3	12.50% 1	12.50% 1	0.00% 0	12.50% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	8	9.63
Financial issues	40.00% 2	20.00% 1	40.00% 2	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	5	11.00
Design/Construction dichotomy	0.00% 0	25.00% 1	0.00% 0	25.00% 1	25.00% 1	25.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	4	8.75
Structural and cultural barriers	10.00% 1	20.00% 2	30.00% 3	0.00% 0	30.00% 3	10.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	10	9.50
Other: please specify	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0	0.00

Figure 5.55: Significant barriers to LC implementation

Theme 18: Question 59 – Earned Value Method

Q59 – The earned value method (EVM) is considered an advanced project control technique that provides a quantitative measure of work performance. At the assignment level, do you measure earned value or cost performance?



ANSWER CHOICES	RESPONSES	
Yes	38.46%	5
No	61.54%	8
TOTAL		13

Figure 5.56: Earned value or cost performance measurement

Theme 19: Questions 60 to 62 – Any other comments and associated administration

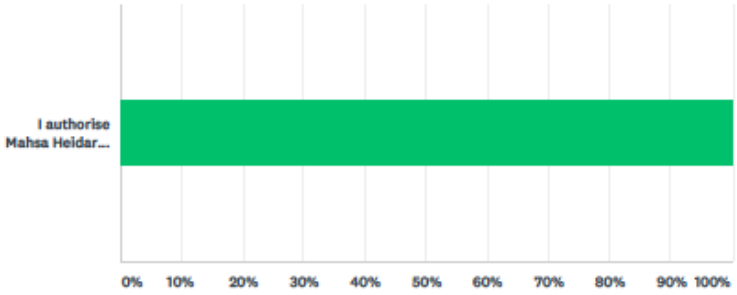
Q60 – Any other comments?

*Q61 – **The comment box**: Please complete the consent form provided on the intro page by writing your answers in the comment box below.*

Q61 Please complete the consent form provided in the intro page by writing your answers in the comment box below.1. General Information/QuestionsYour main responsibility/position/Role:---------Your years of experience:----------Project types:----------Location:----------I, _____, of (position) _____, authorise Mahsa Heidar Barghi PhD researcher of/at the University of Birmingham to use my answer for the purpose of her research. Print Name_____Sign_____Date__ Please choose whether or not if you want to receive the following: I do/do not wish to receive a report with the results of both questionnaires and interviews at the end of the survey process. 3. Please note that you may wish to withdraw from the survey at any time during the research without any negative consequences by simply notifying the decision to the researcher within 28 calendar days after the submission of the questionnaire or the day of the interview.

RESPONSES
Design Eng. 35 years Water works (Treatment plants, Pump stations, Reverse osmosis) IRAN K 5th June 2018
construction manager 11 years make buildings Tehran. Iran MM 2018.6.10
CEO 45 years Power Transmission Line IRAN MS 6/6/18
Construction manager 15 years Residential Building Tehran, Iran A Gh 13 june 2018
Project Manager 7 Residential buildings Tehran Iran ES 6/6/18
Chief planning Eng. 14 years building projects Tehran, Iran 18th June 2018
CEO 40 years Dwelling building Iran I, Kazem Heydarbarghi, of (position) Ceo, authorise Mahsa Heidar Barghi PhD researcher of/at the University of Birmingham to use my answer for the purpose of her research. Kazem Heydarbarghi K.H.B June 28, 2018

*Q62 – **The consent form:** Please complete the consent form below. Please answer this question regarding the consent form provided in question.*



ANSWER CHOICES	RESPONSES	
I authorise Mahsa Heidar Barghi PhD researcher of/at the University of Birmingham to use my answer for the purpose of her research.	100.00%	20
TOTAL		20

Figure 5.57: The consent form

Please see Chapter 6 regarding the key messages and the thesis contribution from the data gathered across the 62 responses.

This LC conformance research is designed to extend into construction sites, incorporating construction site managers, foremen, and construction workers in the research effort. This study has elicited valuable perceptions of and information from such operational people on their companies' conformance to lean principles.

It should be mentioned that, in a study of LC conformance levels among construction contractors in Turkey, Tezel et al. (2013) presented the results of a questionnaire which showed the LC concept had not yet been adopted and was not yet adequately known by construction companies operating in Turkey. One shortfall of this study is the fact it is

missing valuable perceptions of and information from ‘operational’ people. This echoes the findings of Solis et al. (2013).

5.3 Case Study

Further work has been conducted in this research study using case studies to validate the framework through empirical data-gathering.

5.3.1 Introduction

From the start, it was planned that the case studies would be carried out to tie together the research set out with what occurs on site (see Chapter 3). As a case study, two building projects from Iran were used to achieve this goal.

5.3.2 Research Design

5.3.2.1 Research Inspiration

Despite different site locations, companies, and project management methods and approaches used, to some degree, all projects present similar problematic characteristics, namely, time and cost overruns, a lack of coordination, a lack of safety and quality, conflict and disagreement between the client, subcontractors, and contractor, and an unreliable programme. This was, in part the motivation for undertaking this research. The case studies allow demonstration of the core principle of LC and how such an approach benefits construction projects.

5.3.2.2 The Research Strategy

In this research project, two case studies were used, based on construction projects in Iran. In studying the projects, several methods for collecting information were used. The methods are outlined in the next section (see Section 5.3.2.3). According to Yin (quoted in Robson, 2002), “*case study is a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidence*”.

5.3.2.3 Methodology

Interviews were conducted with a broad range of people, from Iranian engineers who are members of the Iran Construction Engineering Organization, including: contractors,

designers, subcontractors, consultants, directors of companies, working labours, and foremen. In addition, in Iran the questionnaire was distributed to the contractors chosen among members of the Iran Institute of Civil Engineers and The Iranian Contractors Association. The analysis and explanation of the data that were collected are presented in the following sections (see Sections 5.3.3 to 5.9).

5.3.3 The Construction Projects

5.3.3.1 The Case Study in Iran (PROJECT 1)

5.3.3.1.1 General Specifications

Seyed Residential Project 1 was constructed on land with an area of 350 square metres in district 7 in the centre of the city of Tehran. This project was a 7-storey concrete frame building, a self-build, which included a basement floor, a ground floor, 5 upper storeys, and 10 units. The 5 floors each with 2 units (10 residential units) have been built on top of the ground floor. The basement and ground floor included car parking areas, storage units, an elevator, public areas, a lobby, 1 unit for the custodian area/caretaker's room, installations, and a central powerhouse location/facilities. The total area of the infrastructure is 1800 square metres and, from this amount, 1200 square metres has been used for the 10 residential units. The construction project had 6 subcontractors.

5.3.3.1.2 Structural Materials and Technical Data

Excavations of some 650 cubic metres, concrete consumption of 620 cubic meters, and 98 tons of steel bars were used for construction of the concrete frame building.

Executive operations of this project started in September 2015, and it was expected to be completed by February 2018, according to the timing schedule and programme plan, assuming no difficulties with project budget funds However, due to financial problems when the project was in the finishing stages (progression of about 95%), completion took longer. Final completion of the project was reached in March 2019.

Excluding land costs, the project price was estimated to be approximately $1.2 million. However, due to the remaining executive operations and the high inflation rate in Iran during this period, the project needed an extra $50,000–100,000 for completion.

It was expected that this project would be completed with 30% variability in the budget and time schedule. A master schedule was prepared using Primavera PERT Master software as part of the research presented here (see master schedule (schedule of executive steps) provided in Appendix D).

According to Al-Reshaid et al. (2005), "project budgets are affected by two factors:

1. Inflation, sometimes referred to as escalation; and
2. Contingency.

Inflation (or escalation) is an allowance for an inflationary 'cost increase' of items in the estimates between the time of 'estimation of projects' and time of 'actual purchase during project execution'. Escalation or inflation affects all items, more or less uniformly, if the project proceeds during the time period envisaged in the budget.

Inflation varies from region to region of the world. For example, the inflation in prices of construction material/labour/equipment would not be the same in North America, in Asia, or in Africa during a given period. Therefore, the inflation factor is always subject to adjustment based on the economic conditions prevailing at that time period in the region".

5.3.3.2 The Case Study in Iran (PROJECT 2)

5.3.3.2.1 General Specifications

Safai Residential Project 2 was built on land with an area of 570 square metres in zone 22 of the city of Tehran. This project was a construction of a 10-storey concrete frame structure, which included 2 basement floors, a ground floor, and 7 upper floors (14 dwellings/residential units) built on top of the ground floor; it was self-built and had subcontractors.

The basement and ground floor included car parking areas, storage units, an elevator, public areas, a lobby, 1 unit for the custodian area/caretaker's room, installations, and a central powerhouse location/facilities.

The total area of the infrastructure is 3600 square metres and, from this amount, 2200 square meters have been used for 14 residential units. The rest of the infrastructure includes the parking area, storage area, installations, powerhouse facilities, staircase, and lift.

5.3.3.2.2 Structural Materials and Technical Data

Excavation of 2500 cubic metres, concrete consumption of 1650 cubic metres, and 280 tons of steel bar were used for the construction of the concrete frame building.

Executive operations of this project started in February 2016, and it was expected to be completed in August 2018, according to the timing schedule and programme plan, and if the project budget funds faced no difficulties. However, due to financial problems when the project was in the finishing stages (some 98% completed), completion took longer. Final completion of the project was reached in May 2019.

Excluding the price of land, $2.5 million has been used for the construction of this building, and according to the remaining executive operations of the project and including the impact of inflation in Iran over the period of works it was expected the project would need an extra $50,000–60,000 for completion.

It was expected that this project would be completed with 30% variability in budget and time schedule. A master schedule was produced using Primavera PERT Master software as part of this research (see Master Schedule (Schedule of executive steps) in Appendix D).

It should be noted that the case studies were run whilst Iran was experiencing a period of high inflation and exchange rate instability. This means that construction and building expenses experienced yearly increases of approximately 10–15%, necessitating project completion as quickly as possible. This meant that in both projects in particular, there were delays. Whilst external factors cannot be controlled, their impacts can be mitigated. As such, these

circumstances and the vulnerability of the projects to their impacts can be described because of attitude, stemming from weak production planning. This wastes resource and is connected to the serious and extreme dependence of the management tools on the transformation theory of production.

Please see section 5.3.9 for pictures of the projects.

5.3.4 The Project Management Method on a Site in Iran

5.3.4.1 Organisation and Structure of Companies

The author had interviews with managers of different construction companies in Iran and most of them cited their companies as dynamic and flexible. In addition, it should be noted that the author supplemented the material by utilising the companies' management documents, where a large amount of data was found to explain their organisational structure.

Moreover, some interviews were carried out with high-level managers of those companies, which helped the author to find out more about those documents. It was understood that those companies recognise themselves as having dynamic, decentralised, flexible, coordinated and synchronised management, based on the sources of data. Also, the interviewees confirmed that the companies use a matrix structure for each project. In a matrix organisation, the practical and operative departments and the commerce units have more or less equivalent priorities, according to Seymour (2005). Thus, people working in the company's units should work with two viewpoints in mind, the end product and functional basis. Thus, here, the double focus let the project groups unite resources and functional skills with an orientation run and determined by the main tasks and challenges from the organisation's situation.

While on site, the director in charge of the business unit visited the site on a weekly basis. During these visits, the director discussed with members of the project team several diverse managerial issues, for example about productions, procurement, and logistics. Also, there were times during meetings that the director talked about site problems with the client representatives and contract manager. This was an obvious example that problems on site were hand over upwards.

Regarding the kind of planning techniques, based on the survey results, both modern (lean) (e.g. critical chain programming and Last Planner) and conventional/traditional time planning techniques (e.g. critical path methods, bar charts) are used for construction projects in Iran (15% and 100% respectively; Q9).

For planning and time control techniques, e.g. other techniques (8.40), Simulation (score 7.71), Elemental Trend Analysis/ Line of Balance LOB (7.5), PERT (7.42), PND (7.00), CPM(6.06), Milestone (6.06), Gantt Bar chart (5.88), are used for construction projects in Iran (Q8). For project planning they use computer programs and software. They structure detail plans (weekly work plans) from the Master Schedules. Questions 8, 9, 10, and 11).

They Utilise computer programs for planning: (Yes 100%) (Q10). The degree of computer software utilisation for the planning activity is Fully integrated (80%) (Q11).

5.3.4.2 Organisational Structure of the Construction Project

The structure of the site organisation can be described as a bureaucracy, run by a chief team of management. A bureaucratic type of organisation is presented as a pyramidal arrangement where there is a top-down allocation of power, so it is greatly based on the philosophy of management created from the schools of Taylor, Fayol, and Urwick (Walker, 1984). Because of peculiarities of the environment in the function of an organisation, the requirement for a chief management team arose. It would not be possible to codify all suitable answers with no management team, because the environment is dynamic and complex, and new problems, concerns, and issues are made on a continuing basis.

In construction work and projects, a suitable designed organisational arrangement is important to give a structure for dealing with all the issues and differences intrinsic to construction, which influence the performance of the process of project management. Therefore, management and organisation are in fact essentially connected concepts that require particular attention on site, according to Walker (1984).

5.3.4.3 The Contract Strategy

In Iran, there are more traditional Design-Bid-Build projects than Design and Build projects.
For the traditional Design-Bid-Build projects, a consultant carries out the design and a contractor builds. Some contractors use/sign conventions with some subcontractors, for

example for tiling, plastering, iron-working, steel frame structure, and concrete slab making. Design and Build are used for private projects by private companies or value-demanded projects.

5.3.4.4 The Production Theory

To better understand the construction project management, the project studied was evaluated using system theory. A system imports resources, converts a project, then adds value, and exports services and products to the environment (Seymour, 2005). Thus, this project is a system where environmental forces influenced a group of investors to build up a new building project, in this case in Tehran. So, the main task of this system is to transform and convert investors' inputs, which are information, material, energy, and money, into an output, which is the construction of a 7-storey or 10-storey concrete frame building, and after that, commercialise it at a profit. Therefore, the process of construction, as well as design, is a subsystem of this transformation, conversion, and alteration (Figure 5.58), being subcontracted to a specialist and expert contractor based on a contractual system. Therefore, the aim of this sub-system was design and construction of a project to satisfy and fulfil the client's expectations and requirements, at profit and advantage for the contractor's corporation.

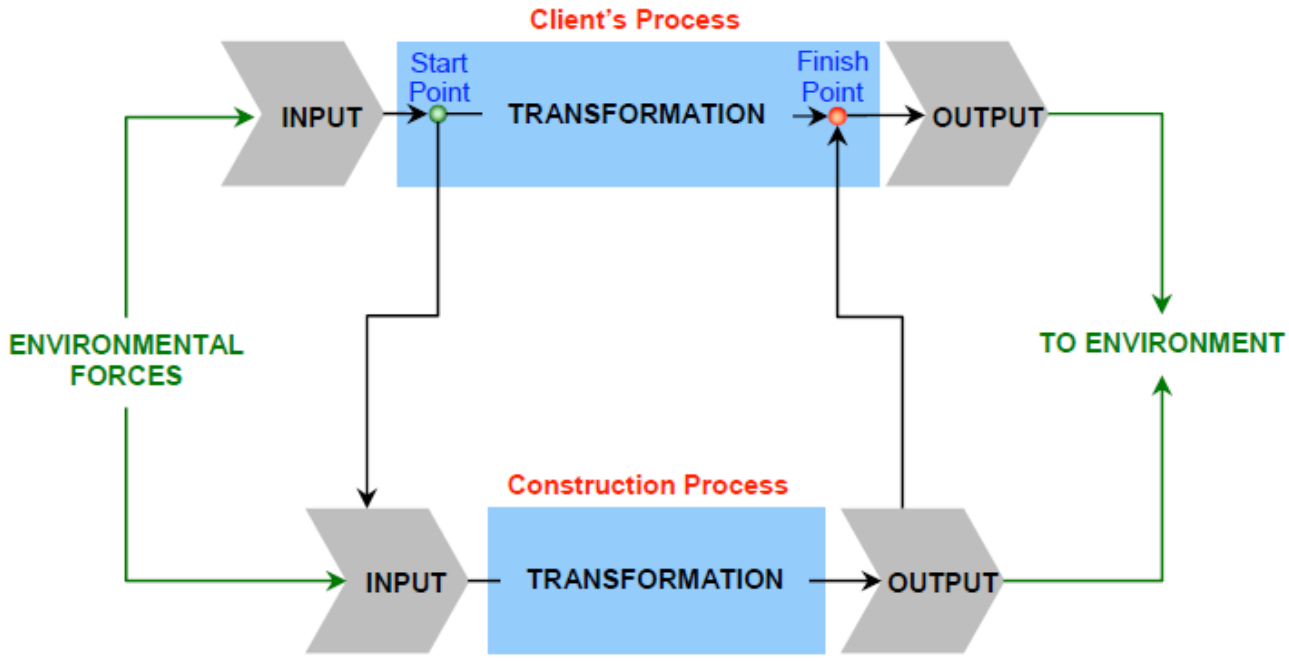


Figure 5.58: Construction as an open system (Walker, 1984)

Thus, it was concluded that the production theory on site conceptualises production as transformation of inputs to outputs. The whole transformation of the work, the system of construction procedure (Figure 5.58), was decomposed into manageable and controllable sub-transformations, such as tasks, subsystems, and activities which are also understood well, and after that subcontracted to specialised firms, i.e. all work was captured by top-down breakdown of the whole transformation (Koskela and Howell, 2002b). Therefore, there was a common belief that project can be understood in a best possible approach by comprehending every task in an optimal series and arrangement (Koskela and Howell, 2002b).

Improving the tasks can enhance the performance of a project, and this is normally attained by using more resources, typically human resources, or by using new tools and technologies. In several developing countries, because of the social and economic features, employing labour is a lot cheaper than using equipment, so labour is often used.

During an observation on site, it was noticed that the concrete-pouring process was carried out in a strange and unusual manner, which resulted in lots of waste. Typically, a concrete pouring is done through a truck-mixer which gathers the concrete from a batching plant, transports it to the site, and finally pours the concrete using one of the following techniques: by hand, by a concrete-pump, or by bucket and crane.

Certainly, unusual and strange practices result in a waste of resources; utilisation of site resources, such as a concrete pump or crane, could have compromised the implementation of other activities.

Here, these circumstances could be described as an attitude, which was present as a direct result of weak production planning. This waste of resource could also be connected to the serious and extreme dependence of the management tools on the transformation theory of production. A transformation model does not reflect what occurs between transformations. So, by utilising these tools, the project team might not be able to differentiate a transformation activity from a non-transformation activity. As a result, efforts to develop transformation activities are practical and apply to non-transformation activities as all the activities are observed as transformation activities.

Thus, it was seen that, in practice, in some cases the idea of improving and developing project performance through the improvement of tasks is not correct.

Again, in some cases, even the use of expensive technological devices will not enhance the performance of a task. In contrast, the task turns out to be more expensive at the same time as its performance, in the best case, stays similar. Therefore, the improvement of a task should not focus on an activity that does not add value to the procedure, such as transporting.

According to Plossl (1991) – quoted in Koskela (2000) – "*major investments in new equipment are not the solution to a confused factory*".

Therefore, the production theory currently utilised on site is not sufficient to recognise a dynamic and complex system such as construction and thus requires an overhaul.

5.3.5 The Management Theory

The following analysis aims at presenting how the management system established on site deals with the three fundamental project management areas: planning, execution, and control.

The tender plan, which was arranged for the construction of the buildings in the tendering phase, is a critical path network. Based on an interview, it was confirmed that the tender plan represents the outcomes of complete discussions, careful thinking, actions and decisions, and commitments made between contractual parties and other people through the pre-construction phase. Thus, the tendered plan includes all activities within the construction interval in an adequate and satisfactory manner that allowed the contractor to arrange the tender for the project. This plan developed into the Master Plan, which was the official and certified version of the working plan on site. Therefore, all the milestones which also include the completion date, presented by the contractor while tendering, were converted into contractual clauses that ought to be pursued along the project's execution. Any slip in meeting one of these milestones can be a costly penalty and punishment for the contractor.

As a result, the Master Plan (tendered plan), was the main planning document found on site and appeared to run the entire managerial decisions of the project.

Construction projects are complex and dynamic; situations will almost unavoidably change throughout the construction phase. The management of construction projects should include reformation, revision, redesign, and strategic implementation of plans, to meet the objectives of the project successfully. The Master Plan does not necessarily present the most suitable programme of execution, though it does present the project milestones. The cyclic planning process on site is based on the appraisal and evaluation of the present condition of the construction, the preferred project objectives, and the evaluation of the allowable transformation of state, which can be attained through proceedings. Considering these inputs, the plan is revised, amended, modified, or developed in a sequence of actions that, at the time of its preparation, can be the best means for satisfying the requirements of contract.

If the managerial liability for planning depends on determining the work breakdown structure to break down the work into task and subtasks, making decisions on the tactics and strategy, and through this allocating responsibility for completion of the task to organisations, individuals, and teams, then, even after making changes and variations, there would be no disturbance to the contractual milestones. This was suggested and planned by the contractor back in the tender phase, corresponding to the tendered plan.

According to an interviewee, the client's representative proposed and recommended a weekly meeting, which included all the subcontractors involved in the production process as well as the contractor's production team. There was a thought that these meetings on site are the same as the release of a WWP (Ballard, 2000).

As a conclusion, it can be appreciated that the fundamental role of management in planning should not be underestimated where planning is handed over to those people who are responsible for doing the planning. Therefore, the programme submitted to the client periodically is an expression of what has been finished on site and a theoretical wish list which, optimistically, would be completed the following week. However, the practice proposed and recommended by the client was a high-quality method to improve the reliability of the plan and, if genuinely applied, would result in enhanced control and management of the project and all the activities.

For each project, a Master Schedule using the Primavera PERT Master software was prepared as part of this research. The graph was a remarkable illustration of the site planning reliability. Therefore from the results that the graph would show, it would be possible to compare the percentage of activities that were planned and completed, and say whether the current practices of planning on site were adequate and suitable or whether they had limitations. Then if there were limitations, it could be concluded that there was a need to make new decisions and practices to enhance the planning reliability. Also, if the graph showed that, for example, the percentage completed increased considerably, then it could be concluded that the project team was concerned with the process of planning and that, even though not perfect, the new practices and decisions had changed the reliability of planning on site. From the results and the information achieved from the graph, it would be possible to assess whether the work and project was on track or not, and if not, there would be a need to plan and to make new decisions and practices in order to bring the tasks and activities back on track.

In the case that was studied and analysed in this research, the production process can be explained as a black box with inputs on one side and the preferred output on the other side (Halpin and Kueckmann, 2002). It was noticed that the initial techniques and methods of control and management focused on measuring the outputs out of the black boxes, which would be, typically, in terms of time, cost, quality, and the standard of performance. Only if the production was late or over-budget would the processes be revised and examined to decide how the violated end-product criterion could be attained. The process is accepted, only if the output is in given and specified range, even if it might not be the best or good though.

The control of time was carried out on an experiential basis through simple visual comparison between what was complete and what should have been completed. One of the methods which are efficiently and successfully used in controlling production on site is cost control, which is done by expensive and sophisticated software used by the companies. This suggests that cost control was over-emphasised. It is argued that this extreme concern and attention to the financial management is related to the culture of the organisation. In essence, production control is much more than just a comparison between planned and executed costs.

In general, this suggests that planning, execution, and control, which are the three areas of concern, control and execution, are more open and clear in the Iranian organisations studied than planning, in terms of project management. In addition, much of the resources such as people, software, effort, and hard work are directly related to these areas rather than the area of planning (Table 5.2).

Table 5.2 The theory of project management found on the case(s) studied

Focus of theory		Theory
Production		Transformation Value generation
Management	Planning	Management as planning
	Execution	Classical communication theory
	Control	Thermostat model Systematic experimentation model

Please refer to Chapter 4 Figure 4.6 for the implementation and control system (ICS) proposed by the researcher. This suggests that integration of LPS and SBCE will improve pull management and the commitment to eliminating rework on site.

Table 5.3 shows the integration of proposed system in Figure 4.6 and Table 5.2.

Table 5.3 Last Planner System: the theoretical consequences on site

Focus of theory		Theory
Production		Transformation **Flow** ← Last planner Value generation
Management	Planning	Management as planning
	Implementation	**Management as organising** **Management as pull** ← Last planner
	Monitoring and Control	Thermostat model **Scientific experimentation model** ← Last planner
	Review and Execution **(Sign off)**	Classical communication theory **Language/action perspective** ← Last planner

It is worth noting here that Koskela and Howell (2002) used the thermostat and scientific model to explain the features of traditional project management and lean project management. The new development regarding this research can be seen in Table 5.3.

5.3.6 Waste and Value-loss

A key finding was that the identification of waste and value-loss in a construction project shows how well-organised and competent the system of project management is. In the following section, the waste and value-loss found on Iranian sites are explained. Identification can be an excellent guide to the possible impact of the LC philosophy.

The list of identified waste(s) at Iranian sites was gained from questionnaire results (see Section 5.2).

Issues and operations related to waste in Iranian Site Which Ranked/ordered from the most important are (1) Cutting of reinforcement (Score 4.44), 2. wrong or improper welding, 3.a Improper excavation (Total 17), 3.b General waste (Total 18); (3.a-3.b, the same score), 4. Pouring concrete (see Q47).

The Top 5 Identified waste and value-loss that found and discovered on site are Ground preparation, Soil condition, Weather conditions (Rain, Snow, etc.), Material handling, Breakdown of equipment (see Q48).

The most important types of waste most relevant to the activities during the construction phase, are: Overproduction, Excess inventory, Over-processing, Poor level of commitment to quality improvement, construction defects (see Q49).

Impact that has been seen on waste on site since adopting the LPS are Less Waste (66.67%), Neutral/No change (33.33%) (see Q50).

Evaluation of the impact on waste on site, by development and adopting new construction control, measurement and performance methods are significantly less waste equal to less waste (46.67%), Neutral/No change (6.67%) (see Q51).

By adopting the new methods, the following wastes will be eliminated from the construction process, which are Construction changes; unrealistic constraints of project time (see Q52). Thus the problems highlighted in Question 49, would be reduced.

Thus, the significance of the techniques for improving the reliability of planning are: Other, Improve/develop the quality of material, Improve project planner's abilities, Improve/develop the quality of labour, learn from previous works and projects, Employ specialist teams (see Q53).

5.3.7 Improvement programme for Iranian construction projects – Improving construction management practice with LC principles: A case study

In project 1 had progressed further than project 2 when the case study data were gathered (it was in the middle to near the finishing stage), it was harder to implement LC methods in project 1. It was easier to implement these methods in project 2 as it was in a much earlier stage of construction. Ballard (*pers. comms*, 2013, 2015), in response to a question about applying the principles of LC when a project has already started, indicated that applying the Last Planner on a project that is already under way is more difficult as the project managers have already established a way of doing things. Likewise, AlSehaimi et al. (2014) carried out a study in which, in both case studies, LPS was implemented halfway through the project, which resulted in significant improvement.

The purpose of this research project is to evaluate the effectiveness of implementing the techniques and principles developed for LC to improve construction planning and control practice and enhance site management in the construction industry in the UK and Iran, representing examples of a developed and a developing country's construction sectors, respectively. Thus, this research project presents a study of two ongoing construction projects in which specific LC principles were tested through an action research process (see Chapter 3). Each technique was evaluated based on its impact on the performance of each of the projects. Based on the results and findings of the study, a new 'lean assessment system' has been proposed to quantify the results of implementing lean principles. The assessment system evaluates eight LC elements: (1) Last Planner, (2) visual inspection and increased visualisation, (3) daily huddle meetings, (4) first-run studies (PDCA), (5) 5Ss and (6) fail-

safe for quality, (7) JIT, and (8) KPIs. This study provides a simple and comprehensive approach that is transferable to any construction project. This aligns with the work of Arditi and Gunaydin (1997), who set out that quality in construction is primarily related to product conformance.

The main objective of the case studies was to implement and evaluate the values of different LC principles for two construction projects in Iran. By implementing LC techniques, the contractors would practise human resource management and technical learning.

In the paper by Gao and Low (2014), only three of the frameworks they selected (Diekmann et al., 2004; Paez et al., 2004; Green and May, 2005) considered the soft side of the lean approach, while the remaining ones did not consider human resource management (HRM) implications at all. The knowledge gap could be filled if the LC paradigm were to move forward to shift its present focus onto human resources, which is the soft aspect of lean.

The management team associated with these case studies agreed to implement and test the eight LC listed above. The implementation of these techniques in construction projects was monitored mainly during a 12-month period, by the civil project engineer who was also the supervising engineer of the project, and with direct site visits and involvement from the researcher for 5 weeks. During the case study, work contact with the project engineer regarding the progress of the construction projects remained throughout, until the completion of the buildings.

Based on the results and the feedback provided by all participants, an overall assessment was prepared and improvement suggestions for future implementations were proposed. The planning team, controlled and guided by the project manager, focused on operational planning and included subcontractors as well as the staff. The workers' team, guided by the foreman, focused on the improvement activities, and included workers. A tool was selected for the implementation of each technique. The research team provided reference materials and collected data to monitor the progress on the implementation of each LC tool. For foreman planning, for example, using drawings and specifications, a construction sequence, and the immediate site situation, foremen can translate earlier plans into actual work assignments for their own crews (Laufer et al., 1992).

Furthermore, non-participant observation, which lasted for 12 months, aimed to help identify existing planning practices, prior to implementation of the tools and framework.

Facilitation of tool implementation, through participant observation: the researcher attended weekly meetings over 5 weeks with the project teams, at both case study sites. In these meetings, PPC figures were recorded and reasons for incomplete assignments were tracked and analysed. There were subcontractors working on the projects, doing structural, architectural, mechanical, and electrical work. In both case studies, tools were implemented halfway through the project. AlSehaimi et al. (2014) carried out a similar case study but only with LPS implementation. However, this was not as detailed as the ones presented herein. In the present study, the master schedule produced for the case studies allowed each technique to be evaluated based on its impact on the performance of each of the projects (see Sections 5.7 and 5.8).

5.3.8. Questions, Answers and Discussions (in relation to case study implementation)

The question related to: How do you implement Lean Construction? And what are the challenges to implementing it?

(1) Improvement programme for Iranian construction projects

Here, training that their staff had undertaken is key and if they use the LPS they are Other (Not using the LPS, Not working with LPS), In-house training is equal to (the same percentage) Attendance at external workshops courses (see Q54).

(2) Inhibiting factors and mitigating measures

Drawing from the case study work and the previous questionnaire, factors inhibiting projects are highlighted. The factors affecting the ability to effectively control the time of their construction projects include: use of inappropriate software, contract and specification interpretation disagreement, discrepancies in contract documentation, project fraud and corruption, and conflict between project parties (see Q55).

Factors affecting the ability to effectively control the cost of their construction projects include: use of inappropriate software, complexity of works, unpredictable weather

conditions, lack of proper training and experience of the project manager, and project fraud and corruption (see Q56). Here, the problems faced by construction industry are Choice 3: score (25.00), choice 5 (26.00), choice 12 (25.00), 13 (25.33), 18 (25.00) (see Q57).

The significant barriers to the successful implementation of LC in Iran are financial issues, culture and human attitudinal issues, a lack of process-based project management, time and commercial pressure, and structural and cultural barriers (see Q58). Most of them do not measure earned value or cost performance at the assignment level: Yes (38.46%), No (61.54)% (see Q59).

5.3.9. Tool Implementation Strategy in the Studied Projects and Pictures for case study Iran

As the project progress towards its completion, the respondents (experts) were asked to complete the questionnaires for each phase of implementation of the developed framework and it worked, as shown in the steps of project completion in the Primavera Figure, steps of project completion progress (See Appendix D). Figures 5.58a to d, and 5.58e to p, show different aspects of the two projects used in the case studies undertaken in this research.

Project 1



Figure 5.58a: Foundation and retaining structure



Figure 5.58b: Concreting/concrete framework



Figure 5.58c: Stone wall implementation (parking)



Figure 5.58d: Façade

Project 2



Figure 5.58e: Excavation



Figure 5.58f: Foundation



Figure 5.58g: Shear walls



Figure 5.58h: Foundation after excavation



Figure 5.58i: Finishes



Figure 5.58j: Façade scaffolding



Figure 5.58k: Plumbing



Figure 5.58l: Stone wall implementation (parking)



Figure 5.58m: Electrical

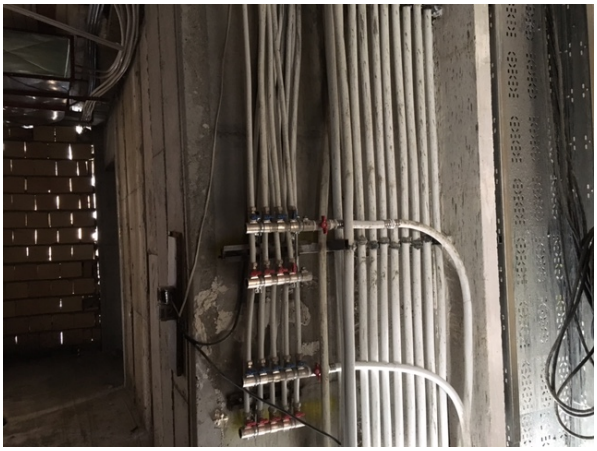


Figure 5.58n: Plumbing





Figure 5.58o: Making façade/front view (building façade)



Figure 5.58p: South view

Figure 5.59 shows the tool implementation strategy used in the studied projects. See Sections 5.3.9.1 and 5.3.10 for more details.

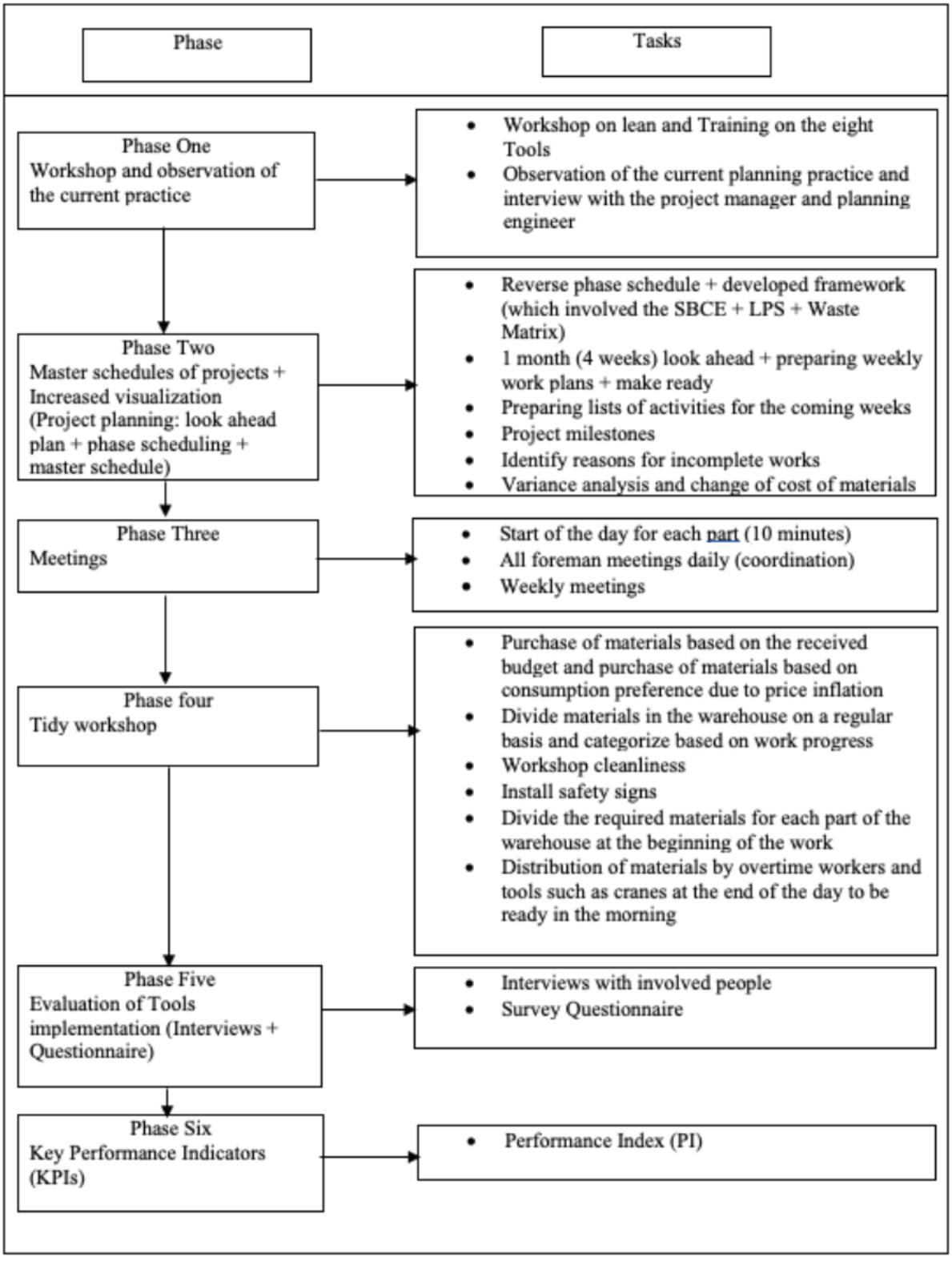


Figure 5.59: Tool implementation strategy used in the studied projects

5.3.9.1 Strategy

For implementation of the Last Planner in practice, the practical steps that need to be applied to a particular project are: procedures, organisation of project team, and standardised papers and forms. Implementing an updated hierarchy of project planning, with phase scheduling placed between the master schedule and the lookahead plan, is suggested, as shown in Phase Two in Figure 5.59.

Having a team of specialists on the subject or issue, who work closely and faithfully on the project, is the first important step required in every organisation for the successful implementation of LPS. Even when things go wrong, they will stay together and all problems will be discussed first in the group, to formulate an effective way forward.

Simplification and clarity of the management process is the aim of the LPS with SBCE and, therefore, all the standardised forms or paperwork are simple and can be simply and easily set up, in a format as simple as a Microsoft Excel spreadsheet.

Finally, the essential and required factors for implementation of LPS with SBCE, in Iran, as an example of a developing country, are discussed in detail.

5.3.9.2 Framework Implementation (SBCE + LPS + Waste Matrix)

Existing planning practices

In the first phase of implementation, a questionnaire, interviews, and non-participant observations were conducted to examine the current planning practice. The findings suggest that planning was mostly based on a master plan presented on a bar chart issued at the beginning of the construction phase.

Planning and time control techniques such as simulation, elemental trend analysis/line of balance (LOB), PERT, PND, CPM, the Milestone Data Programming Technique, and Gantt bar chart were being used for project planning (Q8). Construction commenced with a meeting of the main parties involved in the project execution, to establish acceptable ground rules to ensure that the contractors understood all the job requirements. However, a systematic review of project planning was found to be rare.

Regarding the kind of planning techniques, based on the survey results, both modern (lean) 15% (e.g., critical chain programming and Last Planner) and conventional/ traditional time planning techniques 100% (e.g. critical path methods, bar charts) are used for construction projects in Iran (Q9). For project planning, they use computer programs and software. They structure detail plans (WWPs) from the master schedules.

Regarding project evaluation, most interviewees said that they did not tend to refer to post-job records, as these were either non-existent or inadequate. The interviews also revealed an absence of detailed short-term planning and improvement meetings to discuss project progress. As for planning techniques, most of the interviewees stated that their firms used the critical path method.

After the interviews, the application of LPS with SBCE and other tools was discussed in detail with construction staff as part of the ongoing discussion up to completion of the projects reviewed in the case studies, and examples from previous studies were considered. As part of these discussions, the weaknesses of the current planning practices were observed, and thought was given to how the LPS with SBCE and other tools could enhance practice. This also included training on implementation of the tools.

According to respondents, results regarding assessment of the present methods of project planning are as follows: None (0.00%): Out of date; Sufficient (26.32%); Require upgrading/development, additional aspects need to be analysed such as human factor (73.68%) (Q13).

Regarding the awareness of LPS, most of the respondents were not aware of it: Yes (31.58%); No (68.42%) (Q15). Most of the respondents do not use LPS: Yes (33.33%); No (66.67%) (Q16). However, all of the respondents use PPC as a measurement: Yes (100%); No (0.00%) (Q18). Of note was the fact that more than half of the respondents would consider using LPS if not already using it: Yes (53.33%); No (46.67%) (Q19).

Interestingly, respondents' current structure of WWPs is as follows: Build it on the Master Schedule and form/create additional information (45%); Obtain and pick out from the master schedule (75%); Totally form/construct a modern work plan (0.00%) (Q20).

The preferred technique in the planning phase to accommodate uncertainties in the last phases of work are: Set up and begin the process early (29.41%); Use of time buffers (70.59%); Utilising resource buffers (11.67%) (Q21), with Site conditions (26.67); weather (26.67); Lack of experience of project type (26.50); Imported materials and plant items (26.00); Additional works (26.00), all identified as the most common factors that often causes and lead to project cost overruns (Q33).

Respondents stated that they manage and control sustainability: (1) by sustainability assessment, and (2) by using standard materials in quality control and use of experienced labour (Q37).

Factors they consider regarding the sustainability are: Sustainable indicators and benchmark (25.00%) and Sustainable assessment (83.33%) (Q38); steps they consider while doing quality management and control are: Quality control and inspection (100%), Quality assurance (15.79%), and Quality measurement systems (15.79%) (Q34).

5.3.9.3 Implementation

An implementation strategy was developed for each case study company, where the main components of tools were gradually implemented in six phases, with an evaluation at the end of each phase. Whilst in most prior studies on LPS, the implementation has started from upstream stages, from master and phase planning, here the implementation started from weekly planning, and progressed then towards upstream stages. However, a few studies have implemented LPS from short-term planning upwards, including those of Koskenvosa and Koskela (2005) and Bortolazza and Formoso (2006).

The strategy was agreed upon after intensive discussion between project teams and the researcher. In both projects, the strategy of implementation started with short-term planning (Figure 5.59). Figure 5.59 shows the implementation strategy adopted in both cases, followed

by a description of the phases. For Q39 to Q46 (Development of Measurement and Control Methods), the Top 5 Methods that have been used in respondents' company for construction planning efforts are: CPM (100%); long-term planning (55%); short-term planning (45%); buffer (20%); LPS (10%) (Q39) (refer to Figures 4.8, 4.9 and Figure 5.67).

The Top 4 Methods that have been used in respondents' company for the implementation are: other (70%) (experimental controlling method (experimental control); traditional way and methods are used; based on experiment) (Q40) (see also Figures 4.10 and 5.68).

Methods that have been used in respondents' company for monitoring/control are: commitment-based planning (90%); other (20%) (traditional control methods such as visual control method; only by control of maps and eye and lab control); LPS (10%) (Q41) (see also Figures 4.11 and 5.69). They review their construction process by PPC (100%); other (7.14%) (also, financial control) (Q42) (see also Figures 4.12 and Figure 5.70). Most of the respondents measure the reasons for failure of the project process: Yes (87.50%); No (12.50%) (Q43). In addition, most of them use root cause analysis: Yes (87.50%); No (12.50%) (Q44), and at the operational level; most of them do not measure cost performance: Yes (37.50%); No (62.50%) (Q45). Finally, when assigning tasks, most of them do not think that shielding is essential/important: Yes (30%); No (70%) (Q46).

5.3.9.4 Research findings

All of the respondents use PPC as a measurement: Yes (100%); No (0.00%) (Q18), and all of them have had cost performance index improvement, after LPS was adopted: Yes (100%); No (0.00%) (Q17). Effectiveness of using LPS: Farayand Bahrevari (Q22) (see Section 5.4.1.2).

5.3.9.5 Reasons for incomplete assignments

The most common influencing factors that often lead to project time overruns, ranked from the most important, were found to be: skilled labour shortage; poor labour productivity; inclement weather; material shortages; and financing and payment of completed works (Q14).

Site conditions (26.67); weather (26.67); lack of experience of project type (26.50); imported materials and plant items (26.00); and additional works (26.00) were all identified as the most common factors that often lead to project cost overruns (Q33).

In addition, factors leading to the problem of reduced and low quality are: variables causing cost overruns (65.00%); variations (35%) (project and client characteristics, project organisation factors); variables causing time overruns (30%); and errors/omissions in construction work (30%) (Q36).

It should be noted that according to Al-Sehaimi et al. (2014), the reasons for incomplete assignments in the two projects they studied were: prerequisite work, material, approval, changed priority, labour, equipment, design, late request for inspection, overestimate of achievement, incomplete information, defects requiring rework, scheduling/coordination, interface with other packages, space, weather, other (technical specification), other (rock under floor).

5.3.9.6 Questionnaire outcomes (participants perceptions): effectiveness of LPS implementation

According to respondents, Effectiveness of the use of the last planner system LPS. is/was Good (100%) (Q23) and regarding Any shortcomings responses are: No (58.33%); Yes (33.33%); Other (8.33%), Yes, the system needs to be more defined and usable, and therefore it is a very good idea that a new developed system would be introduced that can complete the current system in use. (Q24).

5.3.9.7 Perceived benefits, CSFs, and barriers

The most important problems for production control in construction are Out-of-date methods for production management/control; Attitude of people; Type of construction projects; Other (Q25). The factors that hamper the effective controlling of projects are: Finance and payments; Poor labour productivity and shortage of materials (Q26). In addition, the extent of

utilisation of LC or the LPS for production management are: Not using it; Testing on a number of works = Completely utilised, At training level (Q27).

The impact on production management of implementing the LPS was found to be: Not applicable; Excellent, Good (Q28). And finally to guarantee that the real work follow the plan. Respondents arranged an expert project management group…; Rely on the Quality of the subcontractor's work; Other: Everyone should have the commitment to follow the plan that is understandable by them. (Q29).

All the answers to the questionnaire questions have been used in the development of the main Framework.

According to Al-Sehaimi et al. (2014), the benefits, CSFs, and barriers to implementation of LPS. Following the research presented herein these are in turn:

1. The key benefits are:

- Enabling site supervisors to plan their workload,
- Improving the learning process,
- Improving planning and control practice,
- Enabling accurate prediction of resources,
- Reducing uncertainty,
- Preparing team members to collaborate.

2. The critical success factors are:

- Top management support,
- Commitment to promises,
- Involvement of all stakeholders,
- Communication between parties to achieve teamwork,
- Close relationship with suppliers,
- Motivating people to make change.

3. Barriers include:

- Lengthy approval by client,
- Cultural issues,
- Commitment and attitude to time,

- Short-term vision.

5.3.10 Tool Implementation Strategy in the Studied Projects

In the first phase, a workshop on lean and training on the use of the eight tools were provided to highlight the benefits of integrated tools. After this, there was a one-week observation period to monitor the current practices, to interview the participants and to make notes. Figure 5.59 shows each phase and the relevant/related tool(s). Here, WWPs and short-term weekly planning were produced.

In the second phase, it was agreed that project milestones and reasons for incomplete works would be recorded weekly for 4/5 weeks. The focus was on project planning and increased visualisation and 'look-ahead' planning. Weekly meetings were held with the involvement of all project parties (contractors, client, and consultant engineers).

To start with, the Reverse Phase Schedule and the developed Framework which involved the combined/Integrated (SBCE+LPS+Waste Matrix) was introduced; the other elements of the eight tools were gradually introduced through preparing lists of activities for the coming weeks (through which components of LPS were introduced: look-ahead planning and phase planning). Phase planning allowed activities to be pulled through by reverse team planning and for resources to be optimised in the long term.

In both projects, there were 4-week look-ahead windows. The involvement of many subcontractors made it difficult to have 6-week look-ahead plans.

AlSehaimi et al. (2014) also stated that a 4-week look-ahead window was feasible for the of LPS implementation case study they conducted in Saudi Arabia. In another LC techniques implementation study in Egypt by Issa (2013), a 3-week look-ahead window was used successfully.

Look-ahead planning was extracted from the master plan zone by zone, coordinated in the Last Planner (weekly) sheets. All planning levels were linked.

Phase two: In practice, phase planning generates a detailed plan covering the respective project phase, thus allowing better visualisation of the flow of work, which assists all parties to negotiate deadlines for the planned work.

Invoking specific requirements such as definition, soundness, sequence, size and learning (Ballard and Howell, 1994) was introduced to achieve quality assignments. Furthermore, reasons for incomplete works were identified, analysed, and acted upon, together with the project milestones in the weekly meetings. Barriers/variance were documented according to indications given by the project team and variance analysis and change of cost of materials was performed jointly by all project members. Data, i.e. project milestones percentage complete and reasons for incomplete assignments/works, were collected during the summer. Taken together, these factors significantly affected labour productivity and, hence, assignment completion.

During the third phase, lasting for 2 weeks in each project, project meetings took place. Each phase planning session was dedicated to a certain type of activity (i.e., finishing, mechanical), aiming to provide goals in each phase and then work backwards from the target completion date to achieve the proposed milestones.

The fourth phase was the Tidy workshop (5Ss) (see Figure 5.59).

In the Fifth phase (Evaluation of Tools implementation), a survey questionnaire was administered to evaluate implementation of the eight tools (i.e. LPS, etc.). The key objective was to allow participants to self-report the benefits achieved, CSFs and barriers to implementation of tools (LPS, etc.) in the project. The questionnaire contained 62 questions, but only the questions related to the achieved benefits, CSFs, and barriers for implementation of tools (LPS etc.) are covered here.

Questions were formulated using a five-point Likert scale that requested participants to indicate their degree of agreement or disagreement with a series of statements. The respondents were given sufficient time to read the questionnaire, think about it, and ask any questions they wished. Most participants answered in group sessions in the presence of the researcher who explained the questions, provided any clarification necessary, and asked the

participants to choose the answers they believed to be the most appropriate. The key findings obtained through the questionnaire are discussed in more detail below.

Phase six was regarding the Key Performance Indicators (KPIs) and Performance Index (PI). AlSehaimi et al. (2014) carried out a similar case study but only with LPS implementation and a major shortfall of this work a lack of completeness. The research presented in this thesis goes a significant way to filling this gap. In particular, the key contribution and novelty of the research presented can be found in in Chapter 2.

According to Issa (2013), the form of these indices can be introduced as linguistic variables. The states of linguistic variables are defined as follows: very low (vl), low (l), medium (m), high (h), and very high (vh).

Look-ahead planning is the process undertaken to achieve possible constraints, free assignment, and cut down uncertainty. The WWP is produced based on 4-week look-ahead basis, the master schedule, and field conditions. Look-ahead schedules were updated on a weekly basis during project meetings. Ballard and Howell (1994) indicated that a WWP should emphasise the learning process more by investigating the causes of delays on the WWP instead of assigning blame and only focusing on PPC values.

In this project, a systematic approach to identifying inhibiting factors (i.e. barriers, waste, etc.) and developing mitigating measures is used. Effective look-ahead scheduling and management are used to eliminate the effects of the obstacles in the works. The most important activities and both positive and negative observations during project execution and the solutions for any problem are suggested and introduced. The master schedule is modified every 4 weeks based on the available suggestions, results, and evaluation.

Even though the project process and performance were improved because of using LC techniques, not all factors were affected by these techniques. From the results of observations and surveys, it is noticed that some factors not affected by using lean. Issa (2013) recommended to applying lean techniques in construction projects in developing countries due to their high efficiency.

5.3.10.1 Implementation: Observation during project execution

Regarding the implementation and observation during project execution, look-ahead planning (4-Week Look-Ahead Planning for the Two Case Studies) is shown in Table 5.4 below (see Appendix D regarding the Master Schedules of Projects 1 and 2).

Table 5.4 Activities and observations during project execution

Activities	Positive observations
Weeks 31–38 (7/6/2017–9/11/2017) Weeks 31–36	Project 1: Master Schedule Primavera Project 2: Master Schedule Primavera

5.3.10.2 Round 2 (UK)

The questions used for Round 2 of Re-Analysis are shown in Table 5.5 below.

Table 5.5 Questions used for Round 2 of Re-Analysis

Round 1 (UK)	Round 2 (UK)
Q8	Q1 (Q8 in Round 1 is shown as Q1 in Round 2).
Q12	Q2 (Q12 in Round 1 is shown as Q2 in Round 2).
Q31	Q3 (Q31 in Round 1 is shown as Q3 in Round 2).
Q32	Q4 (Q32 in Round 1 is shown as Q4 in Round 2).
Q35	Q5 (Q35 in Round 1 is shown as Q5 in Round 2).
Q53	Q6 (Q53 in Round 1 is shown as Q6 in Round 2).
Q58	Q7 (Q58 in Round 1 is shown as Q7 in Round 2).

Round 1 (Iran) used questionnaires and Round 2 (Iran) used inerviews. Only the questions that needed re-evaluation in the development of the framework were considered in the Delphi analysis. Only the questions that were used in the Delphi were named/mentioned in the Delphi Questionnaire, in order to keep the respondents motivated and encourage them to answer the questions.

5.4 SPSS Analysis of Round 2 of Questionnaire and Interview (UK)

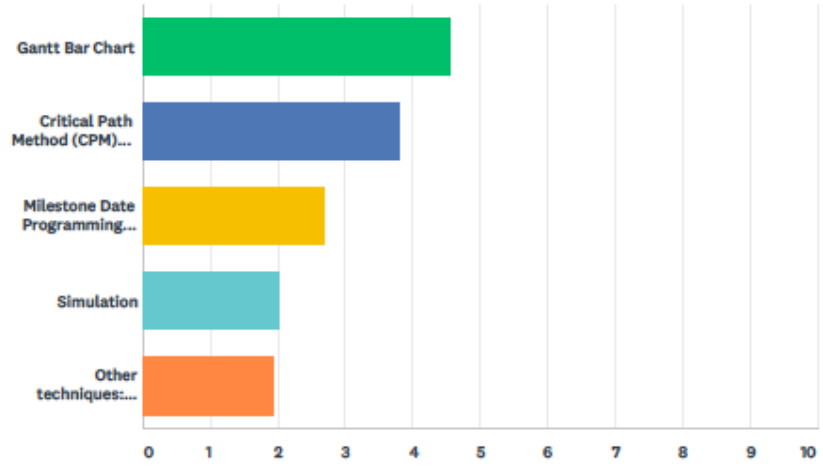
In order to reach statistically significant results, Round 2 was used here to reach significance. The results include:

- Gantt bar chart was the most-used technique for planning and time control (Q1).
- Microsoft Project was the most-used software application for planning (Q2).
- Unit costing and earned value analysis was the most-used technique for project cost control (Q3).
- Microsoft Project was the most-used software package for cost control (Q4).
- Quality control was the most-used quality tool for improving quality and productivity (Q5).
- Improving the project planner's abilities was the most significant technique for improving the reliability of planning (Q6).
- A lack of adequate lean awareness/understanding was the most significant barrier to the successful implementation of LC in the UK (Q7).
- Successful implementation of LC in the UK (Q7).

Further details of the results for each question are presented below, see Q1–Q7.

Q1 Time Control Techniques and Software Applications: In terms of Planning and Time Control, which of the following control techniques being used by you? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

Answered: 16 Skipped: 0



	1	2	3	4	5	TOTAL	SCORE
Gantt Bar Chart	75.00% 12	12.50% 2	6.25% 1	6.25% 1	0.00% 0	16	4.56
Critical Path Method (CPM) (Critical Path Networks/Method)	12.50% 2	62.50% 10	18.75% 3	6.25% 1	0.00% 0	16	3.81
Milestone Date Programming Technique	0.00% 0	12.50% 2	50.00% 8	31.25% 5	6.25% 1	16	2.69
Simulation	6.25% 1	0.00% 0	18.75% 3	37.50% 6	37.50% 6	16	2.00
Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	6.25% 1	12.50% 2	6.25% 1	18.75% 3	56.25% 9	16	1.94

Figure 5.60a: Techniques used for project planning and time control

Correlations

			Gantt Bar Chart	Critical Path Method (CPM) (Critical Path Networks/Method)	Milestone Date Programming Technique	Simulation	Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule
Kendall's tau_b	Gantt Bar Chart	Correlation Coefficient	1.000	-.033	-.412	-.133	-.031
		Sig. (2-tailed)	.	.890	.079	.568	.895
		N	16	16	16	16	16
	Critical Path Method (CPM) (Critical Path Networks/Method)	Correlation Coefficient	-.033	1.000	.382	.013	-.345
		Sig. (2-tailed)	.890	.	.097	.956	.130
		N	16	16	16	16	16
	Milestone Date Programming Technique	Correlation Coefficient	-.412	.382	1.000	.250	-.522*
		Sig. (2-tailed)	.079	.097	.	.271	.021
		N	16	16	16	16	16
	Simulation	Correlation Coefficient	-.133	.013	.250	1.000	-.659**
		Sig. (2-tailed)	.568	.956	.271	.	.003
		N	16	16	16	16	16
	Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	Correlation Coefficient	-.031	-.345	-.522*	-.659**	1.000
		Sig. (2-tailed)	.895	.130	.021	.003	.
		N	16	16	16	16	16
Spearman's rho	Gantt Bar Chart	Correlation Coefficient	1.000	-.059	-.456	-.189	-.030
		Sig. (2-tailed)	.	.828	.076	.484	.912
		N	16	16	16	16	16
	Critical Path Method (CPM) (Critical Path Networks/Method)	Correlation Coefficient	-.059	1.000	.376	-.008	-.387
		Sig. (2-tailed)	.828	.	.151	.976	.138
		N	16	16	16	16	16
	Milestone Date Programming Technique	Correlation Coefficient	-.456	.376	1.000	.276	-.579*
		Sig. (2-tailed)	.076	.151	.	.301	.019
		N	16	16	16	16	16
	Simulation	Correlation Coefficient	-.189	-.008	.276	1.000	-.769**
		Sig. (2-tailed)	.484	.976	.301	.	.000
		N	16	16	16	16	16
	Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	Correlation Coefficient	-.030	-.387	-.579*	-.769**	1.000
		Sig. (2-tailed)	.912	.138	.019	.000	.
		N	16	16	16	16	16

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Gantt Bar Chart	16	1.4375	.89209	1.00	4.00
Critical Path Method (CPM) (Critical Path Networks/Method)	16	2.1875	.75000	1.00	4.00
Milestone Date Programming Technique	16	3.3125	.79320	2.00	5.00
Simulation	16	4.0000	1.09545	1.00	5.00
Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	16	4.0625	1.34009	1.00	5.00

Ranks

	Mean Rank
Gantt Bar Chart	1.44
Critical Path Method (CPM) (Critical Path Networks/Method)	2.19
Milestone Date Programming Technique	3.31
Simulation	4.00
Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule	4.06

Test Statistics

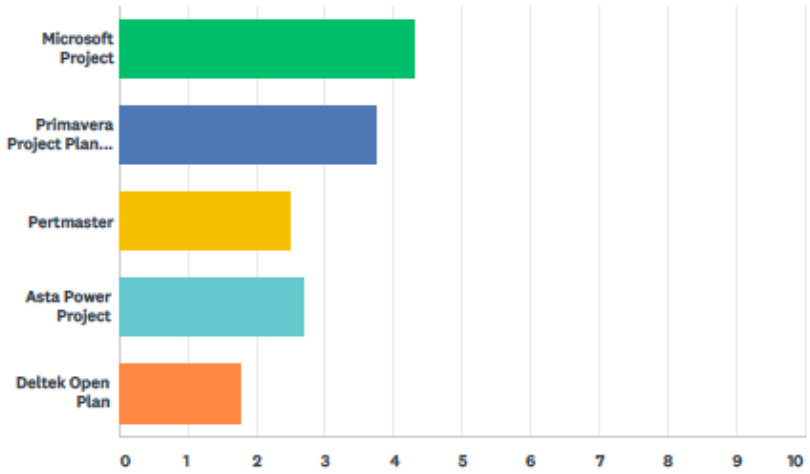
N	16
Kendall's W[a]	.533
Chi-Square	34.100
df	4
Asymp. Sig.	.000

a. Kendall's Coefficient of Concordance

Figure: 5.60b: Techniques used for project planning and time control

Q2 Which of the following software applications/programs are you using for planning and scheduling of construction works? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

Answered: 16 Skipped: 0



	1	2	3	4	5	TOTAL	SCORE
Microsoft Project	81.25% 13	0.00% 0	0.00% 0	6.25% 1	12.50% 2	16	4.31
Primavera Project Planner	6.25% 1	75.00% 12	6.25% 1	12.50% 2	0.00% 0	16	3.75
Pertmaster	0.00% 0	12.50% 2	43.75% 7	25.00% 4	18.75% 3	16	2.50
Asta Power Project	0.00% 0	12.50% 2	43.75% 7	43.75% 7	0.00% 0	16	2.69
Deltek Open Plan	12.50% 2	0.00% 0	6.25% 1	12.50% 2	68.75% 11	16	1.75

Figure 5.61a: Software programs used for planning and scheduling

Correlations

			Microsoft Project	Primavera Project Planner	Pertmaster	Asta Power Project	Deltek Open Plan
Kendall's tau_b	Microsoft Project	Correlation Coefficient	1.000	.257	.050	-.570*	-.807**
		Sig. (2-tailed)	.	.291	.832	.019	.001
		N	16	16	16	16	16
	Primavera Project Planner	Correlation Coefficient	.257	1.000	-.495*	-.157	-.173
		Sig. (2-tailed)	.291	.	.031	.512	.465
		N	16	16	16	16	16
	Pertmaster	Correlation Coefficient	.050	-.495*	1.000	-.483*	-.334
		Sig. (2-tailed)	.832	.031	.	.035	.143
		N	16	16	16	16	16
	Asta Power Project	Correlation Coefficient	-.570*	-.157	-.483*	1.000	.660**
		Sig. (2-tailed)	.019	.512	.035	.	.005
		N	16	16	16	16	16
	Deltek Open Plan	Correlation Coefficient	-.807**	-.173	-.334	.660**	1.000
		Sig. (2-tailed)	.001	.465	.143	.005	.
		N	16	16	16	16	16
Spearman's rho	Microsoft Project	Correlation Coefficient	1.000	.306	.053	-.614*	-.829**
		Sig. (2-tailed)	.	.250	.847	.011	.000
		N	16	16	16	16	16
	Primavera Project Planner	Correlation Coefficient	.306	1.000	-.551*	-.169	-.216
		Sig. (2-tailed)	.250	.	.027	.530	.422
		N	16	16	16	16	16
	Pertmaster	Correlation Coefficient	.053	-.551*	1.000	-.562*	-.373
		Sig. (2-tailed)	.847	.027	.	.023	.155
		N	16	16	16	16	16
	Asta Power Project	Correlation Coefficient	-.614*	-.169	-.562*	1.000	.702**
		Sig. (2-tailed)	.011	.530	.023	.	.002
		N	16	16	16	16	16
	Deltek Open Plan	Correlation Coefficient	-.829**	-.216	-.373	.702**	1.000
		Sig. (2-tailed)	.000	.422	.155	.002	.
		N	16	16	16	16	16

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Microsoft Project	16	1.6875	1.49304	1.00	5.00
Primavera Project Planner	16	2.2500	.77460	1.00	4.00
Pertmaster	16	3.5000	.96609	2.00	5.00
Asta Power Project	16	3.3125	.70415	2.00	4.00
Deltek Open Plan	16	4.2500	1.39044	1.00	5.00

Ranks

	Mean Rank
Microsoft Project	1.69
Primavera Project Planner	2.25
Pertmaster	3.50
Asta Power Project	3.31
Deltek Open Plan	4.25

Test Statistics

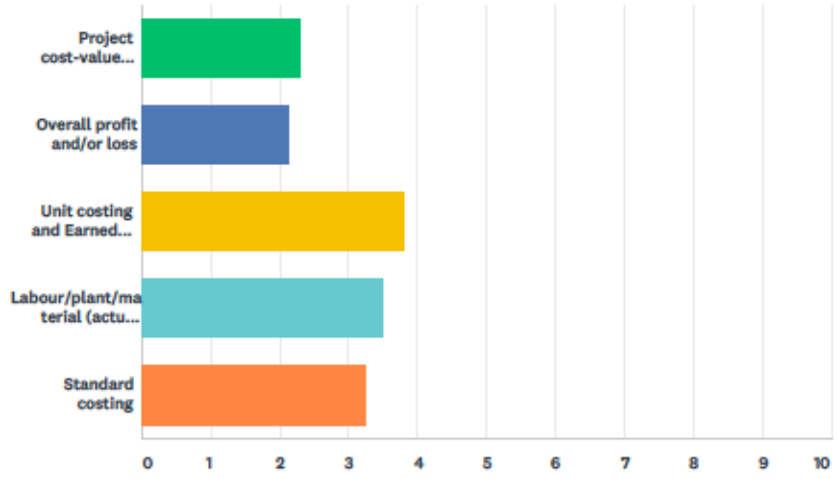
N	16
Kendall's W[a]	.420
Chi-Square	26.850
df	4
Asymp. Sig.	.000

a. Kendall's Coefficient of Concordance

Figure 5.61b: Software programs used for planning and scheduling

Q3 Cost Control Techniques: For project Cost Control, which of the following control methods/techniques being used by you? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

Answered: 16 Skipped: 0



	1	2	3	4	5	TOTAL	SCORE
Project cost-value reconciliation	18.75% 3	6.25% 1	0.00% 0	37.50% 6	37.50% 6	16	2.31
Overall profit and/or loss	0.00% 0	18.75% 3	12.50% 2	31.25% 5	37.50% 6	16	2.13
Unit costing and Earned value analysis	50.00% 8	0.00% 0	37.50% 6	6.25% 1	6.25% 1	16	3.81
Labour/plant/material (actual versus forecast reconciliation)	12.50% 2	62.50% 10	0.00% 0	12.50% 2	12.50% 2	16	3.50
Standard costing	18.75% 3	12.50% 2	50.00% 8	12.50% 2	6.25% 1	16	3.25

Figure 5.62a: Cost control techniques used

Correlations

			Project cost-value reconciliation	Overall profit and/or loss	Unit costing and Earned value analysis	Labour/plant/material (actual versus forecast reconciliation)	Standard costing
Kendall's tau_b	Project cost-value reconciliation	Correlation Coefficient	1.000	-.180	-.134	-.606**	.046
		Sig. (2-tailed)	.	.420	.559	.008	.836
		N	16	16	16	16	16
	Overall profit and/or loss	Correlation Coefficient	-.180	1.000	-.693**	-.025	.101
		Sig. (2-tailed)	.420	.	.002	.913	.645
		N	16	16	16	16	16
	Unit costing and Earned value analysis	Correlation Coefficient	-.134	-.693**	1.000	.161	-.195
		Sig. (2-tailed)	.559	.002	.	.488	.389
		N	16	16	16	16	16
	Labour/plant/material (actual versus forecast reconciliation)	Correlation Coefficient	-.606**	-.025	.161	1.000	-.581**
		Sig. (2-tailed)	.008	.913	.488	.	.010
		N	16	16	16	16	16
	Standard costing	Correlation Coefficient	.046	.101	-.195	-.581**	1.000
		Sig. (2-tailed)	.836	.645	.389	.010	.
		N	16	16	16	16	16
Spearman's rho	Project cost-value reconciliation	Correlation Coefficient	1.000	-.198	-.190	-.668**	.018
		Sig. (2-tailed)	.	.462	.480	.005	.949
		N	16	16	16	16	16
	Overall profit and/or loss	Correlation Coefficient	-.198	1.000	-.797**	.000	.093
		Sig. (2-tailed)	.462	.	.000	1.000	.733
		N	16	16	16	16	16
	Unit costing and Earned value analysis	Correlation Coefficient	-.190	-.797**	1.000	.228	-.306
		Sig. (2-tailed)	.480	.000	.	.396	.249
		N	16	16	16	16	16
	Labour/plant/material (actual versus forecast reconciliation)	Correlation Coefficient	-.668**	.000	.228	1.000	-.633**
		Sig. (2-tailed)	.005	1.000	.396	.	.008
		N	16	16	16	16	16
	Standard costing	Correlation Coefficient	.018	.093	-.306	-.633**	1.000
		Sig. (2-tailed)	.949	.733	.249	.008	.
		N	16	16	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Project cost-value reconciliation	16	3.6875	1.53704	1.00	5.00
Overall profit and/or loss	16	3.8750	1.14746	2.00	5.00
Unit costing and Earned value analysis	16	2.1875	1.32759	1.00	5.00
Labour/plant/material (actual versus forecast reconciliation)	16	2.5000	1.26491	1.00	5.00
Standard costing	16	2.7500	1.12546	1.00	5.00

Ranks

	Mean Rank
Project cost-value reconciliation	3.69
Overall profit and/or loss	3.88
Unit costing and Earned value analysis	2.19
Labour/plant/material (actual versus forecast reconciliation)	2.50
Standard costing	2.75

Test Statistics

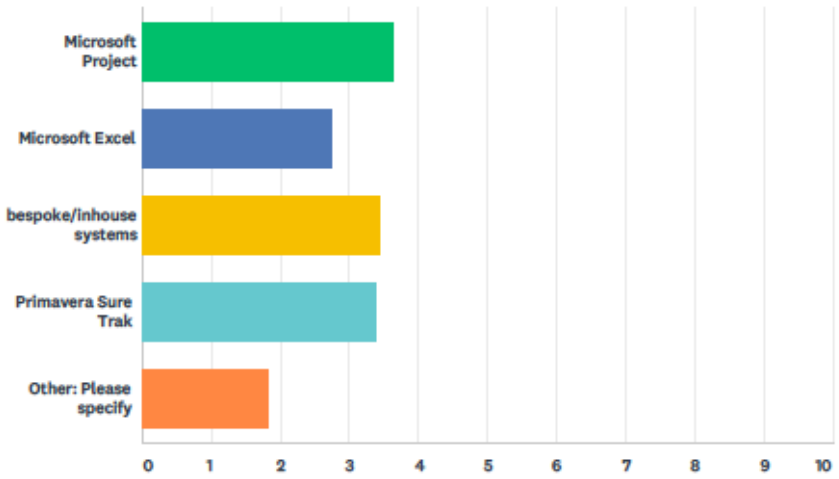
N	16
Kendall's W[a]	.221
Chi-Square	14.150
df	4
Asymp. Sig.	.007

a. Kendall's Coefficient of Concordance

Figure 5.62b: Cost control techniques used

Q4 For Cost Control, which of the following software packages being used by you? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

Answered: 16 Skipped: 0



	1	2	3	4	5	TOTAL	SCORE
Microsoft Project	43.75% 7	12.50% 2	18.75% 3	12.50% 2	12.50% 2	16	3.63
Microsoft Excel	12.50% 2	18.75% 3	12.50% 2	43.75% 7	12.50% 2	16	2.75
bespoke/inhouse systems	6.25% 1	56.25% 9	18.75% 3	12.50% 2	6.25% 1	16	3.44
Primavera Sure Trak	31.25% 5	6.25% 1	37.50% 6	18.75% 3	6.25% 1	16	3.38
Other: Please specify	6.25% 1	6.25% 1	12.50% 2	12.50% 2	62.50% 10	16	1.81

Figure 5.63a: Software packages used for cost control

Correlations

			Microsoft Project	Microsoft Excel	bespoke/inhouse systems	Primavera Sure Trak	Other: Please specify
Kendall's tau_b	Microsoft Project	Correlation Coefficient	1.000	-.290	.174	-.173	-.692**
		Sig. (2-tailed)	.	.176	.428	.424	.002
		N	16	16	16	16	16
	Microsoft Excel	Correlation Coefficient	-.290	1.000	-.383	-.432*	.182
		Sig. (2-tailed)	.176	.	.081	.046	.410
		N	16	16	16	16	16
	bespoke/inhouse systems	Correlation Coefficient	.174	-.383	1.000	.082	-.222
		Sig. (2-tailed)	.428	.081	.	.712	.324
		N	16	16	16	16	16
	Primavera Sure Trak	Correlation Coefficient	-.173	-.432*	.082	1.000	.061
		Sig. (2-tailed)	.424	.046	.712	.	.784
		N	16	16	16	16	16
	Other: Please specify	Correlation Coefficient	-.692**	.182	-.222	.061	1.000
		Sig. (2-tailed)	.002	.410	.324	.784	.
		N	16	16	16	16	16
Spearman's rho	Microsoft Project	Correlation Coefficient	1.000	-.353	.175	-.216	-.817**
		Sig. (2-tailed)	.	.179	.516	.421	.000
		N	16	16	16	16	16
	Microsoft Excel	Correlation Coefficient	-.353	1.000	-.493	-.551*	.227
		Sig. (2-tailed)	.179	.	.052	.027	.399
		N	16	16	16	16	16
	bespoke/inhouse systems	Correlation Coefficient	.175	-.493	1.000	.026	-.286
		Sig. (2-tailed)	.516	.052	.	.925	.283
		N	16	16	16	16	16
	Primavera Sure Trak	Correlation Coefficient	-.216	-.551*	.026	1.000	.018
		Sig. (2-tailed)	.421	.027	.925	.	.948
		N	16	16	16	16	16
	Other: Please specify	Correlation Coefficient	-.817**	.227	-.286	.018	1.000
		Sig. (2-tailed)	.000	.399	.283	.948	.
		N	16	16	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Microsoft Project	16	2.3750	1.50000	1.00	5.00
Microsoft Excel	16	3.2500	1.29099	1.00	5.00
bespoke/inhouse systems	16	2.5625	1.03078	1.00	5.00
Primavera Sure Trak	16	2.6250	1.31022	1.00	5.00
Other: Please specify	16	4.1875	1.27639	1.00	5.00

Ranks

	Mean Rank
Microsoft Project	2.38
Microsoft Excel	3.25
bespoke/inhouse systems	2.56
Primavera Sure Trak	2.63
Other: Please specify	4.19

Test Statistics

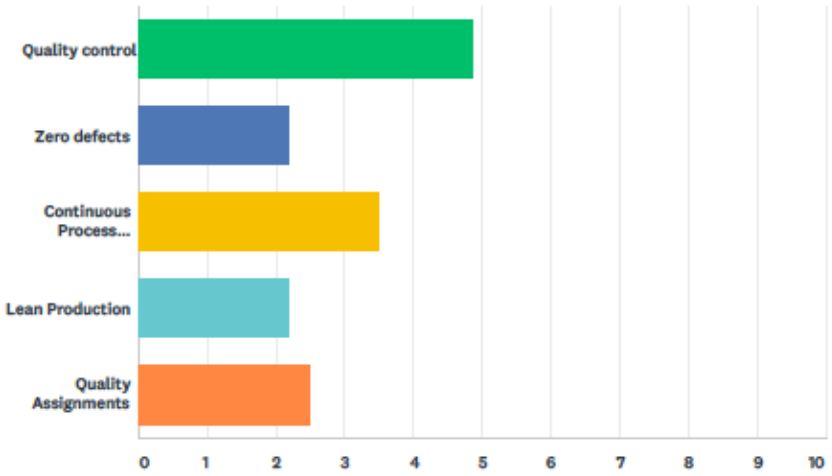
N	16
Kendall's W[a]	.220
Chi-Square	14.050
df	4
Asymp. Sig.	.007

a. Kendall's Coefficient of Concordance

Figure 5.63b: Software packages used for cost control

Q5 which of the following Quality Tools have been used by you in order to improving quality and productivity? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

Answered: 16 Skipped: 0



	1	2	3	4	5	TOTAL	SCORE
Quality control	86.67% 13	13.33% 2	0.00% 0	0.00% 0	0.00% 0	15	4.87
Zero defects	0.00% 0	12.50% 2	37.50% 6	6.25% 1	43.75% 7	16	2.19
Continuous Process Improvement	12.50% 2	56.25% 9	6.25% 1	18.75% 3	6.25% 1	16	3.50
Lean Production	6.25% 1	0.00% 0	31.25% 5	31.25% 5	31.25% 5	16	2.19
Quality Assignments	0.00% 0	18.75% 3	25.00% 4	43.75% 7	12.50% 2	16	2.50

Figure 5.64a: Quality improvement tools

Correlations

			Quality control	Zero defects	Continuous Process Improvement	Lean Production	Quality Assignments
Kendall's tau_b	Quality control	Correlation Coefficient	1.000	-.165	-.193	-.088	.395
		Sig. (2-tailed)	.	.516	.441	.722	.109
		N	15	15	15	15	15
	Zero defects	Correlation Coefficient	-.165	1.000	-.221	-.220	-.128
		Sig. (2-tailed)	.516	.	.330	.330	.570
		N	15	16	16	16	16
	Continuous Process Improvement	Correlation Coefficient	-.193	-.221	1.000	.012	-.273
		Sig. (2-tailed)	.441	.330	.	.958	.221
		N	15	16	16	16	16
	Lean Production	Correlation Coefficient	-.088	-.220	.012	1.000	-.503*
		Sig. (2-tailed)	.722	.330	.958	.	.024
		N	15	16	16	16	16
	Quality Assignments	Correlation Coefficient	.395	-.128	-.273	-.503*	1.000
		Sig. (2-tailed)	.109	.570	.221	.024	.
		N	15	16	16	16	16
Spearman's rho	Quality control	Correlation Coefficient	1.000	-.174	-.206	-.095	.428
		Sig. (2-tailed)	.	.536	.462	.736	.111
		N	15	15	15	15	15
	Zero defects	Correlation Coefficient	-.174	1.000	-.212	-.253	-.158
		Sig. (2-tailed)	.536	.	.431	.344	.559
		N	15	16	16	16	16
	Continuous Process Improvement	Correlation Coefficient	-.206	-.212	1.000	.024	-.320
		Sig. (2-tailed)	.462	.431	.	.930	.227
		N	15	16	16	16	16
	Lean Production	Correlation Coefficient	-.095	-.253	.024	1.000	-.548*
		Sig. (2-tailed)	.736	.344	.930	.	.028
		N	15	16	16	16	16
	Quality Assignments	Correlation Coefficient	.428	-.158	-.320	-.548*	1.000
		Sig. (2-tailed)	.111	.559	.227	.028	.
		N	15	16	16	16	16

*. Correlation is significant at the 0.05 level (2-tailed).

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Quality control	15	1.1333	.35187	1.00	2.00
Zero defects	15	3.9333	1.09978	2.00	5.00
Continuous Process Improvement	15	2.6000	1.12122	1.00	5.00
Lean Production	15	3.8667	1.12546	1.00	5.00
Quality Assignments	15	3.4667	.99043	2.00	5.00

Ranks

	Mean Rank
Quality control	1.13
Zero defects	3.93
Continuous Process Improvement	2.60
Lean Production	3.87
Quality Assignments	3.47

Test Statistics

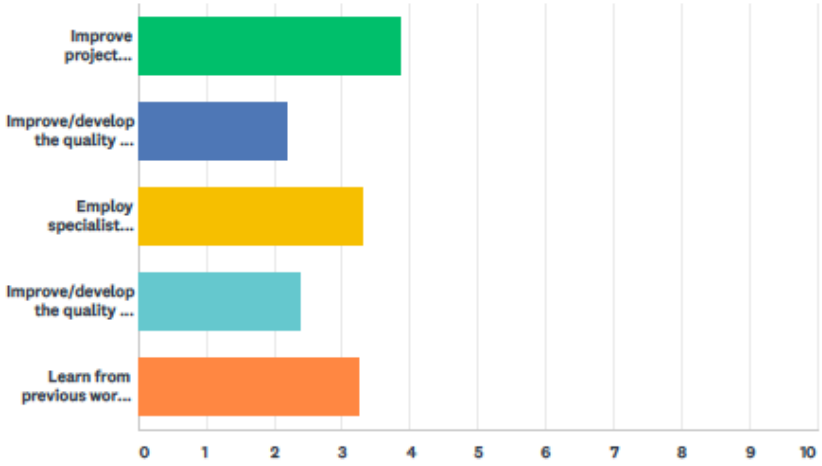
N	15
Kendall's W[a]	.548
Chi-Square	32.907
df	4
Asymp. Sig.	.000

a. Kendall's Coefficient of Concordance

Figure 5.64b: Quality improvement tools

Q6 For improving the reliability of planning, can you rate the significance of the following mentioned techniques? Please order/rank from the most important (1) to the least important (5).

Answered: 16 Skipped: 0



	1	2	3	4	5	TOTAL	SCORE
Improve project planner's abilities	37.50% 6	31.25% 5	18.75% 3	6.25% 1	6.25% 1	16	3.88
Improve/develop the quality of material	6.25% 1	25.00% 4	0.00% 0	18.75% 3	50.00% 8	16	2.19
Employ specialist teams	25.00% 4	12.50% 2	43.75% 7	6.25% 1	12.50% 2	16	3.31
Improve/develop the quality of labour	6.25% 1	18.75% 3	0.00% 0	56.25% 9	18.75% 3	16	2.38
Learn from previous works and projects	25.00% 4	12.50% 2	37.50% 6	12.50% 2	12.50% 2	16	3.25

Figure 5.65a: Improving the reliability of planning

Correlations

			Improve project planner's abilities	Improve/develop the quality of material	Employ specialist teams	Improve/develop the quality of labour	Learn from previous works and projects
Kendall's tau_b	Improve project planner's abilities	Correlation Coefficient	1.000	-.309	.186	.201	-.787**
		Sig. (2-tailed)	.	.165	.394	.369	.000
		N	16	16	16	16	16
	Improve/develop the quality of material	Correlation Coefficient	-.309	1.000	-.426	-.348	.202
		Sig. (2-tailed)	.165	.	.055	.126	.359
		N	16	16	16	16	16
	Employ specialist teams	Correlation Coefficient	.186	-.426	1.000	-.344	-.203
		Sig. (2-tailed)	.394	.055	.	.123	.345
		N	16	16	16	16	16
	Improve/develop the quality of labour	Correlation Coefficient	.201	-.348	-.344	1.000	-.289
		Sig. (2-tailed)	.369	.126	.123	.	.191
		N	16	16	16	16	16
	Learn from previous works and projects	Correlation Coefficient	-.787**	.202	-.203	-.289	1.000
		Sig. (2-tailed)	.000	.359	.345	.191	.
		N	16	16	16	16	16
Spearman's rho	Improve project planner's abilities	Correlation Coefficient	1.000	-.403	.316	.225	-.859**
		Sig. (2-tailed)	.	.122	.233	.401	.000
		N	16	16	16	16	16
	Improve/develop the quality of material	Correlation Coefficient	-.403	1.000	-.478	-.420	.277
		Sig. (2-tailed)	.122	.	.061	.105	.299
		N	16	16	16	16	16
	Employ specialist teams	Correlation Coefficient	.316	-.478	1.000	-.399	-.323
		Sig. (2-tailed)	.233	.061	.	.126	.222
		N	16	16	16	16	16
	Improve/develop the quality of labour	Correlation Coefficient	.225	-.420	-.399	1.000	-.345
		Sig. (2-tailed)	.401	.105	.126	.	.190
		N	16	16	16	16	16
	Learn from previous works and projects	Correlation Coefficient	-.859**	.277	-.323	-.345	1.000
		Sig. (2-tailed)	.000	.299	.222	.190	.
		N	16	16	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Improve project planner's abilities	16	2.1250	1.20416	1.00	5.00
Improve/develop the quality of material	16	3.8125	1.47054	1.00	5.00
Employ specialist teams	16	2.6875	1.30224	1.00	5.00
Improve/develop the quality of labour	16	3.6250	1.20416	1.00	5.00
Learn from previous works and projects	16	2.7500	1.34164	1.00	5.00

Ranks

	Mean Rank
Improve project planner's abilities	2.13
Improve/develop the quality of material	3.81
Employ specialist teams	2.69
Improve/develop the quality of labour	3.63
Learn from previous works and projects	2.75

Test Statistics

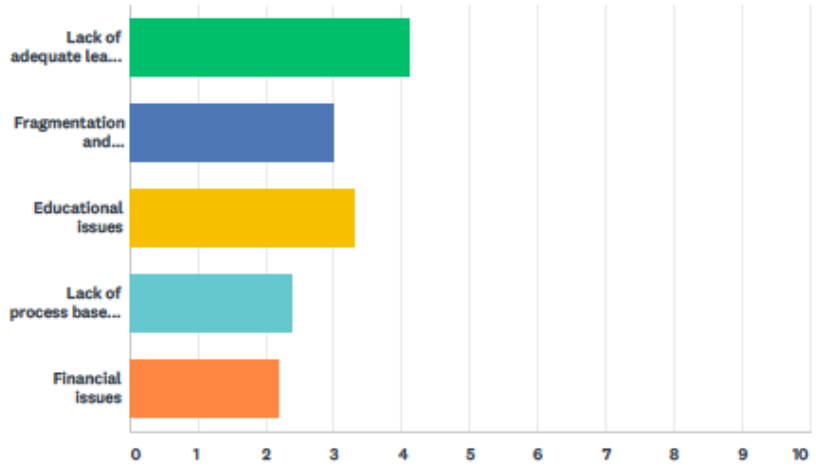
N	16
Kendall's W[a]	.198
Chi-Square	12.650
df	4
Asymp. Sig.	.013

a. Kendall's Coefficient of Concordance

Figure 5.65b: Improving the reliability of planning

Q7 The following is the list of the significant barriers to the successful implementation of LC in the UK. Please can you rank/order from the most important to the least important.

Answered: 16 Skipped: 0



	1	2	3	4	5	TOTAL	SCORE
Lack of adequate lean awareness/understanding	50.00% 8	25.00% 4	18.75% 3	0.00% 0	6.25% 1	16	4.13
Fragmentation and subcontracting	12.50% 2	25.00% 4	25.00% 4	25.00% 4	12.50% 2	16	3.00
Educational issues	25.00% 4	25.00% 4	18.75% 3	18.75% 3	12.50% 2	16	3.31
Lack of process based PMSs	0.00% 0	18.75% 3	25.00% 4	31.25% 5	25.00% 4	16	2.38
Financial issues	12.50% 2	6.25% 1	12.50% 2	25.00% 4	43.75% 7	16	2.19

Figure 5.66a: Significant barriers to LC implementation

Correlations

			Lack of adequate lean awareness/understanding	Fragmentation and subcontracting	Educational issues	Lack of process based PMSs	Financial issues
Kendall's tau_b	Lack of adequate lean awareness/understanding	Correlation Coefficient	1.000	-.417	-.164	.169	-.219
		Sig. (2-tailed)	.	.056	.451	.446	.325
		N	16	16	16	16	16
	Fragmentation and subcontracting	Correlation Coefficient	-.417	1.000	-.259	-.492*	.210
		Sig. (2-tailed)	.056	.	.217	.021	.327
		N	16	16	16	16	16
	Educational issues	Correlation Coefficient	-.164	-.259	1.000	.153	-.459*
		Sig. (2-tailed)	.451	.217	.	.472	.031
		N	16	16	16	16	16
	Lack of process based PMSs	Correlation Coefficient	.169	-.492*	.153	1.000	-.419
		Sig. (2-tailed)	.446	.021	.472	.	.053
		N	16	16	16	16	16
	Financial issues	Correlation Coefficient	-.219	.210	-.459*	-.419	1.000
		Sig. (2-tailed)	.325	.327	.031	.053	.
		N	16	16	16	16	16
Spearman's rho	Lack of adequate lean awareness/understanding	Correlation Coefficient	1.000	-.536*	-.194	.197	-.261
		Sig. (2-tailed)	.	.032	.471	.464	.330
		N	16	16	16	16	16
	Fragmentation and subcontracting	Correlation Coefficient	-.536*	1.000	-.342	-.583*	.268
		Sig. (2-tailed)	.032	.	.195	.018	.315
		N	16	16	16	16	16
	Educational issues	Correlation Coefficient	-.194	-.342	1.000	.212	-.551*
		Sig. (2-tailed)	.471	.195	.	.430	.027
		N	16	16	16	16	16
	Lack of process based PMSs	Correlation Coefficient	.197	-.583*	.212	1.000	-.537*
		Sig. (2-tailed)	.464	.018	.430	.	.032
		N	16	16	16	16	16
	Financial issues	Correlation Coefficient	-.261	.268	-.551*	-.537*	1.000
		Sig. (2-tailed)	.330	.315	.027	.032	.
		N	16	16	16	16	16

*. Correlation is significant at the 0.05 level (2-tailed).

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Lack of adequate lean awareness/understanding	16	1.8750	1.14746	1.00	5.00
Fragmentation and subcontracting	16	3.0000	1.26491	1.00	5.00
Educational issues	16	2.6875	1.40089	1.00	5.00
Lack of process based PMSs	16	3.6250	1.08781	2.00	5.00
Financial issues	16	3.8125	1.42449	1.00	5.00

Ranks

	Mean Rank
Lack of adequate lean awareness/understanding	1.88
Fragmentation and subcontracting	3.00
Educational issues	2.69
Lack of process based PMSs	3.63
Financial issues	3.81

Test Statistics

N	16
Kendall's W[a]	.241
Chi-Square	15.450
df	4
Asymp. Sig.	.004

a. Kendall's Coefficient of Concordance

Figure 5.66b: Significant barriers to LC implementation

Data were collected through a number of methods, including semi-structured interviews conducted with project managers, site managers, planning engineers, construction managers, a chief executive officer (CEO), engineers (planning, civil, design), builders, and managing directors. This enabled a balanced view to be gleaned with focus on each of the projects under study, to evaluate the existing planning practices. In all, direct observations were made over a 5-week period.

Unstructured interviews were undertaken with four different groups: project managers, site engineers, client representatives, and consultant engineers. The aim here was to seek their views of the tools as a planning system, together with the advantages and the benefits gained during their implementation. Additionally, these allowed reporting of difficulties so that potential solutions could be examined.

5.4.1 The Interview Iran

5.4.1.1 Introduction

In this research, information about how planning is done in Iran was the focus, with the view of looking at the possibility of implementing LC and new developments there. The aim of this interview was specifically about the issues involved in implementation. Project management has been around now for many years, but a key question is why there are still

failing projects. A lot of it maybe is to do with implementation, and through getting people to change the way they do things.

During the research a survey was conducted. Care was taken to ensure a balance was achieved as set out in Chapter 3.

The same population used for the quantitative stage of the research was used. The interviewees were a mix of contractors and consultants with varying but quite often similar kinds of projects. They were highly experienced practitioners.

5.4.1.2 Interviews in Iran

Table 5.6 details the responses from an engineer interviewee regarding the survey questions. Details of questions used have been previously provided in Chapters 3 and 4 and Appendix B.

Table 5.6 Responses from an Interview in Iran

Question	Comment
1	Building project with electrical and mechanical works associated within 1 to 3 years.
2	Project controlling division does the planning via MSP and by gathering comments from the colleague experts and controlling by site-visiting.
3	Cost control is considered for important and effective activities manually.
4	Last experiences.
5	Good enough for the company field.
6	I don't think so.
7	Usually no.
8	Estimation of activities is measured by the previously known rate and the binding the activities in plan forms the total project time.
9	Sure. By this way some activities which have been dropped out becomes clear and integrated into the next plan.
10	LPS method is not practiced in the company.
11	EV is not practiced but cost measures for critical items is watched out.
12	Site processed usually follows daily and weekly plan generated from Master Plan. Then % completed work is calculated and compared to values expected in plan.
13	Almost all of projects encounters time and/or cost overruns.
14	Yes, but site facilities for certain type of projects which the company involves are something conventional and obviously affects productivity.
15	In most cases clients are eager to start the contract before fully prepared.
16	As mentioned in Question 2.
17	Waste usually concerns to labour effort and changes in design.
18	By replanning and taking into consideration the new situation and taking necessary measures.
19	By educating people for the first step.
20	If they feel the changes quickly then easily accepted otherwise neglected.
21	Regarding to estimating overall cost and time is partially successful.
22	Sure.
23	HSE division prepares a list of hazardous scenarios and plan to manage the risk associated.
24	Experience and continuous checking in completed works.

Another interviewee, asked how successful planning and design have been in terms of estimating the overall cost, execution time, and quality of the construction project, said very good/excellent. According to an engineer interviewee, another name for LC in Iran, which is used in Farsi/Persian language as a synonym to LC, is '*Farayand Bahrevari*'.* The English translation of each of the words separately would be as follows: Farayand means Process or Procedure, and Bahrevari means Benefit or Profit. Thus, Farayand Bahrevari can be thought of as a Benefitting or Profiting Process (Exploitation Process). A Benefit Process means a procedure that brings benefit for everyone and provides a profit for a company and the work, and increases the value and quality of the work and the final product. In addition, this will manage and control construction time and cost so that the project is completed on time or earlier and within budget and tries to reduce or eliminate waste, and works towards customer satisfaction, and so in many ways it is similar to the LC philosophy.

In addition, the interviewee engineer has used Farayand Bahrevari in his own construction company, which brought satisfactory results for the company (Heydarbarghi *pers. comms*). (*An Iranian engineer, Mr. Kazem Heydarbarghi, a self-employed construction company owner in Iran, provided this interesting view about Farayand Bahrevari).

There are different kinds of production in Iran; according to interviewee engineers, the following are some of the common examples of construction production on Iranian sites:

- Aggregate production
- Materials production
- Construction materials
- Dwellings
- Building production (building and construction is a kind of production).

5.5 Conclusions

The system is not adopted as particularly being called LC or LPS, but due to experienced engineers, managers, planners, and others involved in the projects, the system gets followed intuitively.

In Iran, for about 40 years, they have used concrete prefabricated joists and pre-tensioned concrete joists as well as concrete and clay blocks, clay bricks, bricks made from sand, and mineral empty shells (taken from volcano mountains), and recently 3D prefabricated walls, concrete exterior panels, etc.

It can be concluded that lean production is being used in Iran without knowing it, which means although they have been using the basic concepts already, they don't know that it is called lean production or LC. Efficient managers are generally lean without knowing it. It is not introduced; as an example, they produce some elements of a structure and transport it to the site. Here, in small-scale projects, construction managers mainly adopt lean practices to reduce site waste. Also, through customising the construction, they maximise customer satisfaction.

It can be seen that, although construction managers are aware of the issues that result in waste, there will always be waste in construction works. In every project in the construction industry there are always problems, but there are always opportunities to try to reduce the waste. As a solution, it is better to investigate what is done, and what goes wrong. Lean is a culture, about avoiding all aspects of waste. However, different practitioners will do things differently depending on the work project.

Figures 5.67 to 5.70 set out the Lean plan, implementation, monitoring/control, and review development.

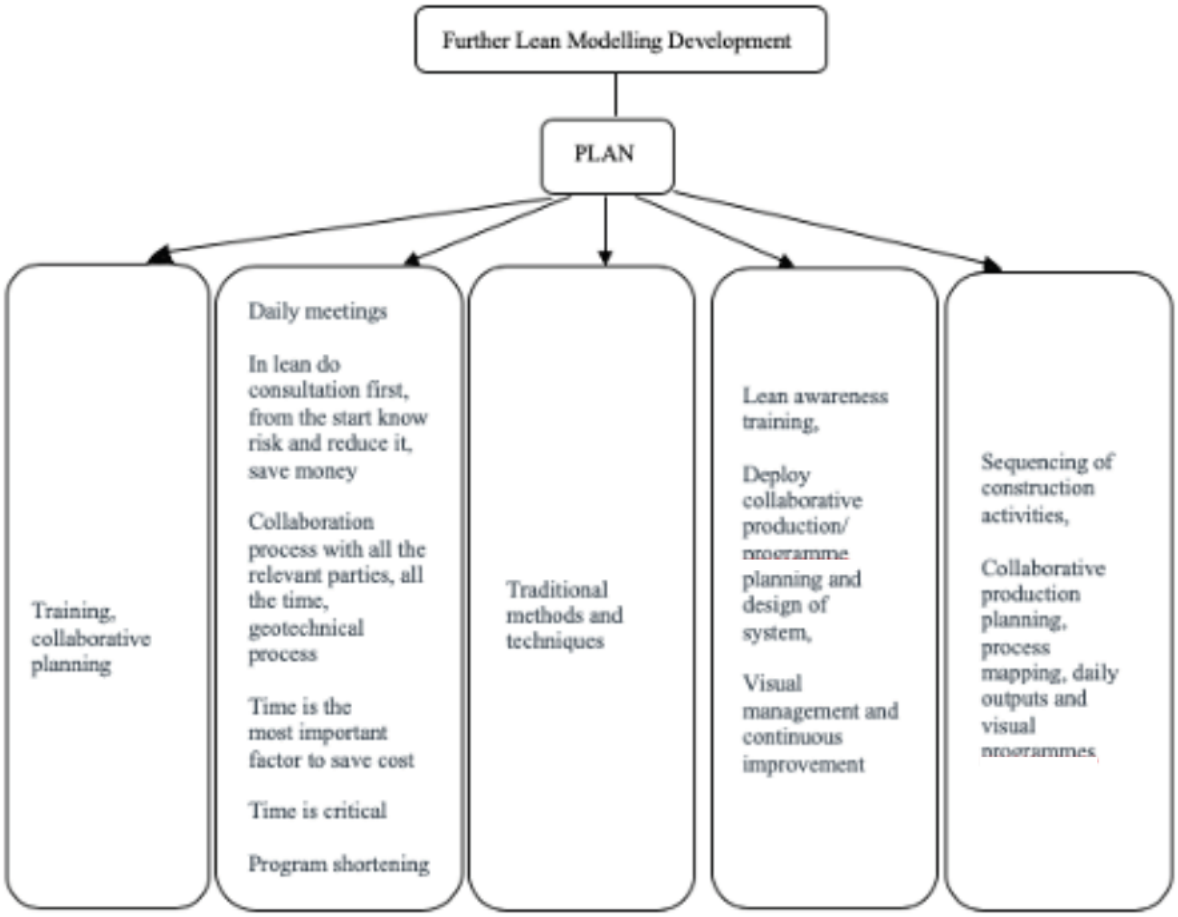


Figure 5.67 Lean Plan Development

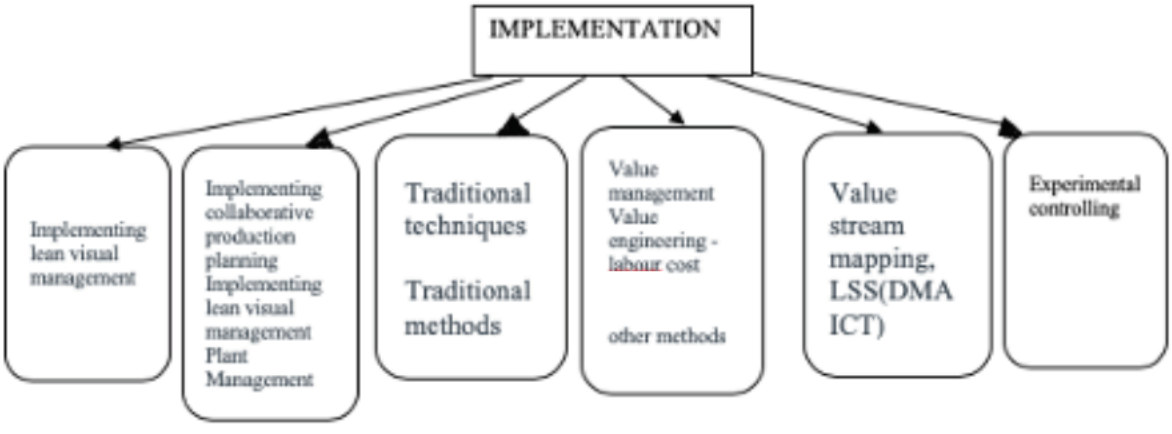


Figure 5.68 Lean Implementation Development

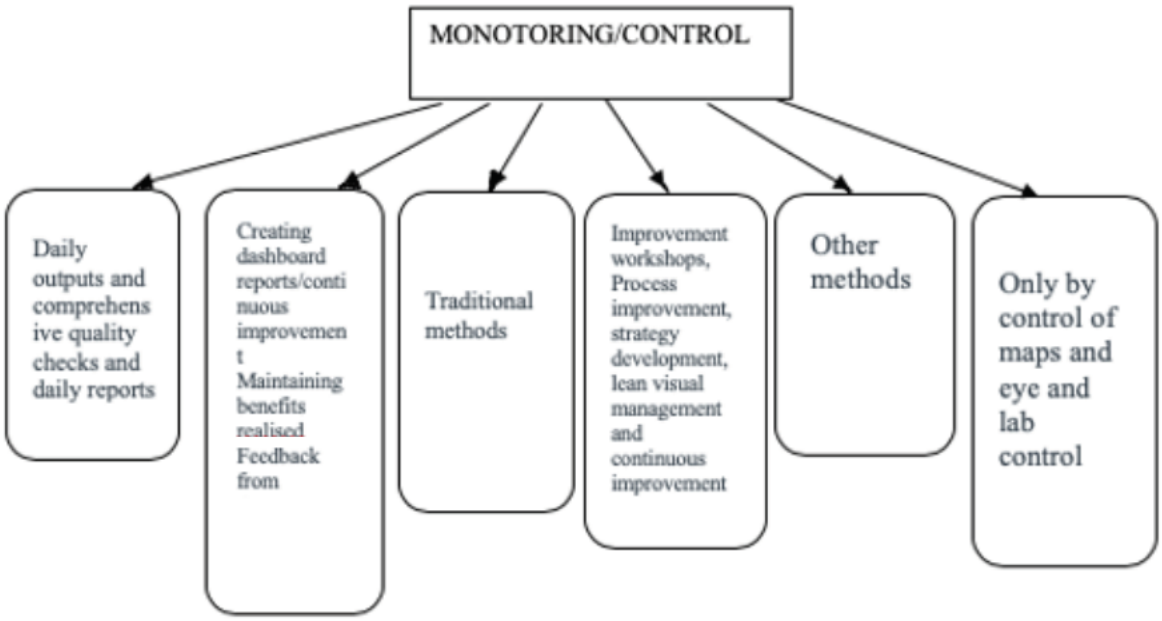


Figure 5.69 Lean Monitoring/Control Development

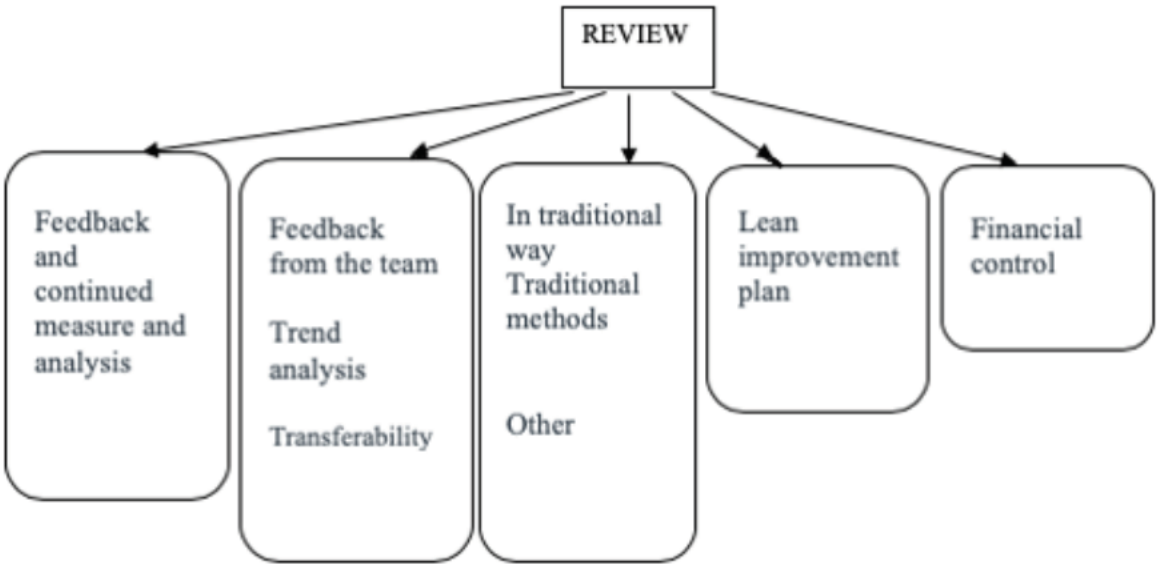


Figure 5.70 Lean Review Development

The methods/enablers can be adopted in any order based on the needs of the users/builders.

5.6 Performance Development – Improving performance

According to Huan Yang (2010), "Performance measurement in construction focuses on project performance in terms of time, cost, and quality" (Ward et al., 1991; Kugioglou et al., 2001). To aid this, KPIs models are used.

The main advantage of a KPI model is that it provides a tool to benchmark activities both at a strategic level and at an operational level, such as rectifying defects and meeting the expectations of clients (see The KPI Working Group, 2000). However, among its main criticisms is that none of the indicators deal with the "*innovation and learning perspective*" (Kagioglou et al., 2001).

There are a number of applications for KPI models, including: project, organisational, and stakeholder levels (see Chapter 2). As part of this Integrated performance index are used. Pillai et al. (2002) established an integrated performance index, which included different aspects, such as the merit, risk, project status, cost effectiveness, and production preparedness of the project. Later, Luu et al. (2008) carried out performance measurement of construction firms in developing countries.

Mahmoud and Scott (2002) conducted a study of the development and use of KPIs in the UK construction industry. This work described the development of the construction KPIs and raised some issues that are important about their use. Through a series of discussions with professionals in the industry and several interviews, it has been possible to gain an insight into some of these areas. The preliminary results have shown that the most noteworthy problems with the use of KPIs relate to the extent of their use by the industry, their definition, and their interpretation.

According to Mahmoud and Scott (2002), the indicators published in the government KPIs Report (2002) represent the industry's performance in seven key areas:

1. Time;
2. Cost;
3. Quality;

4. Client satisfaction;
5. Client changes;
6. Business performance; and
7. Health and safety.

Moreover the KPIs are produced to address these seven areas. The project performance measures are:

1. Client satisfaction – product;
2. Client satisfaction – service;
3. Defects;
4. Predictability – cost (design and construction);
5. Predictability – time (design and construction);
6. Construction time; and
7. Construction cost.

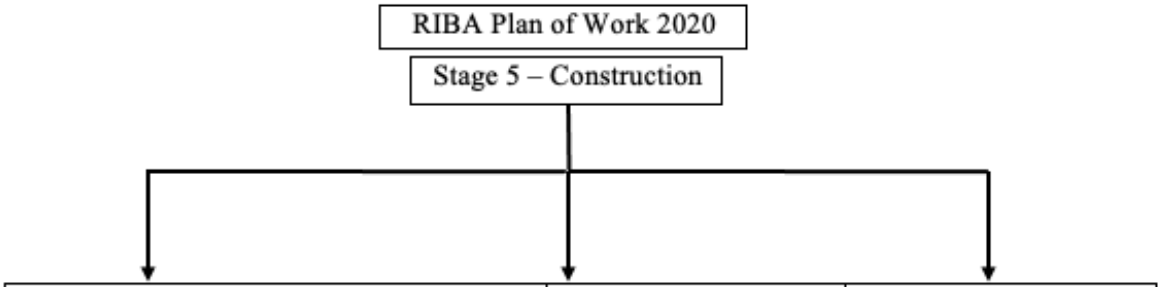
And the company measures are:
8. Safety;
9. Profitability; and
10. Productivity.

To cover more specific performance areas, operational KPIs have also been produced. Examples include the time taken to rectify defects, the cost of rectifying defects in the maintenance period, profit predictability, etc. Diagnostic indicators have also been offered. More sector-specific KPIs have also been produced in response to the benchmarking issues. These KPIs focus on training, profitability, productivity and client satisfaction, time delivery, health and safety, value for money, quality, and capability.

According to Aziz et al. (2013), “Lean construction results from the application of a new form of production management to construction. Essential features of lean construction include a clear set of objectives for the delivery process, aimed at maximizing performance for the customer at the project level, concurrent design, construction, and the application of

project control throughout the life cycle of the project from design to delivery". Aziz et al. (2013) proposed a construction re-engineering framework.

Significant research is still required to complete the translation of LT to construction in Iran as a developing country. The proposed construction reengineering framework in this project was useful, with Figure 5.71 showing the development of the construction framework.



Control	Measurement	Performance
PLANNING AND TIME CONTROL TECHNIQUES: Gantt Bar Chart; CPM; Milestone data Programming Technique; PERT; PND; LOB; Simulation; and Other techniques. SOFTWARE PACKAGES USED FOR PLANNING AND TIME CONTROL: Microsoft Project; Asta Power Project; Primavera; Deltek Open Plan; Project Commander.	Conduct a RI and RII in relation with the Likert scale. "Relative Indices" (RI) technique; relative importance index (RII).	Performance Measurement: The earned value method (EVM); Customer Earned Value (CEV).
COST CONTROL TECHNIQUES: Project Cost-Value Reconciliation; Earned Value Analysis; Labour/Plant/Material (actual versus forecast reconciliation); (PERT/COST); Leading Parameter Method; Unit Costing; Overall profit or loss; Profit or loss on each contract at valuation dates; Standard Costing. SOFTWARE PACKAGES USED FOR COST CONTROL: Project Costing System (PCS); Microsoft Project; Asta Power Project; Primavera Sure Trak; Microsoft Excel; Construction Industry Software (COINS); Bespoke/in-house Systems; WinQS. PCIM; EVM(MBR); LPS(MBM); statistical quality control charts; Project Control System (PCS).	PPC; Master Schedule using the Primavera PERT Master software; To select the top project success criteria to be used for the model; To Create a Correlation Matrix in SPSS; To Propose project measurement model; To Calculate the project success index using the proposed equation; To Propose the performance matrix for stages 5, 6 and 7 of RIBA Plan of Work for construction project success.	Key Performance Indicators (KPI): TPI, CPI, QPI, SPI.
QUALITY CONTROL	Mitigating Measures were classified as: Preventive, Predictive, Corrective and Organizational Measures.	Performance Indicators (preventive, predictive, and corrective).
SUSTAINBILITY CONTROL	The Delphi method ("critical", "important", or "helpful" measures).	Performance Measurement

Figure 5.71 Proposed Development of construction framework, showing how it ties into the RIBA PoW.

Table 5.7 shows the control methods and software applications being used by practitioners as well as inhibiting factors.

Table 5.7 Control methods and software applications used by practitioners as well as inhibiting factors (after Olawale and Sun, 2010)

TIME	
TECHNIQUES USED FOR PROJECT PLANNING AND TIME CONTROL: The most popular time planning and control technique is 1)Gantt Bar Chart, 2) Critical Path Method (CPM) (Critical Path Networks/Method), 3) Milestone Date Programming Technique, 4)Program Evaluation Review Technique (PERT), 5)Precedence Network Diagram (PND), 6)Elemental Trend Analysis/Line of Balance (LOB), and 7)Simulation *(after Olawale & Sun 2010).*	SOFTWARE PACKAGES USED FOR PROJECT PLANNING AND TIME CONTROL: 1) Microsoft Project, 2) Asta Power Project, 3) Primavera, 4) Project Commander, and 5) Deltek Open Plan *(after Olawale & Sun 2010).*
COST	
TECHNIQUES USED FOR PROJECT COST CONTROL: Cost control techniques: 1)project cost–value reconciliation, 2)overall profit and/or loss, 3)profit and/or loss on each contract at valuation dates, 4)unit costing and earned value analysis ((Unit costing),(Earned value analysis)), 5) Labour/plant/material (actual versus forecast reconciliation), 6) Standard costing, 7) Program Evaluation and Review Technique (PERT/COST), and 8) Leading parameter method *(after Olawale & Sun 2010).*	SOFTWARE PACKAGES USED FOR PROJECT COST CONTROL: 1)Microsoft Project, 2)Asta Power Project, Other specialist cost control software including 3)Project Costing System (PCS), 4)Construction Industry Software (COINS), 5)WinOS. 6)The general purpose Microsoft Excel spreadsheet is also used by some professionals, 7)In fact, the largest option is bespoke/inhouse systems, which is used by contractors and consultants, and 8) Primavera Sure Trak *(after Olawale & Sun 2010).*
QUALITY CONTROL	
SUSTAINBILITY CONTROL	

The proposed control and measures models were implemented to improve the cost, time, and quality performance of construction projects. To add value to the production, the author proposes the ICS (Figure 4.6), a quality tool that should be included in the LPS (see Chapter 4). In their paper on performance indicators for successful construction project performance, Takim and Akintoye (2002) provided a review of measurements developed to assess project performance and proposed a model that helps to identify the performance of the stakeholders involved in a construction project (SPM model and IPI framework).

5.7 Key Performance Indicators (KPIs)

Round 1 was used to select the most important KPIs. Round 2 was focused on re-evaluating selected KPIs. Rounds 3 and 4 concentrated on the ratings received from experts and re-evaluating weighted KPIs, respectively. A questionnaire survey and a four-round Delphi questionnaire survey were applied for data gathering and finalising a project performance index for determining project success.

The first round of Delphi questionnaires together with an invitation letter was sent to the respondents by email in early May of 2018. The aim of the research was explained in the invitation letter, and they were informed that there would be a total of four rounds of Delphi questionnaires in the proposed survey. In the first round, the 30 experts identified were asked to select a minimum of five to a maximum of ten KPIs that they believed to be the most important KPIs to evaluate the success of relationship-based projects. Not all the experts completed the questionnaires even after a reminder email was sent to them and, finally, 16 responses were collected in late June and early July of 2018. According to Rowe and Wright (1999) and Adnan and Morledge (2003), for a typical Delphi survey, the sample size usually ranges from 3 to 15 respondents.

In the current study, the questionnaire was the same and the respondents were those used previously (see Section 5.2). Only the questions that needed re-evaluation in the development of the framework were considered in the Delphi analysis.

5.7.1 Results and Analysis

A list of KPIs identified from the literature review was considered for study through Delphi survey questionnaires with 30 construction experts in the UK and Iran. A total of 16 respondents completed the questionnaire regarding KPIs.

In the first round of the Delphi survey, ten KPIs were selected from a list of the most important KPIs, to evaluate the success of projects in the UK and Iran. The following ten KPIs were selected by experts as the most important: (1) Time Performance; (2) Cost Performance; (3) Quality Performance; (4) Sustainability; (5) Innovation and Improvement;

(6) Cliens Satisfaction; (7) HSE; (8) Safety Performance; (9) Effective Communications; and (10) Trust and Respect.

Finally, in terms of Innovation and Performance Improvement that will lead to Project Success, the respondents were asked to rank the significance of the top five selected KPIs on a five-point Likert scale from the most important to the least important, where: Extremely important – 1; Important – 2; Neutral/No change – 3; Unimportant – 4; and Extremely unimportant – 5.

Based on the ratings received from experts, the top five selected KPIs included are: (1) Time Performance; (2) Cost Performance; (3) Quality Performance; (4) Sustainability Performance; (5=) Innovation and Improvement; and (5=) Client Satisfaction (equal frequencies). These were selected by 50% or more of the respondents, and were selected for further analysis.

A Performance Index (PI) measurement model is developed in this research project. Use of the developed formula will help to compare projects and to establish a benchmark for future improvement and for measuring the performance of relationship-based projects and therefore to monitor and update the performance of construction projects. According to Yu et al. (2007), there is a lack of a measurement system that could be used to compare an organisation's performance or be used for benchmarking (see also, Cheah et al. 2004).

5.7.1.1 Results and Analysis: KPIs

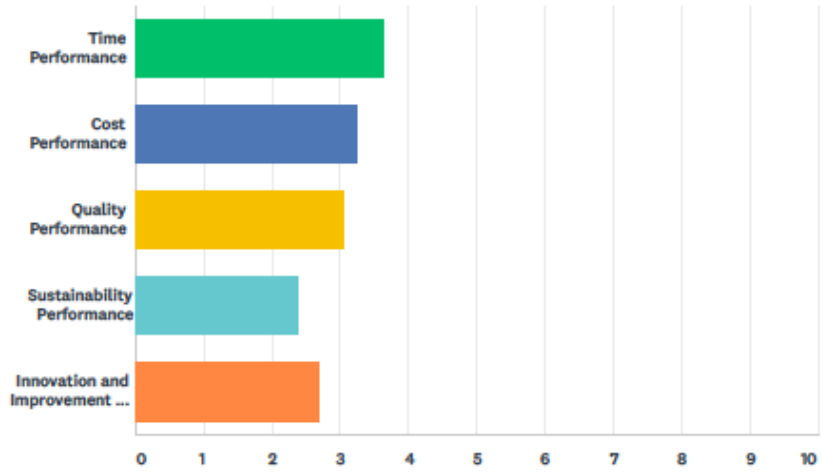
In Round 1, the most important KPIs were selected. Round 2 was about re-evaluating the selected KPIs. Rounds 3 and 4 collected ratings from experts and re-evaluated weighted KPIs, respectively.

5.7.1.2 Round 2 of Delphi Questionnaire: Ratings Received from Experts

Figure 5.72 below details the responses obtained to Question 1.

Q1 In terms of Innovation and Performance Improvement that will lead to Project Success, please can you rank/order the significance of the following top five KPIs from the most important to the least important (Extremely important – 1; important – 2; Neutral / No change – 3; Unimportant – 4; and Extremely unimportant – 5)?

Answered: 16 Skipped: 0



	1	2	3	4	5	TOTAL	SCORE
Time Performance	50.00% 8	12.50% 2	6.25% 1	12.50% 2	18.75% 3	16	3.63
Cost Performance	6.25% 1	50.00% 8	12.50% 2	25.00% 4	6.25% 1	16	3.25
Quality Performance	6.25% 1	6.25% 1	81.25% 13	0.00% 0	6.25% 1	16	3.06
Sustainability Performance	25.00% 4	12.50% 2	0.00% 0	0.00% 0	62.50% 10	16	2.38
Innovation and Improvement and Client Satisfaction	12.50% 2	18.75% 3	0.00% 0	62.50% 10	6.25% 1	16	2.69

Figure 5.72a: The significance of the top five KPIs (Round 2)

Correlations

			Time Performance	Cost Performance	Quality Performance	Sustainability Performance	Innovation and Improvement and Client Satisfaction
Spearman's rho	Time Performance	Correlation Coefficient	1.000	.812**	-.086	-.919**	-.595*
		Sig. (2-tailed)	.	.000	.752	.000	.015
		N	16	16	16	16	16
	Cost Performance	Correlation Coefficient	.812**	1.000	.023	-.840**	-.729**
		Sig. (2-tailed)	.000	.	.932	.000	.001
		N	16	16	16	16	16
	Quality Performance	Correlation Coefficient	-.086	.023	1.000	-.015	-.585*
		Sig. (2-tailed)	.752	.932	.	.956	.017
		N	16	16	16	16	16
	Sustainability Performance	Correlation Coefficient	-.919**	-.840**	-.015	1.000	.544*
		Sig. (2-tailed)	.000	.000	.956	.	.029
		N	16	16	16	16	16
	Innovation and Improvement and Client Satisfaction	Correlation Coefficient	-.595*	-.729**	-.585*	.544*	1.000
		Sig. (2-tailed)	.015	.001	.017	.029	.
		N	16	16	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations

			Time Performance	Cost Performance	Quality Performance	Sustainability Performance	Innovation and Improvement and Client Satisfaction
Kendall's tau_b	Time Performance	Correlation Coefficient	1.000	.686**	-.066	-.871**	-.458*
		Sig. (2-tailed)	.	.002	.774	.000	.042
		N	16	16	16	16	16
	Cost Performance	Correlation Coefficient	.686**	1.000	.000	-.710**	-.631**
		Sig. (2-tailed)	.002	.	1.000	.002	.006
		N	16	16	16	16	16
	Quality Performance	Correlation Coefficient	-.066	.000	1.000	-.019	-.549*
		Sig. (2-tailed)	.774	1.000	.	.938	.021
		N	16	16	16	16	16
	Sustainability Performance	Correlation Coefficient	-.871**	-.710**	-.019	1.000	.461
		Sig. (2-tailed)	.000	.002	.938	.	.051
		N	16	16	16	16	16
	Innovation and Improvement and Client Satisfaction	Correlation Coefficient	-.458*	-.631**	-.549*	.461	1.000
		Sig. (2-tailed)	.042	.006	.021	.051	.
		N	16	16	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Ranks

	Mean Rank
Time Performance	2.38
Cost Performance	2.75
Quality Performance	2.94
Sustainability Performance	3.63
Innovation and Improvement and Client Satisfaction	3.31

Test Statistics

N	16
Kendall's W[a]	.095
Chi-Square	6.050
df	4
Asymp. Sig.	.195

a. Kendall's Coefficient of Concordance

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Time Performance	16	1.00	5.00	2.3750	1.66833
Cost Performance	16	1.00	5.00	2.7500	1.12546
Quality Performance	16	1.00	5.00	2.9375	.77190
Sustainability Performance	16	1.00	5.00	3.6250	1.85742
Innovation and Improvement and Client Satisfaction	16	1.00	5.00	3.3125	1.25000
Valid N (listwise)	16				

Figure 5.72b: Corresponding weight factor for Round 2 for each of project success criteria

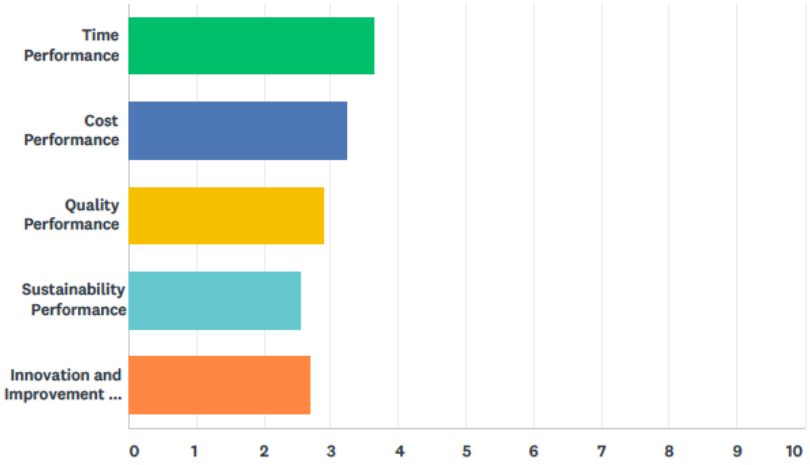
5.7.1.3 Round 3 of Delphi Questionnaire: Re-evaluating Weighted KPIs

SPSS Round 3 Final KPI Results

PhD Project Questionnaire on Lean Construction By Mahsa Heidar Barghi (University of Birmingham, UK): Delphi Study KPIs

Q1 In terms of Innovation and Performance Improvement that will lead to Project Success, please can you rank/order the significance of the following top five KPIs from the most important to the least important (Extremely important – 1; important – 2; Neutral / No change – 3; Unimportant – 4; and Extremely unimportant – 5)?

Answered: 16 Skipped: 0



	1	2	3	4	5	TOTAL	SCORE
Time Performance	50.00% 8	12.50% 2	6.25% 1	12.50% 2	18.75% 3	16	3.63
Cost Performance	6.25% 1	50.00% 8	12.50% 2	25.00% 4	6.25% 1	16	3.25
Quality Performance	6.25% 1	6.25% 1	68.75% 11	6.25% 1	12.50% 2	16	2.88
Sustainability Performance	25.00% 4	12.50% 2	6.25% 1	6.25% 1	50.00% 8	16	2.56
Innovation and Improvement and Client Satisfaction	12.50% 2	18.75% 3	6.25% 1	50.00% 8	12.50% 2	16	2.69

Figure 5.73a: The significance of the top five KPIs (Round 3)

The average ranking is calculated as follows, where:
w = weight of ranked position
x = response count for answer choice

$$\frac{x1w1 + x2w2 + x3w3 \ldots + xnwn}{Total\ response\ count} \qquad (5.1)$$

Weights are applied in reverse.

Correlations

			Time Performance	Cost Performance	Quality Performance	Sustainability Performance	Innovation and Improvement and Client Satisfaction
Kendall's tau_b	Time Performance	Correlation Coefficient	1.000	.686**	-.201	-.837**	-.322
		Sig. (2-tailed)	.	.002	.373	.000	.142
		N	16	16	16	16	16
	Cost Performance	Correlation Coefficient	.686**	1.000	-.095	-.541*	-.674**
		Sig. (2-tailed)	.002	.	.676	.015	.002
		N	16	16	16	16	16
	Quality Performance	Correlation Coefficient	-.201	-.095	1.000	-.014	-.362
		Sig. (2-tailed)	.373	.676	.	.952	.108
		N	16	16	16	16	16
	Sustainability Performance	Correlation Coefficient	-.837**	-.541*	-.014	1.000	.291
		Sig. (2-tailed)	.000	.015	.952	.	.188
		N	16	16	16	16	16
	Innovation and Improvement and Client Satisfaction	Correlation Coefficient	-.322	-.674**	-.362	.291	1.000
		Sig. (2-tailed)	.142	.002	.108	.188	.
		N	16	16	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations

			Time Performance	Cost Performance	Quality Performance	Sustainability Performance	Innovation and Improvement and Client Satisfaction
Spearman's rho	Time Performance	Correlation Coefficient	1.000	.812**	-.255	-.895**	-.482
		Sig. (2-tailed)	.	.000	.341	.000	.059
		N	16	16	16	16	16
	Cost Performance	Correlation Coefficient	.812**	1.000	-.112	-.709**	-.763**
		Sig. (2-tailed)	.000	.	.680	.002	.001
		N	16	16	16	16	16
	Quality Performance	Correlation Coefficient	-.255	-.112	1.000	-.007	-.417
		Sig. (2-tailed)	.341	.680	.	.980	.108
		N	16	16	16	16	16
	Sustainability Performance	Correlation Coefficient	-.895**	-.709**	-.007	1.000	.410
		Sig. (2-tailed)	.000	.002	.980	.	.115
		N	16	16	16	16	16
	Innovation and Improvement and Client Satisfaction	Correlation Coefficient	-.482	-.763**	-.417	.410	1.000
		Sig. (2-tailed)	.059	.001	.108	.115	.
		N	16	16	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 5.73b: Correlation matrix among five weighted KPIs

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Time Performance	16	2.3750	1.66833	1.00	5.00
Cost Performance	16	2.7500	1.12546	1.00	5.00
Quality Performance	16	3.1250	.95743	1.00	5.00
Sustainability Performance	16	3.4375	1.78769	1.00	5.00
Innovation and Improvement and Client Satisfaction	16	3.3125	1.30224	1.00	5.00

Figure 5.73c: Descriptive Statistics

To obtain a measure of consistency, a statistical test was applied involving the calculation of the Kendall's coefficient of concordance (W) for the KPIs provided by the 16 experts using the Statistical Packages for Social Sciences (SPSS) software. If the Kendall's concordance coefficient is equal to 1, it means that all the experts rank the KPIs identically. In contrast, if the concordance coefficient is equal to 0, it means that all the experts rank the KPIs totally differently.

The test statistics below (Figure 5.73d) also shows that Kendall's W for the rankings of the five weighted KPIs was 0.076. The computed W was statistically significant at a 10% significance level.

Ranks

	Mean Rank
Time Performance	2.38
Cost Performance	2.75
Quality Performance	3.13
Sustainability Performance	3.44
Innovation and Improvement and Client Satisfaction	3.31

Test Statistics

N	16
Kendall's W[a]	.076
Chi-Square	4.850
df	4
Asymp. Sig.	.303

a. Kendall's Coefficient of Concordance

Figure 5.73d: Test statistics

By using SPSS software, the Mean Rank method was applied for the weighting for each of the project success criteria. The corresponding weight factors for each of project success criteria are shown in Figure 5.73. The correlation matrix shown above reveals that the five project success criteria are not highly correlated with each other at 1% and 5% significance levels, except for Time Performance and Cost Performance which have a strong positive correlation (0.686 and 0.812) at the 0.01 significance level.

To state a weight factor for the final project success criteria, the weighting for each of the five KPIs was calculated by Equation 5.2:

$$W_{KPIa} = \frac{M_{KPIa}}{\sum_g M_{KPIg}} \text{ for } \alpha = 1 \qquad 5.2.$$

where W_{KPIa} is the weighting of a particular KPI; M_{KPIa} represents the mean ratings of a particular KPI; and $\sum_g M_{KPIg}$ represents the summation of the mean ratings of all eight resultant KPIs.

Table 5.8 Corresponding weight factor for Round 3 for each of the project success criteria

Project Success KPIs	**Corresponding Weighting**
Time Performance	0.158
Cost Performance	0.183
Quality Performance	0.208
Sustainability Performance	0.229
Innovation and Improvement and Client's Satisfaction	0.220

Table 5.8 shows the five resultant KPIs together with their corresponding weightings. They are: (1) time performance, with a weighting of 0.158; (2) cost performance, with a weighting of 0.183; (3) quality performance, with a weighting of 0.208; (4) innovation and improvement and client satisfaction, with a weighting of 0.220; and (5) sustainability performance, with a weighting of 0.229.

In order to establish a measurement model as an indicator to evaluate the success of projects as a benchmark, a PI has been developed; it can be represented by the following proposed formula (performance index for construction projects in Round 3):

The project success index will be calculated by using equation 5.3:

$$PI = 0.158 \times TP + 0.183 \times CP + 0.208 \times QP + 0.229 \times SP + 0.220 \times IICS \quad 5.3$$

where
PI: Performance Index; TP: Time Performance; CP: Cost Performance; QP: Quality Performance; SP: Sustainability Performance; and IICS: Innovation and Improvement and Client's Satisfaction.

All five success KPIs should be measured based on a method applied by each project-based organisation.

According to Yeung et al. (2007), the index is derived based on the assumption that this is a linear and additive model. It is logical and valid to derive this linear and additive model because the correlation matrix shown in Figure 5.73b and correlation matrix among the five weighted KPIs in Round 3 (see Section 5.7.1.3) reveal that the five weighted KPIs are not highly correlated with each other at a 5% significance level (more than 90% of them are even insignificantly correlated with each other).

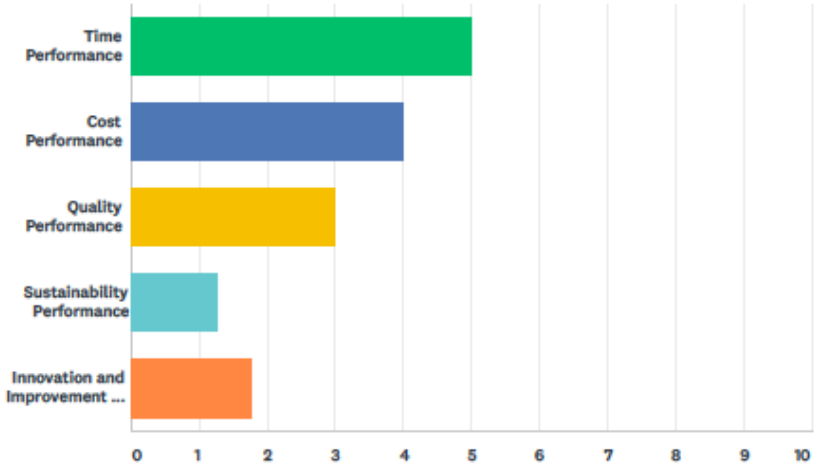
Also, as the units of measurement for the five weighted KPIs are different, there is not likely to be any multiplier effect between them. Though it seems more sophisticated to use a nonlinear model to fit the data obtained, overfitting is a common problem with nonlinear models, especially when the sample size is not sufficiently large (Neter et al., 2005; Weisberg, 2005). That is why a linear rather than a nonlinear model is recommended if the relationship amongst variables is not proved to be nonlinear.

5.7.1.4 ROUND 4

In Round 4, the results of Round 3 were given to the 16 experts. The respondents were asked to re-evaluate their ratings based on the mean scored obtained by them.

Q1 In terms of Innovation and Performance Improvement that will lead to Project Success, please can you rank/order the significance of the following top five KPIs from the most important to the least important (Extremely important – 1; important – 2; Neutral / No change – 3; Unimportant – 4; and Extremely unimportant – 5)?

Answered: 16 Skipped: 0



	TOTAL	SCORE
Time Performance	16	5.00
Cost Performance	16	4.00
Quality Performance	16	3.00
Sustainability Performance	16	1.25
Innovation and Improvement and Client Satisfaction	16	1.75

Figure 5.74a: The significance of the top five KPIs (Round 4)

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum
Time Performance	16	1.0000	.00000	1.00	1.00
Cost Performance	16	2.0000	.00000	2.00	2.00
Quality Performance	16	3.0000	.00000	3.00	3.00
Sustainability Performance	16	4.7500	.44721	4.00	5.00
Innovation and Improvement and Client Satisfaction	16	4.2500	.44721	4.00	5.00

Ranks

	Mean Rank
Time Performance	1.00
Cost Performance	2.00
Quality Performance	3.00
Sustainability Performance	4.75
Innovation and Improvement and Client Satisfaction	4.25

Test Statistics

N	16
Kendall's W[a]	.963
Chi-Square	61.600
df	4
Asymp. Sig.	.000

a. Kendall's Coefficient of Concordance

Figure 5.74b: Corresponding weight factor for Round 4 for each of project success criteria

Descriptive Statistics

	N	Mean	Std. Deviation
Time Performance	16	1.0000	.00000
Cost Performance	16	2.0000	.00000
Quality Performance	16	3.0000	.00000
Sustainability Performance	16	4.7500	.44721
Innovation and Improvement and Client Satisfaction	16	4.2500	.44721
Valid N (listwise)	16		

Table 5.9 Corresponding weight factor for Round F4our for each of project success criteria

Project Success KPIs	Corresponding Weighting
Time Performance	0.066
Cost Performance	0.133
Quality Performance	0.2
Sustainability Performance	0.283
Innovation and Improvement and Client's Satisfaction	0.316

Experts reconsidered their ratings provided in Round 3 and made modifications to their ratings. The consistency of the experts' weightings was computed using SPSS to calculate the Kendall's W. The results here show that there was no change in the order of their mean ratings. It also reveals that the consistency of the experts' rankings for the eight KPIs was improved over Round 3 and it was statistically significant (the significance value of Kendall's coefficient of concordance is 0.000 i.e. < 0.05, meaning a statistically significant result, and indicating that there was agreement). The coefficient of concordance for the eight KPIs between Rounds 3 and 4 improved.

Table 5.9 shows the five resultant KPIs together with their corresponding weightings. They are: (1) time performance, with a weighting of 0.066; (2) cost performance, with a weighting of 0.133; (3) quality performance, a weighting of 0.2; (4) innovation and improvement and client satisfaction, with a weighting of 0.316; and (5) sustainability performance, with a weighting of 0.283.

To establish a measurement model as an indicator to evaluate the success of projects as a benchmark, a PI has been developed; it can be represented by the following formula: performance index for construction projects in Round 4:

The project success index will be calculated by using equation 5.4.:

$$PI = 0.066 \times TP + 0.133 \times CP + 0.2 \times QP + 0.283 \times SP + 0.316 \times IICS \quad 5.4$$

where

PI: Performance Index; TP: Time Performance; CP: Cost Performance; QP: Quality Performance; SP: Sustainability Performance; and IICS: Innovation and Improvement and Client's Satisfaction.

All five success KPIs should be measured based on a method applied by each project-based organisation.

Spearman's Rank-order Correlation (Spearman's rho) in SPSS and Interpretation of Spearman's rho output from SPSS were usedin this research.

Chi-square $\chi^2 = m(n-1)W$ (5.5)

Table of Critical Values of Chi-Square (χ^2) was also reviewed.

The null hypothesis, that the respondents' ratings within the group are unrelated to each other, had to be rejected. Therefore, it can be concluded that there is a significant amount of agreement among the respondents within the group in ranking those KPIs under study.

The PI is composed of the five weighted KPIs identified in Round 4 of the Delphi questionnaire and the coefficients are their individual weightings, which are calculated by their individual mean ratings divided by the total mean ratings.

A linear model is assumed to be a linearised model of an unknown nonlinear model if it really exists (Morrison, 1991; Griffiths, 1993). Practically speaking, it is simpler and easier to use this model to measure the performance of relationship-based projects in the UK and Iran construction industry. It is valid to assume this linear and additive model.

5.8 Case Studies – Implementation of Lean Principles and Application of KPIs and PI

Project manager, planners, all subcontractors, foreman/foremen, workers, staff, personnel etc., were encouraged to be familiar and learn about the following lean principles. Last planner: Reverse phase scheduling (bottom-up decision-making process); 6 week look ahead; variance analysis; and PPC charts. Increased visualisation through: Commitment charts; mobile signs; and project milestones. Daily huddle meetings: All foreman daily meetings; and weekly work plan meetings. First run studies (PDCA): Plan; do; check; and act. Five S: Sort; Straighten; Standardise; Shine; and Sustain. Fail safe for quality: Check for quality and safety; safety action plans. Just in time. KPIs: Performance Index (PI).

Lean assessment system: The lean assessment system is developed to evaluate the implementation of each lean principle and can provide solutions to existing practical problems, which is based on a checklist of lean construction practices. This checklist is shown in Chapter 4 in Table 4.9 Lean techniques relevant to Time issues; Table 4.10 Lean techniques relevant to Cost issues; Table 4.11 Lean techniques relevant to Quality issues; Table 4.12 Lean techniques relevant to Sustainability issues; and Table 4.3 Waste Management in the UK and Iran; as well as; Table 4.15 Possible Interaction Matrix of Lean Construction Techniques and Time issues; and Table 4.16 Possible Interaction Matrix of Lean Construction Techniques and Cost issues. Also in Chapter 5, in Figure 5.77 Framework for utilising Lean Construction Techniques to Promote Process Improvement on Construction Sites.

The lean assessment system demonstrated an improvement at the end of the study. The following are requirements to achieve more positive results and benefits, which are continuous improvement (kaizen), training, pull system, visual management, build-in quality, indicators, motivations, incentives, workable backlog, foreman and workers empowerment, waste management and elimination, commitment and attitude, cooperation, and standardisation. The Project Case 2 results were:

KPIs survey result (Round 3):
Time performance score: 3.63
Cost performance score: 3.25
Quality Performance: 2.88
Innovation and Improvement and Client's Satisfaction: 2.69
Sustainability Performance: 2.56
Performance index: 2.114 out of 5

KPIs survey result (Round 4):
Time performance score: 5.00
Cost performance score: 4.00
Quality Performance: 3.00
Innovation and Improvement and Client's Satisfaction: 1.75
Sustainability Performance: 1.25

Performance index: 2.37 out of 5, which can be concluded to be a successful project.

5.9 An Integrated Framework for Improvement of the Construction Process by Adopting Lean Construction Principles

The research outcome presented in this chapter is discussed as an integrated framework for improvement of construction process by adopting LC principles and techniques on construction sites. This chapter begins with the need for improvement in construction practices on construction sites, the application of LC techniques, and the results and effects on construction.

5.9.1 Towards a Research Outcome: Improvement in construction practice

The aim of the framework developed in this research is to give guidance on how to use the techniques to improve the construction process and practice on construction sites to those companies already applying LC and those planning and intending to apply and become lean. The conceptual framework shows how the different parts relate to each other in attaining the desired outcome, which is to improve process.

An input must be placed into the system by the company, which would then be involved in several processes to be able to achieve the desired outcome. By means of strategies, it would be possible for the system to address the challenges it may encounter.

It may be necessary to undertake some measures. Any negative impact that may be related with the processes can be addressed and avoided by means of undertaking those measures. The framework includes of the following sections: the input; processes; challenges and inhibiting factors; strategies and mitigating measures for addressing and overcoming the challenges; negative impacts; strategies for addressing or avoiding the negative impacts; and positive outcomes. These components are further discussed below in Section 5.9.2.

5.9.2 The Framework

Given the previous discussions, the link between LC and process improvement in construction can be shown as an integrated conceptual framework (Figures 5.75 to 5.77).

Figure 5.77 is the Framework for utilising LC Techniques to Promote Process Improvement on Construction Sites. This figure shows that certain inputs are needed to be able to promote process improvement, a lean practice driver.

An input is what is required from the company to improve the process. It is something that a company puts into its system to reach some targeted results.

In this case, the input is to engage in the wholistic application of LC principles in its entire system. By engaging in LC practice, the organisation does not just directly apply the tools. It must first ensure that both the employers and employees understand and apply the lean principles. Both should also adopt a continuous improvement culture as a philosophy across all activities in the organisation.

The processes involve the selection and application of the appropriate LC tool or techniques to achieve the desired outcome. In this case, the processes involve applying the appropriate techniques (L1–L20) identified in the matrix to address the relevant improvement issue, Time (T1–T12) or Cost (C1–C25) as shown in the matrix. Regarding the Quality, Sustainability and Waste issues, the appropriate techniques were identified.

These techniques are applied at the construction phase of the project to reduce the occurrence of onsite problems and issues. They can also be used to reduce issues that develop on construction sites at the construction stage. Subsequently, the challenges of applying the lean techniques on construction sites must be addressed. The framework identifies the appropriate LC tools and techniques as inputs, and application of the right process, while at the same time addressing their challenges, improving standards and therefore achieving improvements on construction sites. This will result in improvement of construction process and prevent waste of time and resources, both human and material, and improve quality and sustainability.

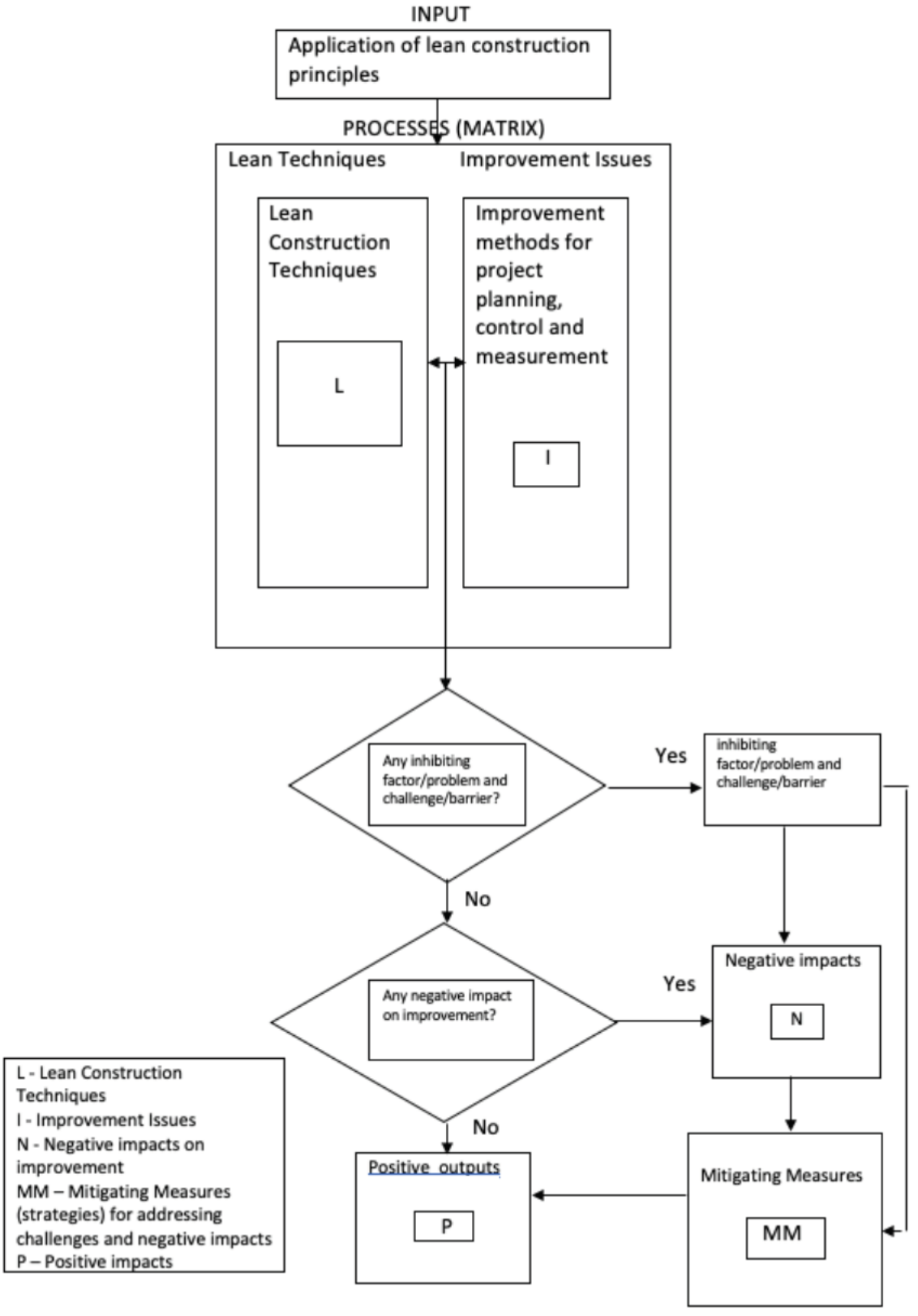


Figure 5.75: Conceptual Framework

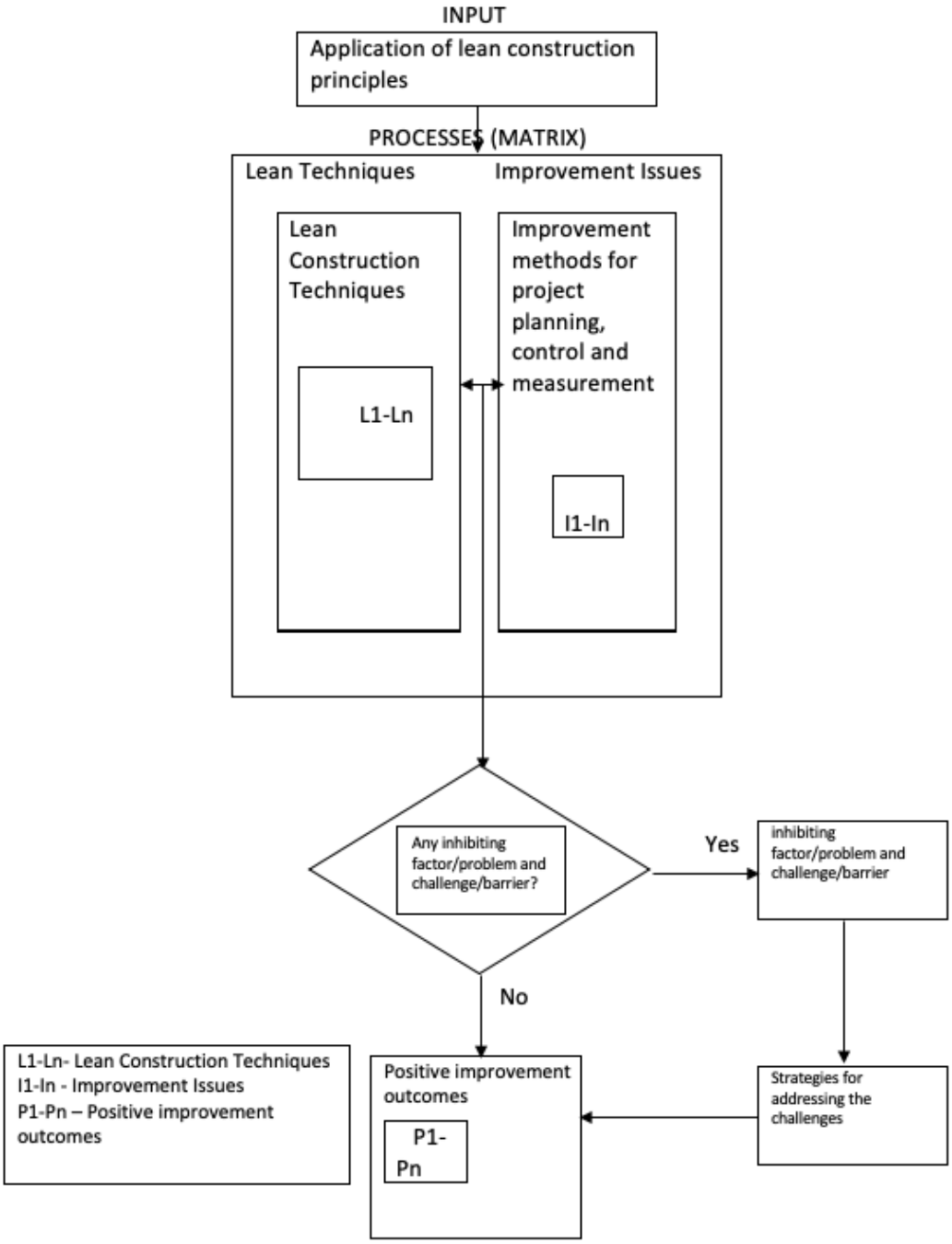


Figure 5.76 Developed Framework

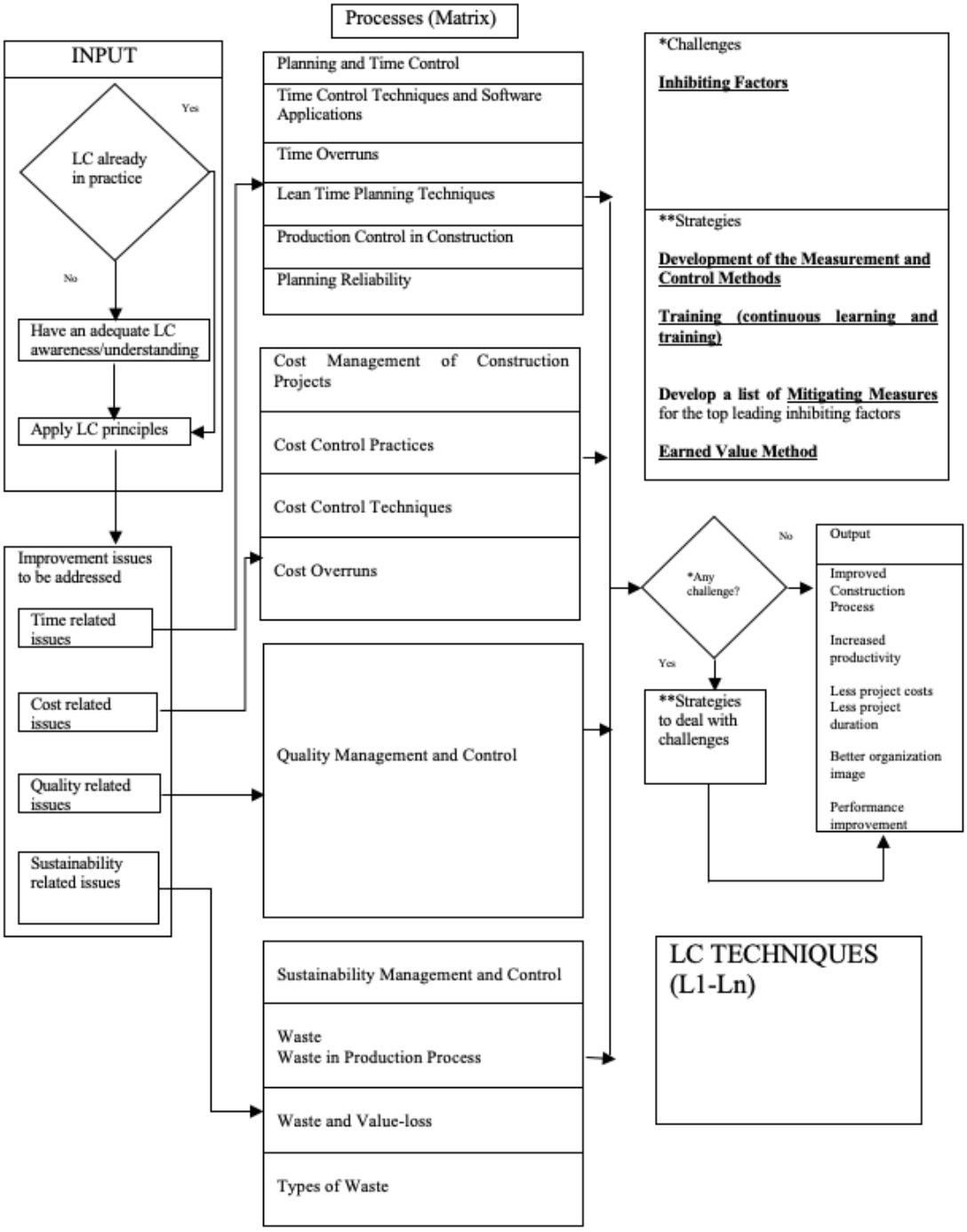


Figure 5.77 Framework for utilising Lean Construction Techniques to Promote Process Improvement on Construction Sites

5.10 Summary

This chapter presents the main outcomes of the research. It initially summarises the research, noting the major findings. Then, based on the qualitative and quantitative study findings, it presents an integrated framework that could serve as a guide to contracting organisations in using LC techniques to achieve an improvement in safety on construction sites. Having developed such an integrated framework, the research moves to validate the framework from practitioners' viewpoint.

Figure 5.78 shows the final framework for utilising Lean Construction Techniques to Promote Process Improvement on Construction Sites (Time-related issues) and Figure 5.79 shows the final framework for utilising LC Techniques to Promote Process Improvement on Construction Sites (Cost-related issues). The developed framework has the capability to synchronise the project steps and manage overlap activities and, based on the project type, it would increase project flexibility very much or up to a certain level. Also, all of the addressed issues can be overcome and lessened by the use of the suitable framework proposed and developed in this thesis.

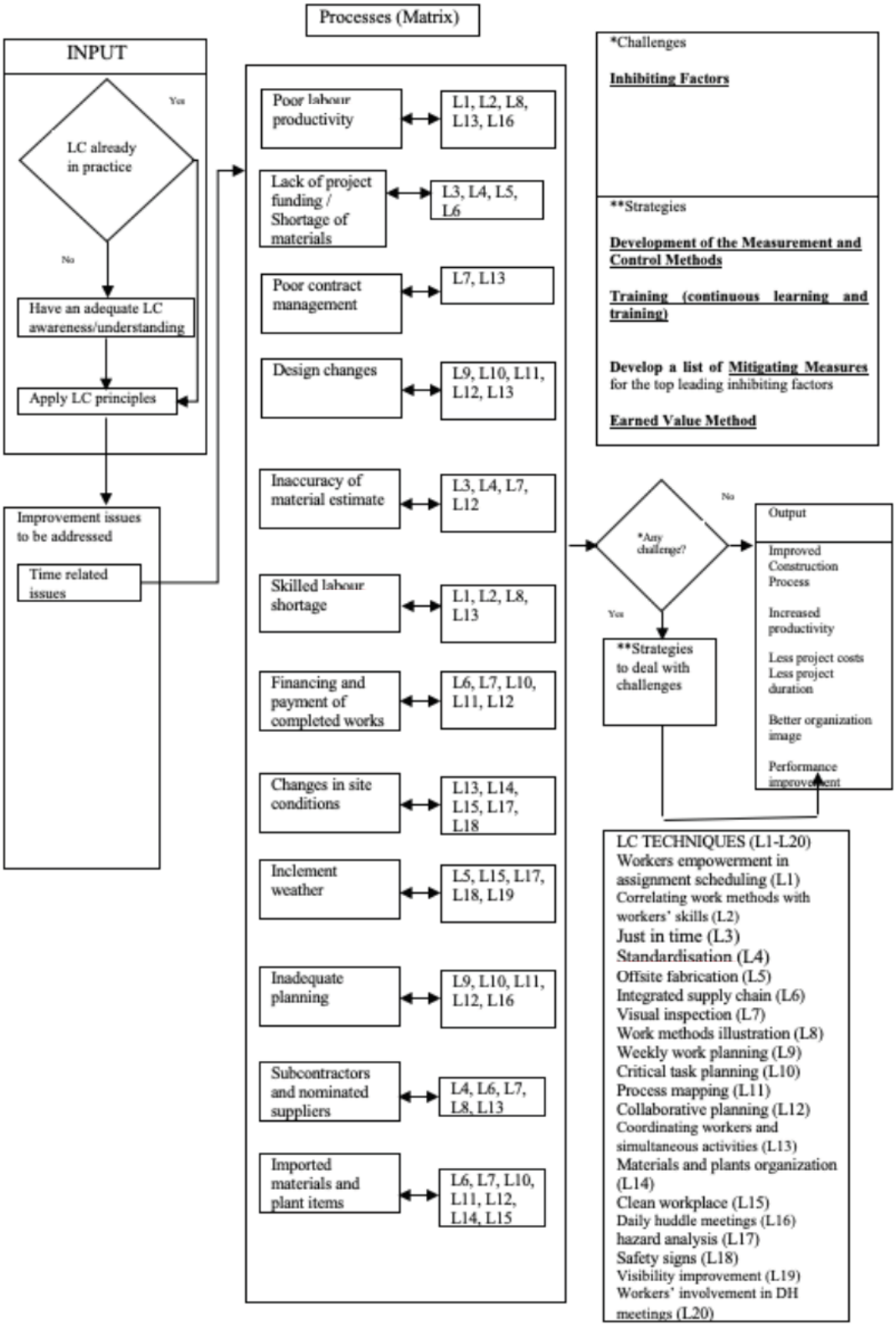


Figure 5.78 Framework for utilising Lean Construction Techniques to Promote Process Improvement on Construction Sites (Time-related issues)

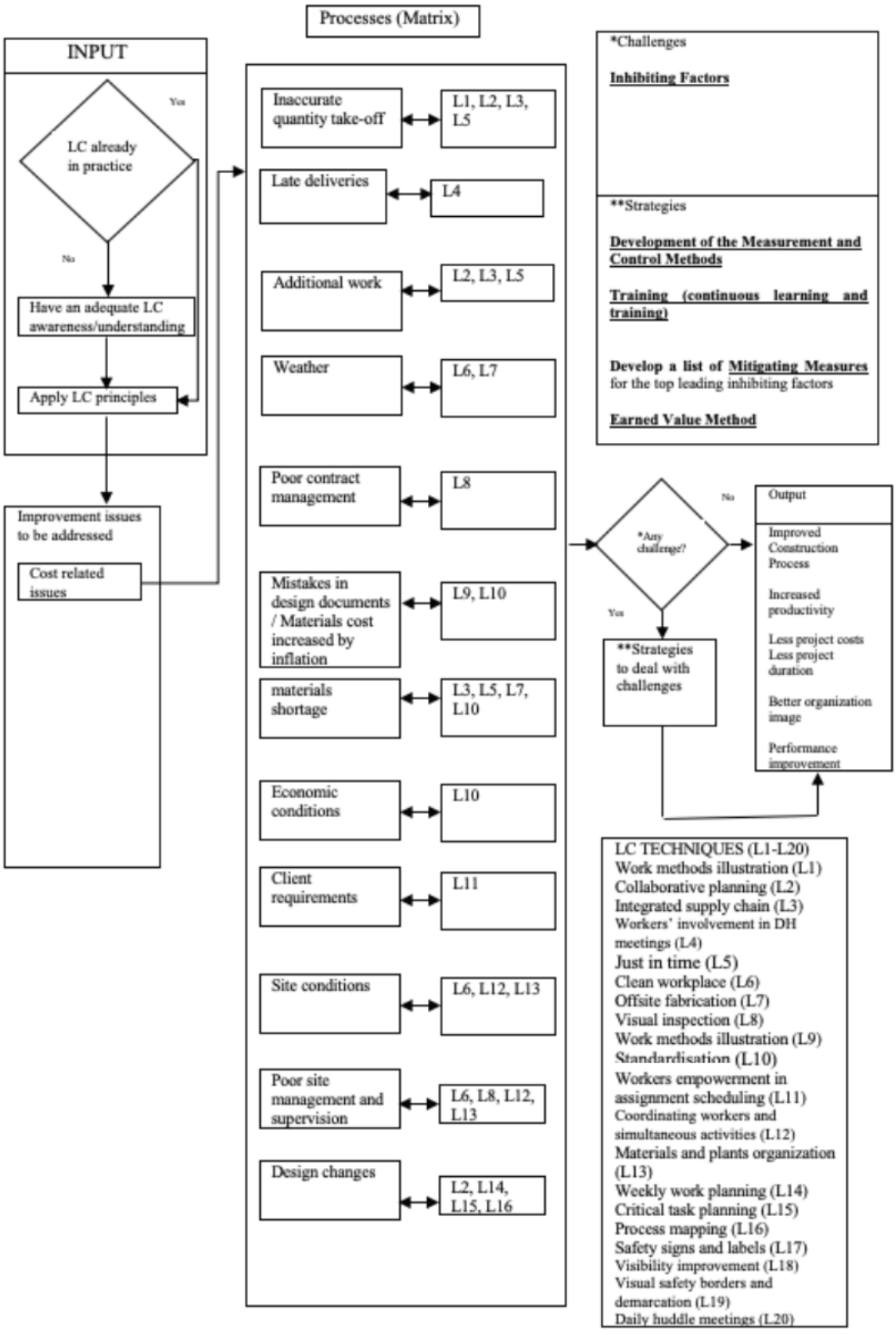


Figure 5.79 Framework for utilising Lean Construction Techniques to Promote Process Improvement on Construction Sites (Cost-related issues)

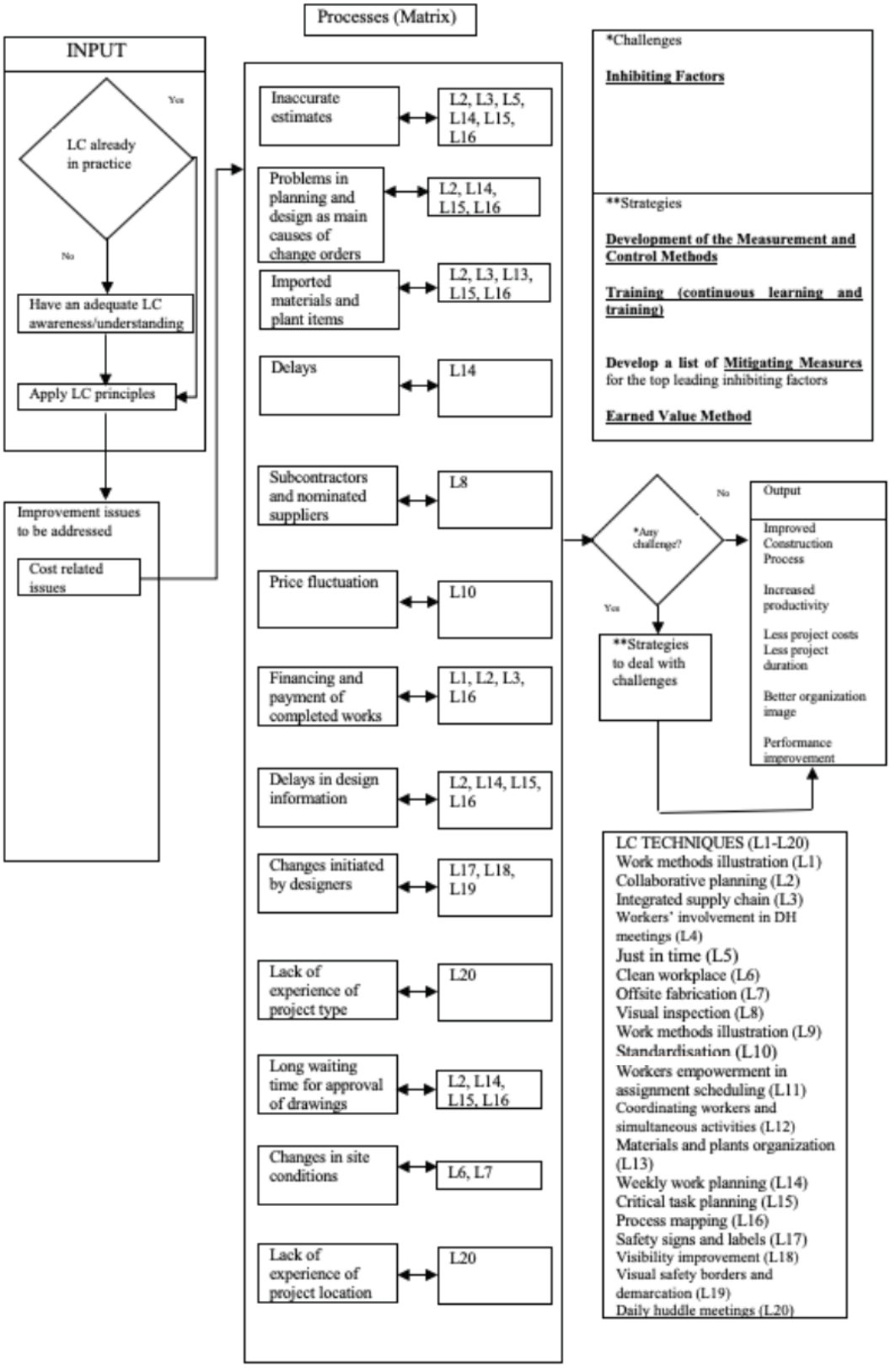


Figure 5.79 (Continued) Framework for utilising Lean Construction Techniques to Promote Process Improvement on Construction Sites (Cost-related issues)

6 CONCLUSIONS

6.1 Introduction

The aim of this research project was to improve the construction process to manage construction waste, time, and cost and to improve the levels of quality and sustainability achieved. The goal of this research was to propose, define, develop, and test a lean-enabled system to support planning and control, value generation, and waste reduction daily on construction sites. The adaptation of lean principles with identified enablers has been assessed; a combination of different lean principles and techniques were considered as the the main enablers to develop a framework for the construction process. The RIBA Plan of Work (PoW) was used to integrate and incorporate several lean construction (LC) principles and techniques to develop a standard model where both the construction stages and the associated activities of the construction process in projects can be described.

The new framework developed starts by applying LC principles to the RIBA PoW for measurement and control of Cost, Time, Quality, and Sustainability. This allows full integration of the RIBA PoW with the concept of lean philosophy.

This research study first investigated the LC techniques currently used in the industry and the principles of applying LC, particularly the problems associated with using LC techniques regarding project planning, construction waste management, project changes, risk and uncertainty management (see Chapter 2). New lean tools that overcome the problems were developed in this study, with these providing an effective and efficient way of managing construction projects. Hence the overriding approach adopted with the research presented herein was the need to have a combination of the RIBA PoW with LC principles to better allow for waste reduction in projects.

The framework model, incorporating the RIBA PoW, has been subsequently developed in this research, allowing incorporation of: models for the control and measurement of cost, time, quality, and sustainability. This was supported and honed through the completion of

work and analysis on case study materials collected from industry.

These case study materials were then used to test the measurement models. These include LC implementation models for construction projects; recent implementation methods; tools, techniques, and models; pilot studies to capture the LC initiatives in developed and developing countries; and conducting and evaluating the case study to validate the application and implementation of developed models (see Chapter 5).

Data collection by questionnaire and interview survey, contacting selected respondents, observation, and documentary analysis, was carried out to evaluate the proposed framework model. Finally, the proposed framework model and the results of the data were discussed and evaluated (see Chapter 5).

This research drew from the RIBA PoW as an appropriate construction management process that is relevant to buildings and, as shown through the case studies, applies to residential buildings. This research assessed a range of waste management methods but, more importantly, highlighted why the LC process is fundamental and offers considerable potential to improve waste management in the construction sector. The framework has been designed to overcome the barriers to implementing good practice in waste minimisation and management (WMM): Time Management (TM), Cost Management (CM), Quality Management (QM), and Sustainability Management (SM). This framework further allows the identification of the actions that need to be taken at both a high strategic level and at a site level to ensure that any resistance is countered and dealt with, and through this the ultimate goals of measurement and control of Cost, Time, Quality, and Sustainability can be best achieved in construction projects.

The gap in knowledge was associated with the different techniques for construction management, with many different techniques for waste management being used, but with no system that combined both waste management and construction management into a logical process that could be used concurrently and in partnership. As such there was currently no system that coherently maps the benefits of LC with the RIBA PoW, and therefore there was a need to develop such an approach so that their joint benefits can be gathered together in one

usable framework. Chapter 3 sets out the methodology used to develop the research and, through this, address these gaps in the current state of knowledge.

Using the methodology outlined in Chapter 3, a new adaptation of the RIBA framework has been developed. Chapter 4 then builds upon this picture, through presentation of results associated with each of the key stages set out above in this section. The development of a construction framework and a first set of results is presented therein based upon the derived questionnaire.

Furthermore, to the best of the author's knowledge, there is no other study which has evaluated these issues and which has addressed these through the developed framework model presented herein. Further, this study has focused on the new insights of the implementation framework development that can continuously be applied to construction projects.

6.2 Conclusions

Although various control techniques and project control software are available, many construction projects still do not achieve their cost and time objectives. The inhibiting factors and mitigating measures in practice can be identified and reduced or eliminated using the developed frameworks presented in this thesis. These mitigating measures are classified as: A) preventive, B) predictive, C) corrective, and D) organisational measures, and are used as a checklist of good practice.

According to Kerzner (2003), in the construction industry, the aim of project control is to ensure that projects finish on time, within budget, and achieve other project objectives. It is a complex task undertaken by project managers in practice, which involves constantly measuring progress, evaluating plans, and taking corrective actions when required. Project control methods and software packages are available for this reason. In this research, the most important variables causing construction delays and cost overruns were identified and discussed. Evidence was further gathered using questionnaires, interviews, and case studies. These case studies were used to tie together the research set out, with what occurs on site (see Chapter 3). As a case study, two building projects from Iran were used to achieve this goal. Despite different site locations, companies, and project management methods and approaches

having been used, to some degree, all projects presented similar problematic characteristics, namely, time and cost overruns, a lack of coordination, a lack of safety and quality, conflict and disagreement between the client, subcontractors, and contractor, and an unreliable programme. This was, in part, the motivation for undertaking this research. The case studies allowed demonstration of the core principle of LC and how such an approach benefits construction projects.

Interviews were conducted with a broad range of people, from Iranian engineers who are members of the Iran Construction Engineering Organisation, including: contractors, designers, subcontractors, consultants, directors of companies, working labours, and foremen. In addition, in Iran the questionnaire was distributed to the contractors chosen among members of the Iran Institute of Civil Engineers and The Iranian Contractors Association (see Chapter 5). For the case study, the research benefited by the author working as an Assistant Project Manager, allowing a detailed evaluation of the framework developed to take place on real projects. Two residential projects were used for case studies: Project 1 – Seyed Residential Project, Tehran, Iran, and Project 2 – Safai Residential Project, Tehran, Iran. These ran from September 2015 to March 2019 and February 2016 to May 2019, respectively. From direct observation and the implementation of LC through the framework developed, the following aspects were found (see Chapter 5):

(1) Enhanced site management was achieved by improving construction planning and control practice.
(2) Specific LC principles were tested through an action research process, allowing a new lean assessment system and results quantification to be achieved.
(3) Through this work, the development and implementation of lean principles, application of Key Performance Indicators (KPIs) and a Performance Index (PI) measurement model, and performance improvement were successfully achieved.
(4) The proposed control and measurement models allowed improved cost, time, and quality performance to be achieved, demonstrating the potential of the framework for all construction projects.
(5) Importantly, improved identification and recognition of waste and value-loss was achieved on site, again showing the benefits of the framework developed.

(6) In addition, a Master Schedule using Primavera PERT Master software was developed for these projects and this enabled further improvements to be made.

Chapter 4 presents a new proposed model that contains a set of lean methods and techniques to support the application of lean principles in construction project practice and, via this, a method to more consistently achieve the full benefits that LC approaches can offer.

The adaptations of lean principles with enablers in the proposed model are identified and assessed; a combination of different lean methods and techniques as the major enablers are taken into consideration in the construction process. This proposed model has then been integrated and incorporated into the RIBA PoW to implement lean methods and techniques to the construction activities, as this proved to be the most effective way to implement changes associated with the proposed LC model.

The measurement and control methods have been developed to control and manage cost, time, quality, and sustainability, which are also presented in this chapter.

The adaptation of lean principles with the identification of wastes and enablers in the construction process were evaluated. The innovative construction process models presented in this research were developed based on the core enablers that can be used to identify and eliminate waste. The adaptation and consideration of the core enablers of the construction process model are also discussed.

The framework development in this research project consists of two parts, conceptual frameworks (see Section 4.2) and implementation frameworks (see Section 4.3).

In Chapter 4, the framework models, measurement model, matrix of waste management, survey analysis, matrix of time and cost issues, and tables of lean techniques relevant to quality and sustainability issues are proposed and developed. In Chapter 5, based on analysis from the questionnaires and interviews (undertaken in four rounds), a modified framework and performance measurement are developed and tested against two case studies from Iran. Further, they are explained and validated through the case studies, the use of the developed performance index measurement model, and external validation to produce an integrated

framework for improving the construction process by adopting LC principles.

As a conclusion, the fundamental role of management in planning should not be underestimated, not least where planning is handed over to those people who are solely responsible for doing the planning. Therefore, the programme which is submitted to the client periodically is an expression of what has been finished on site pursued by a theoretical wish list which, with any luck, can be optimistically finished on time and within budget. However, the practice that is proposed and recommended by the client is a high-quality method to improve the reliability of the plan and, if genuinely applied, would result in enhanced control and management of the project and all the activities.

The control of time was carried out on an experiential basis through simple visual comparison between what was completed and what should have been completed. Based on this research, one of the methods efficiently and successfully used in controlling production on site is cost control, which is typically carried out using expensive (and sophisticated) software. It can be argued that this extreme concern and attention to financial management is related to the cultural feature of the organisation, as production control is a lot more than just a comparison between planned and executed costs.

In general, the work presented herein suggests that from planning, execution, and control, which cover the three areas of concern, control, and execution are more open and clear in the organisation than planning, in terms of project management. In addition, much of the resources such as software, personnel, and associated hard work are more directly impactful than the area of planning.

Unfortunately, as mentioned, in some cases (see Chapter 2), the concepts of value generation and flow activities have been often ignored by project teams. This was observed in the case histories studied and presented in this thesis, where sometimes the neglect of flow and generation of value are clearly seen. As a consequence, productivity will be affected because of delays in the programme, all of which are wastes.

In conclusion, successful project completion requires being continually attentive and picking up warnings that require more/essential changes. For example, firstly, instead of contractually

oriented management, partnering methods should be encouraged and motivated. Secondly, the original and fundamental project management theory should be changed to one that appreciates construction as flow of transformations which generate and make value in a dynamic and complex system. Whilst this is established, the adoption of LC has been shown to make a real impact therein. Chapter 5 presents the outcome of the research. It initially summarises the research, noting the major findings. Then, based on the qualitative and quantitative study findings, it presents an integrated framework that could serve as a guide to contracting organisations in using LC techniques to achieve an improvement in time, cost, quality, sustainability, and safety on construction sites. Having developed such an integrated framework, the research moves to validate the framework from the practitioners' viewpoint.

Figures 5.78 shows the final framework for utilising LC Techniques to Promote Process Improvement on Construction Sites (Time-related issues) and Figure 5.79 shows the final framework for utilising LC Techniques to Promote Process Improvement on Construction Sites (Cost-related issues). The developed frameworks have the capability to synchronise the project steps and to manage overlap activities based on the project type. Thus, it would increase project flexibility. Also, all of the issues addressed can be overcome and lessened by using the framework proposed and developed in this thesis.

The key impacts of LC techniques; drivers of LC practice in organisations; challenges to the implementation of LC techniques; and the outcome of implementation of LC practice were ranked to demonstrate how the variables compare with one another. The ranking will thus enable organisations to allocate priorities in making decisions.

The results from the research presented herein show a strong positive correlation between the ranking of factors inhibiting time control and those inhibiting cost control. This is similar to the findings of Chang (2002) who argued that it is difficult to separate the reasons causing overrun into those of cost and schedule, concluding that the reasons for cost increases are normally also the reasons for time extensions. Hence, it can also be rightly argued that the factors that inhibit effective time control of projects are also likely to inhibit effective cost control.

This study focused on reducing, removing, or eliminating inhibiting factors and on improving construction performance. Lean production has the distinct advantage of analysing production as both flow and conversion. Improving flows in construction is the aim of LC, which means reducing flow activities, and after that creates conversions in a more effective way, as seen in the manufacturing sector. There is a relation between waste and the project cost. There is no absolute relation between waste and value. Construction potentially includes significant amounts of waste. To have complete improvement in lean production, basic procedures are needed to recognise and identify waste streams, therefore removing them. To reduce waste, the improvement should be focused on eliminating non-value-adding or flow activities and to making conversion or value-adding activities more efficient. LC, through the framework developed in this thesis, presents a new highly-organised method of construction. For example, raised access floors, movable walls, pre-cast concrete, structure steel, structural insulated panels, etc., are different types of off-site construction which will result in a lower cost by using less space. Therein, the many and varied positive effects of lean on the environment should also be considered.

If the plan is disrupted, it may stop the whole project or it may produce several problems for the next phases of construction, which will increase the project's cost. Furthermore, if there is a problem like an unpredictable delay in the delivery of material, then serious loss and failure of production will take place. The negative effects of lean on the environment should also be considered. Lastly, a variation in material requirement is a difficulty that can often occur throughout construction. The main objective of LC using the framework developed in the research presented herein is to remove waste and activities which add no value to the final product and to improve overall construction performance. Thus, models for measurement and control of time, cost, quality, and sustainability have been developed and integrated into RIBA PoW in order to enable the framework to perform. Framework modelling by incorporating the RIBA PoW has been developed. The development of measures to mitigate the inhibiting factors and of a Time Matrix, Cost Matrix, Waste Matrix, and Performance Improvement (KPIs) for measuring performance and developing a performance index was carried out in this research project. On the basis of the qualitative and quantitative study findings, this thesis presents an integrated framework that could serve as a guide to contracting organisations in using LC techniques to achieve an improvement on construction

sites. Further research work has been conducted by case study to validate the framework in order to get an empirical result of the study.

This research concludes that there is no single system that allows for waste management to be done properly and effectively, which includes time, cost, quality, and sustainability management-related issues. Hence a new approach that combines LC with the RIBA PoW is advocated.

The subsequent framework developed will thus overcome the barriers to implementing good practice in WMM, TM, CM, QM, and SM. The framework identifies actions that need to be taken at both a high strategic level and at a site level to ensure that any resistance is countered and dealt with.

Having developed such an integrated framework, the research has validated the framework from the practitioners' viewpoint. The developed framework has the capability to synchronise the project steps and would manage overlap activities and, based on the project type, it can increase project flexibility. Thus, overall, all of the key project issues/problems can be overcome and their adverse impact lessened by the using the framework proposed and developed in this research.

6.3 Recommendations for further work

Finally, some recommendations to the owner, subcontractors, and contractors are set out. The proposed framework has also shown to improve the performance and consistency of scheduling. The link between LC, BIM, and sustainability can also be further studied. Due to the limitations of natural resources, sustainable construction is becoming more important. In the pursuit of greater sustainability, an effective alternative to conventional techniques could be using new methods of construction such as off-site techniques.

Despite its significant advantages, modular construction is a rapidly growing off-site method, though its applications are still limited in the construction industry. Modular construction has several benefits and a few challenges. Further quantitative studies are needed to address the benefits and challenges of modular techniques and how these can be managed through the framework presented.

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APPENDICES

APPENDIX A. SUPPLEMENTARY MATERIALS FOR CHAPTER 2

2.1 Current Waste Production and Management

Construction projects are amongst the largest contributors of waste around the world (Oyedele, et al., 2013). Streamlining the process is a key requirement to reduce this. In order to improve upon current ways of dealing with waste in construction processes there is a need to identify how much waste is being produced currently. This allows for identifying impediments and providing critical solutions (Oyedele, et al., 2013)

2.1.1 Waste minimization techniques

It is crucial that the process of managing the generation of C&D waste starts at the planning and designing stage so that the volume of generated waste could be decreased during the construction cycle.

Table A1: Using Site Waste Management Plans (WRAP, 2020)

England and Wales	SWMPs expected to become a mandatory requirement for projects with a value in excess of £250,000 from April 2008 following separate consultations in England and Wales.
Scotland	The 2006 public consultation on the proposed Scottish Planning Policy 10: Planning for Waste Management, included provision for SWMPs to form part of the planning conditions for new developments with a value in excess of £200,000.
Northern Ireland	The Waste Management Strategy 2006 – 2020 indicated that detailed proposals for a statutory requirement to prepare SWMPs will follow through a public consultation.

As a result, construction clients and developers are increasingly looking to set targets and requirements for good practice Waste Minimisation and Management (WMM) and as such the use of materials containing higher levels of recycled content is required. This is seen as a relatively simple and measurable way of making a difference which can be easily incorporated within a wider sustainability action plan for a project (Table A1).

Bearing in mind the high cost of removing and disposing of waste, it is apparent that producing less waste whilst improving management and recovery options will have the added financial and environmental benefits. Not least given recent and future increases in Landfill Tax.

Key benefits include: Reduced material and disposal costs; increased competitive differentiation; increased performance against CSR objectives; lower CO_2 emissions:

meeting planning requirements; complementing other aspects of sustainable design; responding to and pre-empting public policy.

The impact of CDW management strategies is not easily quantifiable for two main reasons: the evolving economic framework introduces difficulty in the quantification of business as usual, BaU, performance; and the allocation of the environmental benefits between the whole strategy or to a single technique or management practice (e.g. the establishment of a levy or the investment in recycling plants).

To ensure a more effective management of wastes especially towards mitigating impacts on the environment, the integration of 're-imagine' and 're-design' elements is of utmost importance (Esty and Winston, 2006). Not least when considering end-of-life of materials.

Stakeholders in the construction industry are aware of the significance of protecting the environment and are ready to commit towards a better management of C&D wastes that will help to achieve the environmental sustainability. Adoption of 3R principles of reduce, reuse and recycle is imperative at each stage of the construction cycle as the reduce principle should be prioritized at both planning and designing stage and procurement stage. Meanwhile, all 3R principles should be utilized at the construction and demolition stage to ensure the waste generated at this stage will be properly managed.

2.1.2 Good practice waste minimisation and management

The viewpoint of waste minimisation can be traced back to an early study by Skoyles (1976) who drew a distinction between direct and indirect C&D waste, or even earlier than that the work of Taylor's (1856–1915) who wrote about scientific management approaches, in particular his controversial Efficiency Movement. Direct waste comprises of a complete loss of materials through a direct action– these are the wastes materials mentioned by most researchers. However, by contrast, indirect waste can also include aspects such as monetary loss. This statement was also supported by the following studies including Pinto's (1989), Serpell and Alarcon (1998) and Formoso et al. (2002). The definition enables researchers to consider both the material loss and the non-value-adding work. However, this belief has somewhat been overlooked by existing studies, evidenced by the limited number of studies

on this topic. One explanation is that wasted materials in construction are easy to see, as well as relatively easy to measure (Formoso et al., 2002).

2.1.3 Solutions to reduce waste and waste management processes and techniques

Phase I - Site Waste Management Plan (SWMP) design.

In this phase, the scope of the plan is developed, for example by identifying materials to be recovered, re-used, recycled and disposed during construction or demolition. Waste management responsibilities are defined, and the instruments for monitoring, collecting and promoting correct waste management practices are identified, along with measurable indicators and targets. During the plan design phase, waste types will be defined, estimated, and the waste management technologies will be sized. A first cost estimation will be produced and potential savings will be identified.

Phase II - SWMP implementation.

On-site waste prevention and collection are techniques that should have been identified, designed and scoped in a general construction site management protocol, which may be articulated in a specific SWMP. From the endless list of waste management options at construction and demolition sites, four main activities of the waste management activity are identified: Estimation of waste generation and provision of resources. Collection and segregation techniques. Procedures and methodologies to ensure best management options.

Provision of waste logistics.

The SWMP, having been initially developed by the design team, should be fully developed and implemented by the principal contractor. As a minimum, the SWMP will contain detailed measures to comply with relevant waste legislation but should also include good practice guidance and objectives in order to maximise the reduction, re-use and recovery of construction waste, with disposal to landfill as the least preferred option. The SWMP can also be used by the design team as a tool to inform waste minimisation during the design stage of the project to ensure that the desired benefits of implementing the SWMP during later project stages will be realised.

The DTI guidance identifies steps to effectively implementing a project SWMP. The majority of steps involve planning site waste management during pre-construction, illustrating the importance of this project phase to effective waste management. The person responsible for producing and implementing SWMP should be identified. This can result in an immediate noticeable improvement in waste segregation and record keeping for waste. A register is produced of the likely types and quantities of waste generated during construction; Training; Identifying target recovery rates for each waste type along with formal measurement of these targets to demonstrate compliance and implementation of the SWMP. Key aspects of good practice in waste management and minimisation include, but are not limited to:

Design solutions; Demolition; **Logistics**

Logistic Plan – development of a logistic plan at the early stages of the project will ensure that due consideration is given to material requirements through the construction phase of the project, enabling efficient management of the delivery and storage of materials and that the most effective logistic methods are adopted.

'Just-in-time' delivery

Improving the movement of materials to the site and within the site to alleviate space constraints for storage and site congestion.

Construction Consolidation Centres

These provide effective supply chain management solutions enabling the safe and efficient flow of construction materials and equipment from supplier to site.;

Modern Methods of Construction (MMC)

Improvements in the products or processes employed in the construction industry, ranging from innovative components to be used on site through to whole building systems manufactured off-site. Off-Site Manufacturing – utilise prefabrication, factory assembly, pre-assembly, off-site assembly/manufacture, panelised or modular volumetric construction where possible, for example, staircases, lift assemblies, architectural steelwork and toilet blocks for hotels and student accommodation. Waste Minimisation is realised due to the controlled environment and the "production line" type process where there is repeatability in

construction.; Modern methods of construction have a huge impact on waste generation during construction, since off-cuts and concrete handling are avoided. The waste reduction potential is up to 90% for techniques such as *Volumetric building systems:* These are Off-site manufacturing of three-dimensional modules, An example of the application of modern methods of construction is the Middlehaven Hotel in the UK (Waste and Resources Action Programme, 2008b), Jose-Luis Gálvez-Martos et al. (2018).

Materials procurement:

Herein a Supply chain manager – will develop relationships and partnerships with suppliers during construction who can implement waste minimisation at source.

2.1.4. Good practice WMM

2.1.4.1. Construction Phase

Good practice WMM during the construction phase should follow the principles of the waste hierarchy: reduce the quantity of waste generated. Therein waste minimisation includes a range of straightforward methods to 'design-out' waste from a project and limit waste arising during the construction phase.

Fully benefiting from good practice WMM on a project will mean adopting its principles at the earliest possible stage, preferably mandated by the client through procurement requirements. The principles of good practice should then be communicated and implemented by the design team, contractor, subcontractors and waste management contractors through all project phases – from outline design to project completion.

Under good practice WMM, the aim should be to obtain data for the amount and type of waste generated to compare against the estimated quantities identified during the development of the SWMP. Waste measurement can include cost, type of waste, amount by volume and tonnage, reason for generation and management route. The actual waste quantities obtained should be compared with the initial targets to identify if the site is under-performing and whether corrective action is required to get back on track. The SMARTWaste auditing tool may be used as a means of logging and generating data.

For good practice WMM, monitoring will occur throughout the project although not on a regular basis. Under best practice WMM, monitoring and measurement of waste will be ongoing with regular interpretation to identify trends and rectify wasteful practices (Figure A2) The results from monitoring waste arisings should be included in weekly or monthly site meetings.

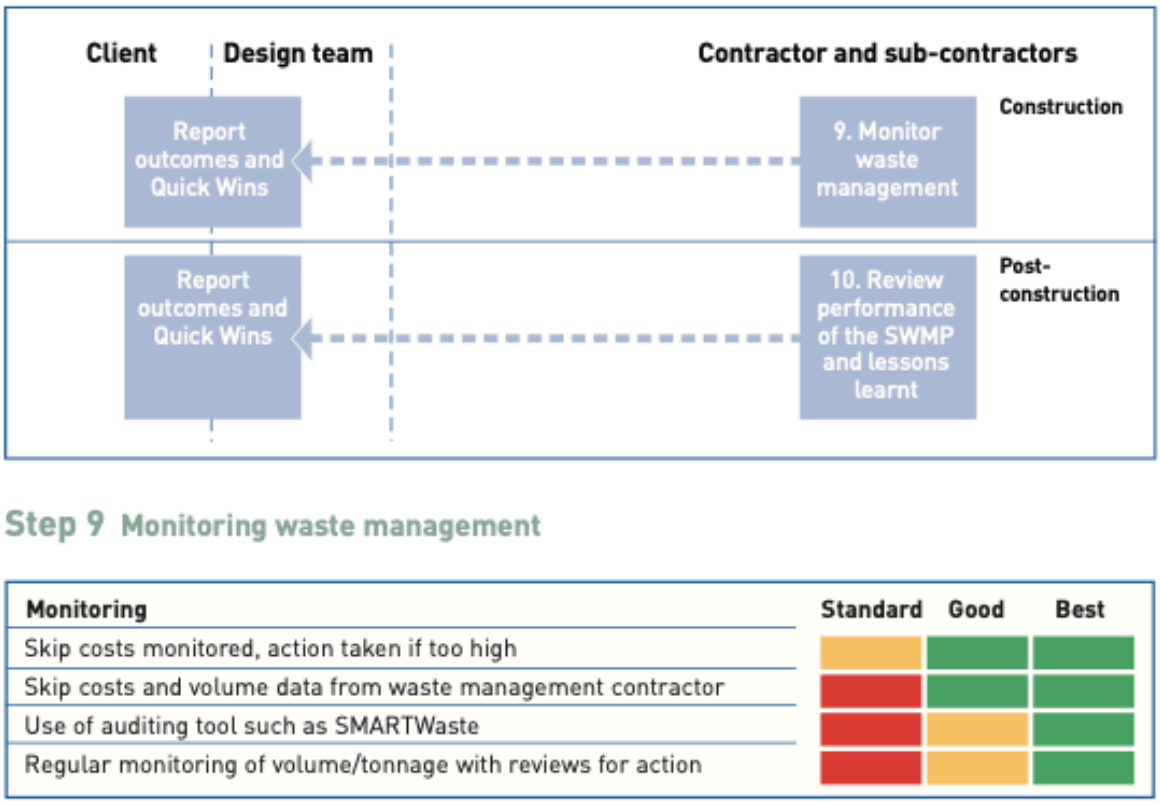


Figure A2. Monitoring Waste Management

2.1.4.2. Post Construction phase – A performance review of the SWMP and lessons learnt

During the implementation of the SWMP on a project, its overall performance in managing waste should be reviewed at least periodically throughout the project to ensure that it is working effectively and so that any anomalies can be addressed.

A final review of implementing the SWMP (Figure A3) once the project is completed is essential to ensure that any lessons learnt are identified and addressed in future projects. It is

better practice however for the lessons learnt to be embedded within the company. Embedding project experience at the company level includes:

- producing generic company-wide SWMP templates;
- integration of SWMPs with existing plans and procedures;
- comparing performance and setting on-going benchmarks and targets for waste; and
- gradual development of a bespoke SWMP format and procedures over the medium to long term.

By embedding the lessons learnt (Figure A3), the implementation of SWMPs will become more effective and efficient requiring lower resource requirements. This will translate into increased cost savings due to a reduction in labour costs associated with developing and implementing the SWMP. Incorporating SWMPs into the culture of a company can be used to illustrate a company-wide commitment to best practice WMM for an improved reputation with clients.

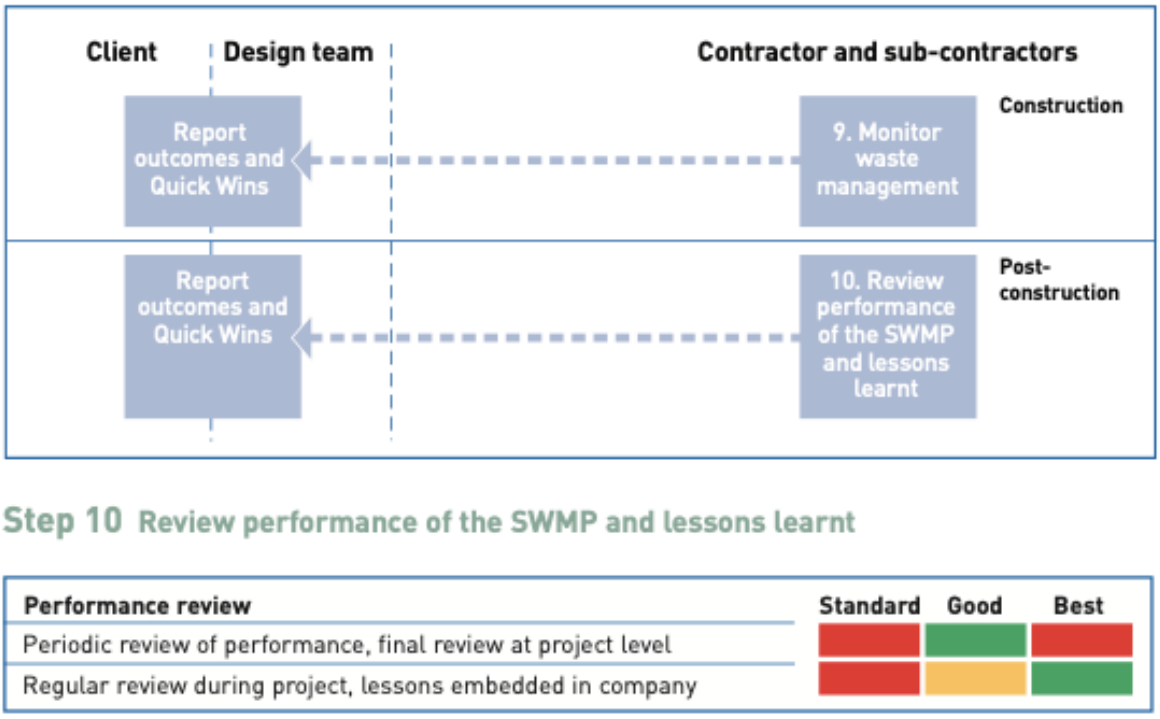


Figure A3. Review performance of SWMP and Lessons learnt

2.2. The concept of Lean Production (LP) and Lean Construction (LC)

This leads to a larger debate whereby supply chain and logistics, in a global sense, are clarified along with the differences between traditional and lean logistics. Most importantly, the literature review shows the challenges affecting logistics in the construction industry including the health and safety regulation factor; inventory factor; material preservation factor; labour performance and material handling factor (performance factor); planning factor; transportation factor; continuous improvement factor; and transparency and information exchange factor.

2.3 Construction Process and Construction Management

2.3.1. Construction Management

The construction industry and civil engineering projects in different countries are complex and unique. Therefore it is very important to choose the most suitable construction contractual arrangements for project.

Before a specific contractual arrangement is implemented different important subjects should be considered which are design responsibility, size and complexity of the project, programme and costs.

Designers required using new methods because skills and materials improved and also clients called for more new and modern services and facilities. As a result the designer's role turns into a complex management duty.

2.3.2. Construction Management Tools, Techniques and Methods

Throughout the 1990s the true capability of CPM as a project management tool has started to be understood. Since the 1990s, growths and developments in the authority and control of computers has allowed software to be run on site and updated right away. On a lot of projects, there is more than one plan.

In the short tender stage, overall project program is produced in hurry, and turns out to be enshrined in the master program. In terms of lead times or time intervals, framework, partnering and concession projects have longer lead times and frequently comprise incentives for improvements in efficiency (Jannarkar D., 2013).

2.3.3. Construction Management Issues and Problems

Systematic implementation of these best practices could dramatically improve resource efficiency and reduce environmental impact by Gálvez-Martos et al., (2018).

- Reducing waste generation;
- Minimising transport impacts;
- Maximising re-use and recycling by improving the quality of secondary materials
- Optimising the environmental performance of treatment methods;

The construction industry and design of civil engineering projects in different countries are complex and unique. Modern building and civil engineering projects are very complex, both in conception and implementation. There should be a good working relationship between participators in a project who have working relationships based on a *contract*.

2.3.4 Lean thinking

The research presented investigates and demonstrates the adaptation of lean thinking towards performance improvement of the design process. The research developed an innovation of design processes that supports the implementation of lean thinking for building construction projects. The proposed design process provides a systematic approach, which is structured into stages and activities in order to obtain a lean design process, Haji Md Yusof, Ismawi (2019).

A research done by Brady, (2014), 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.

2.4 Identification of knowledge gap and innovative features of the research

According to Lu W., Yuan H. (2011), more studies in the future might be needed to examine the non-value-adding work in construction. It is determined that the majority of research efforts have been given to the material loss in construction rather than the nonvalue-adding work as an intangible waste. WGR is an effective indicator for measuring C&D waste and benchmarking C&D WM performance in different economies. However, more research

is desired in developing economies for devising effective WM strategies by measuring and comparing the WGRs. Meanwhile, a clear and unified definition of WGR should be made to enable the comparison and benchmark of WM in different economies.

According to Huanyu Wu, Jian Zuo, George Zillante, Jiayuan Wang, Hongping Yuan, (2019), several future research opportunities are identified which are improving the recyclability of C&D waste; developing the advanced performance evaluation criteria for wasted materials and recycled products; extending the research boundary of waste flows; developing advanced methods to assess the waste management performance; exploring the more efficient use of information technologies in waste management; reducing waste from early project stages; and reducing waste during the building operation. These findings are not only valuable to better understand the waste research, but also useful to assist practitioners to further improve waste management performance and mitigate associated pollution.

2.4.1 Time

2.4.1.1 Time Management and Control

This section will investigate the role of time in managing the construction project, showing how it has become central to the discipline. For many, managing the schedule is the core capability of the project management discipline, as Peter Morris mentions, it has become related with project management as a middle-management, operational discipline, instead of the strategic discipline that its challenges need - it has become the routine of project management. Or, as Eli Goldratt (1997) puts it, there has been nothing new in 40 years. So the task of this chapter will be to identify current good practice with the *critical path method* before moving on to investigate some of the more recent developments which are starting to diffuse - most notably critical space analysis (CSA), *critical chain, last planner and* 4D planning.

The focus in this chapter is on the tools and techniques of scheduling (Graham m.winch, 2010).

The resources available on a project are of three types:

- Plant;
- Labour; and

- Space.

There are facilities available within most CPM software applications for resource levelling. There are limitations with the critical path method (Winch, 2010).

In the following section, the author has recapped management principles of the Critical Path Method.

Work Breakdown Structure (WBS) recognizes tasks or works to be done and the dependencies. In a variety of ways, like organizational, technical and spatial, dependencies might be produced (Aliverdi, Naeni, Salehipour, 2012).

Planning and Control: Planning and Control are two sides of a coin that continue, keep on rotating and turning during and all over a project (see Tezel et al., 2018).

Planning: Describes criterion for success and produces strategies for reaching objectives.

Control: States cause and effect in events to comply with the plan and activates causal learning and re-planning (See Ballard and Howell, 2003).

Planning techniques: Operational and Strategic planning are two main levels of planning which are belonging to and related with construction projects.

There are three types of planners which are:

- The engineers/architects or designers;
- The client organisation; and
- The contractor.

Normally, the engineers or the architects or the client's project manager, will be in charge for preparing the plans which used by the customer in taking the strategic decisions. It is necessary to plan, monitor and control (Harris and Mccaffer, 2006; Ballard, 2000). The activities to be planned, resourced and controlled include:

(1) Investigations;

(2) Design calculations;

(3) Drawings;

(4) Statutory planning approvals;

(5) Preparation of specification;

(6) Preparation of contract documents, tender programme; and

(7) Preparation of quality systems.

The client organisation will use the project's plan to monitor progress. Therein the use of planning techniques has be shown to benefit the control of the design process.

The contractor: the results of a well-planned, carefully monitored and controlled contract reflect directly in the profitability of the contract and the company. The contractor's planning efforts are divided between planning at the estimating stage and production planning.

There are a number of different Planning techniques and presentation protocols. For example, bar charts and linked bar charts; line of balance, for repetitive construction work; and network analysis, either activity-on-the-node (often referred to as precedence networks) or activity-on-the-arrow (also known as arrow diagrams); are the most common and widely used planning techniques. In addition other planning techniques include PERT, Project duration and critical path, Space-time diagrams and Last Planner (Harris and McCaffer, 2006; Ballard H.G., 2000).

According to Harris and McCaffer (2006) "*The act of checking actual progress and actual resource usage against planned progress and planned resource usage is the act of monitoring*". The act of taking decisions to alter the likely future outcome and bring the project back on the planned schedule is *control.*

The decisions relating to the rescheduling of activities, the reordering of activities, the altering of resources to change the duration of activities is *control.* Thus the planner must collect the information on the rate of progress to date and current resource usage in order to update the computer model and *monitor* progress. This information can be presented to the construction managers together with suggestions for rescheduling. The rescheduling decisions taken by the *managers* may need processing before the *control* decisions are implemented" (Harris and McCaffer, 2006; Ballard, 2000).

Planning: The well-developed plan allows all the efforts of *monitoring* and *control* to begin against a background of knowing how the costs were calculated in terms that were readily understood by site planners and construction managers (Harris and McCaffer, 2006; Ballard, 2000).

2.4.1.2 Cost

2.4.1.2.1 Cost Management and Control

Regardless of the scale of process from small subcontractor to the sophisticated supply chain and complex project, monitor and control of costs of production is essential, if the expected profit level is to be realised. Also, cost control is a clear objective of many managers.(Zimina, Ballard and Pasquire, 2012).

The elements in a cost control system are as follows: To Measure progress; To Calculate the budget allowance for that progress; To Compare the budget allowance with actual costs; and to Take corrective action. While, Observation; Comparison of observation with some desired standard; and to take corrective action if required Are the elements of any control system (Aliverdi, Naeni and Salehipour, 2012; Harris and McCaffer, 2006).

In the construction industry the following systems and variants of them are in use. The selection of a system depends in part on the complexity and size of the contract, but more on the complexity level of top management and attitudes.

According to (Harris and McCaffer, 2006) Systems in current use are:

(1) Unit costing;
(2) Overall profit or loss;
(3) Profit or loss on each contract of valuation date; and
(4) Systems based on the principles of standard costing.

Essentially, by comparing the output value with its producing cost, variances are calculated. A variance is the quantity by which the attained profit varies from the budgeted

profit. With suitable records, it is likely to analyse the total variance into sub-variances, for example (Harris and McCaffer, 2006).

1. Price of material,
2. Labour rate,
3. Fixed and variable overhead expenditure,
4. Sales,
5. Material usage,
6. Labour efficiency, and
7. Volume of production

Hybrid cost control system is used for Labour, plant and site overheads (by adopting a limited number of cost codes against which to generate variances); Allocation of costs; and Materials control (generally control of material variances is more difficult than control of anything else).

The factors that add to the difficulty of keeping exact and accurate control of material costs can be divided into (Harris and McCaffer, 2006; Tao, Wu, Luo, 2011):

(1) *Price variances* (i.e. Inflation; and Changes in the procurement situation since the estimation was ready, for example bulk buying, shortages and changes in quality required by the customer or obtainable and accessible at the time, discounts) and

(2) *Quantity variances* (i.e. Short deliveries, Wastage and breakages, Delays in the recording system, Theft and loss, Remedial work, and Inaccurate site measurement of work done)

Cost control of modernistic-type contracts: Modernistic-type contracts, such as design and build, managing agent, partnering, alliances, construction management, etc., Strongly feature management of the supply chain by a principal contractor. Subcontractors commonly embrace design services, labour, equipment, materials or combinations of all these elements. While prices are usually predetermined and included as fixed or nominal sums in the tender estimates, opportunity is subsequently usually available to re-establish prices that are more realistic after construction commences when drawings and specifications become finalised.

Importantly, subcontractors may sometimes also use plant, management and engineering services provided by the employing contractor which will need to be separately accounted for in the latter's cost data, including overheads (Harris and McCaffer, 2006; He and Yin, 2010 and Al-Jibouri, 2003).

Moreover, the main contract may involve open-book accounting, time and financial targets with incentivised rewards for the contractor(s), which will demand flexible budgetary planning and subsequent variance analysis. Each subsequent set of activities is formed into a work package, and subsequently networked together with the other subcontracts for cost evaluation purposes. The time update of the network provides the value of work done as a 'by-product' of the calculation, and the value can be divided further by cost code, provided that the work package information is similarly divided. Thus, when incurred payments to subcontractors are recorded against the same codes, variances can be calculated for management information in a similar manner to the variances demonstrated for materials control described under the hybrid system above. Thereby a valuation document is readily provided in a manner that reflects the operations intended to be performed (Harris and Mccaffer, 2006; He and Yin, 2010; Al-Jibouri, 2003).

Independently, individual subcontractors may control their own costs conventionally as appropriate, valued by a bill of quantities, etc., in relation to completed work (Harris and Mccaffer, 2006; He and Yin, 2010; Al-Jibouri, 2003).

2.4.1.3 Quality

2.4.1.3.1 Quality Management and Control

This section reviews various *concepts* associated with quality and then considers the contributions of quality control, quality assurance and total quality management to the quality of construction. It also addresses the growing use of quality management systems for achieving superior performance in construction. It highlights the fact that quality in construction can be achieved only through the direct effort of all stakeholders of the project.

The field of quality management has its roots in the work of Shewhart at Bell Labs and Western Electric. Shewhart used statistical methods to understand variation and was the first to distinguish between variation by chance and variation by cause. Applying his methods to reduce variation in the manufacturing process vastly improved product quality.

Since Shewhart, many additional quality tools have been developed, most of them rooted in statistics. From Statistical Process Control (SPC) to Quality Control to Quality Circles to Zero Defects to Total Quality Management (TQM) to Baldrige to ISO9000 to Continuous Process Improvement to Reengineering to Six Sigma to Lean Production and beyond, all approaches share a common thread first developed by Shewhart: use of data-driven, statistics-based tools to draw conclusions. The approaches to infrastructure and implementation, as well as the particular techniques, have differed, with mixed results. The fact remains that not only do all approaches share common tools, they also share a common goal — improving quality and productivity (Pheng, 2012).

Each successive approach recognizes the weaknesses of the previous one and seeks to improve upon it. This is exactly what we should expect; the profession that is dedicated to improving quality and productivity is simply following its own mantra of continuous improvement (Pheng, 2012).

There is the history of statistics and the quality movement highlighted several pioneers in laying the foundation for Six Sigma. In tribute to these individuals and others, we recognize them for their significant contributions by induction into the Quality Hall of Fame.

'Quality' now stands alongside *'price'* as a major factor of differentiation in contractor selection by the client as well as determining the efficiency of processes that the contractor adopts for site operations.

'Quality management (QM)': has to provide the environment within which the tools, techniques and procedures presented in the other chapters can be effectively deployed leading to operational success for the company (Harris and Mccaffer, 2006; Thawesaengskulthai and Natcha, 2007). Quality management (QM) is viewed as concepts, principles, or practices within which prescriptive views and empirical facts play roles in constructing and operating the industry to improve the performance (Alshehri, 2016).

Quality transition: The modern quality concept is considered to have developed through major transition phases over many years which are (Shammas-Toma, Clark, 1996):

(1) Quality control and inspection;

(2) Quality assurance;

(3) TQM;

(4) Quality management systems.

It is claimed that at least two of the mentioned criteria have to meet by successful

construction companies so that those companies stay successful. According to Harris and McCaffer (2006) "*The pursuit of total quality is seen as a never-ending journey of continuous improvement*" A brief description of (1) to (4) follows:

(1) Quality control and inspection

Quality defines the sum of attributes for a service or product that allows it to meet the customer requirements. The concept of quality goes hand-in-hand with *value-for-money* as perceived by client.

Control - The concept of being 'in control', or having something 'under control', means we know what we intend to happen and are confident that we can ensure (and have control) that it does. Quality control, however, is primarily concerned with defect detection. The main quality control techniques are inspections and statistical quality control techniques (i.e. sampling)".

Quality control is described by an interpretation of the elements of both 'Quality' and 'Control'. The process of checking what is produced compared to what is required, is called inspection which is the central feature to all quality control systems. Typically quality control is done on a sampling basis dictated by statistical methods. Acceptance sampling and Control charts are the main techniques in statistical quality control.

Quality control implemented in construction: Traditionally there are two sets of documents that are used to determine the required quality of a construction project. These are the Specifications and contract drawings.

In construction quality checks are undertaken as each operation or sub-operation is completed. The majority of quality checks are undertaken visually (Visual quality checks). Quantifable quality checks are also made during the construction stage (harris&mccaffer, 2006).

(2) Quality assurance

Quality assurance (QA) is described under the following headings:

(A) Evolution of QA from quality control;

(B) Definition of quality terms;

(C) QA standards;

(D) Developing and implementing a QA system; and

(E) QA in construction.

(A) Evolution of QA from quality control

"*Quality control* is essentially the activities and techniques employed to achieve and maintain the quality of a product, process or service. It involves a monitoring activity, but also concerns finding and eliminating causes of quality problems so that the requirements of the customer are continually met (Oakland, 1995), (Modern construction management, 2006)".

"*Quality assurance (QA)* is broadly the prevention of quality problems through planned and systematic activities (including documentation). These will include: the establishment of a good quality management system, the assessment of its adequacy, the audit of the operation of the system, and the review of the system itself".

(B) Definition of quality terms

The following Quality terms are obtained from ISO 8402:1994, Quality Management and quality assurance-vocabulary, which are:

(i) Conformity;

(ii) Design review;

(iii) Design verification;

(iv) Preventive actions;

(v) Quality;

(vi) Quality assurance;

(vii) Quality audits;

(viii) Quality control;

(ix) Quality management;

(x) Quality manual;

(xi) Quality planning;

(xii) Quality policy;

(xiii) Quality surveillance;
(xiv) Quality system; and
(xv) TQM (Total Quality Management).

(C) QA standards:

The ISO 9000 family of standards, quality assurance and the international standard for quality management are known as quality standards.

The guidance for selection, ISO 9000, is made up of four parts, which are as follows:

(a) ISO 9000 - Part 1 selection and use;
(b) ISO 9000 - Part 2 application guidelines;
(c) ISO 9000 - Part 3 software; and
(d) ISO 9000 - Part 4 dependability.

"*The ISO 9000 family of standards also has specific application documentation that provides the framework for external quality assurance in which the relationship between parties is essentially contractual.*"

These standards are classed as ISO 9001, ISO 9002 and ISO 9003. In addition, ISO 9004 provides supplementary guidance notes, which allow the principles of quality management to be applied to any organisation irrespective of the nature of the relationships between the parties involved in the process do production or service provision.

(D) Developing and implementing a QA system: The following four stages are common to the development and implementation of any quality assurance system:

(1) Establish awareness;
(2) Develop quality manuals;
(3) Introduce the systems; and
(4) Evaluate the system.

(E) QA in construction:

The construction process involves three parties; the client; the design consultants; and the contractors (Harris and McCaffer, 2006; Alshehri, 2016; Low, 2012; Ahato and Sylvia 2019; Lari et al., 2013 and Bassioni, 2004).

Quality assurance schemes have become a key element for the marketing of secondary materials produced from CDW recycling (Jose-Luis Gálvez-Martos et al., 2018).

3) Total Quality Management (TQM):

This section addresses TQM in construction under the following headings:

(*a) Definition of TQM and the role of QA in the process;*
(b) TQM principles;
(c) Development of TQM in a company; and
(d) TQM Tools and techniques.
(e) Definition of TQM and the role of QA in the process;

The TQM approach realizes that widespread involvement of those closest to the process is the key to improving the process. TQM has its roots in Japan's Total Quality Control, which originated as Company-Wide Quality Control in the 1950s. The construction industry has the problem of poor quality culture, because it is not truly customer focused and it does not see quality as an entire issue driven by satisfying customer need but as a sequence of procedures that deals with materials, site safety or design. TQM is a customer-focused approach to quality improvement that includes all aspects of the organisation. Hence for the modern construction organisation, all of the definitions of quality should be adopted and all of them have a role to play.

The diverse concepts of quality can be translated into a list of seven principal quality dimensions (Evans and William, 1993):

(i) Performance;
(ii) Reliability;
(iii) Conformance;
(iv) Durability;

(v) Serviceability;
(vi) Aesthetics; and
(vii) Perceived quality.

The methods of TQM are Taguchi methods; Failure mode and effects analysis; Statistical process control; and Just-in-Time (Low, 2012).

Total Quality Management (TQM), according to Ahaotu (2019) is a managerial approach that aims to achieve customer satisfaction and global competitiveness. Therefore, TQM is a systematic approach that views quality as the result of the integration of many organisational activities, i.e. engineering/construction, manufacturing, marketing and administration

b) TQM principles:

TQM principles require a commitment to quality*:* "*The successful implementation of TQM results in employees who are committed to quality by taking pride in their work; only then will the full benefits of TQM be realised.*"

They also require Quality chains*:* "*The people involved in operations that constitute a process therefore form a chain of responsibility, the success of each relying on the success of all of the previous. The concept of a quality chain provides an easily understandable concept to aid the adoption of TQM philosophy.*"

c) Development of TQM in a company:

Deming (1988) developed a list of points that can be used to aid the development of Total Quality. Oakland (1995) developed a pictorial multi-step programme for the development of Total Quality, which is suitable for training purposes."

d) TQM Tools and techniques:

In the development of TQM, the main tools and techniques which are used are as follows (Harris and McCaffer, 2006):

(1) Ways to gather and display data;
(2) Brainstorming;
(3) Matrix analysis;
(4) Paired comparisons;
(5) Ranking and rating;
(6) Pareto analysis;
(7) Cause and effect diagrams;
(8) Failure prevention analysis;
(9) Force field analysis; and
(10) Process flow chart

4 Quality management systems

A systems approach to managing qualit is required to ensure a more effective management for quality, construction companies need to tackle quality through a systems methodology. This will allow them to address the quality of the product or service at the more strategic organisation dimension.

Quality schemes include the *EFQM Excellence Model* (the European foundation for quality management), *Malcolm Baldrige Quality Performance* (The Malcolm Baldrige National Quality Award (MBNQA)) and *Six Sigma* (Harris and McCaffer, 2006; Lari, 2013; Bassioni, 2004).

APPENDIX B. SUPPLEMENTARY MATERIALS FOR CHAPTER 3, 4 AND 5

B.1 RESULTS AND ANALYSIS

Questionnaire

Introduction to the questionnaire

Exploring project planning practice, the measurement and control methods, and the use of Lean Construction by the UK's construction companies.

The construction projects are broadly understood as being unpredictable in terms of delivery within budget, on time and to the quality standards, which leads to low performances, such as cost and time overruns, low quality and inconsistent value generation.

Please write X beside your choice.

For the questions that you need to rank/rate, please can you rank/order from the most important (1) to the least important (5).

I have chosen the area of "Lean Construction" and the focus is on "Improvement of Construction Process" under the supervision of Professor Ian Jefferson.

The questionnaire survey is aimed at practitioners, Chief Planning Engineers, Construction Managers, Chief Executives, Managing Directors (Management Team, director/senior management), commercial managers, contracts managers, project managers, and quantity surveyors involved in managing the construction process.

The questionnaire is designed to explore the application of lean principles in your organisation based on your experience.

Please answer the following questions in order to investigate present system of project planning, controls and measurement methods in practice at UK site.

QUESTIONS

General Information/Questions

1. What is your company class?

- ☐ Contractor (principal)
- ☐ Contractor (sub-contractor)
- ☐ Other (e.g. client, consultancy, government agency etc.): Please specify

2. What is your main responsibility/position/Role?

3. Your years of experience?

- ☐ 0-3
- ☐ 4-10
- ☐ 11-20
- ☐ 21-40
- ☐ >40

4. Project types (e.g. building, bridge etc.)?

5. Total Turnover (£m)?

- ☐ <10
- ☐ 11-50
- ☐ 51-100
- ☐ 101-500
- ☐ 501-1000
- ☐ 1001-2000
- ☐ 2001-3000
- ☐ 3001-4000
- ☐ >4000
- ☐ Other: Please specify

6. Number of Live Contracts (on the books)?

- ☐ 1-10
- ☐ 11-50
- ☐ 51-100
- ☐ 101-150
- ☐ 151-200
- ☐ 201-250
- ☐ 251-300

☐ >300
☐ Other: Please specify

Planning and Time Control

7. Do you apply time controls to your project?

☐ Always
☐ Frequently
☐ Rarely/do not apply time control techniques during projects

Time Control Techniques and Software Applications

8. In terms of Planning and Time Control, which of the following control techniques being used by you? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

☐ Gantt Bar Chart
☐ Critical Path Method (CPM) (Critical Path Networks/Method)
☐ Milestone Date Programming Technique
☐ Program Evaluation and Review Technique (PERT)
☐ Precedence Network Diagram (PND)
☐ Elemental Trend Analysis/Line of Balance (LOB)
☐ Simulation
☐ Other techniques: critical space analysis (CSA), critical chain method (CCM), last planner (LPS) and 4D planning, Lean Project Delivery System (LPDS); Dependency structure matrix (DSM); Scheduling reciprocal processes; and Visualising the schedule
☐ Other: Please specify

9. What kind of planning techniques do you use for construction projects?

☐ Conventional/traditional time planning techniques (e.g. Critical Path Methods, Bar charts)
☐ Lean time planning techniques (e.g. Critical Chain Programming and Last Planner)
☐ Other: Please specify

10. For project planning, do you utilize computer programs/package?

☐ Yes
☐ No: please go to question 13

11. For the planning activity of the company, what is the degree of computer software utilization and/or how do you rank/assess and evaluate that?

- ☐ Fully integrated in all planning levels
- ☐ Not using, and all the planning process are prepared and complete by hand
- ☐ Other: (If it is integrated partly, please state the part(s) which require software program utilization), Please specify

12. Which of the following software applications/programs are you using for planning and scheduling of construction works? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

- ☐ Microsoft Project
- ☐ Primavera Project Planner
- ☐ Pertmaster
- ☐ Asta Power Project
- ☐ Project Commander
- ☐ Deltek Open Plan
- ☐ Other: Please specify if you are using any other software packages.

13. How do you assess the present methods of project planning?

- ☐ Out-of-date, lack of a number of important aspects, such as human factor
- ☐ Sufficient, and look at the whole aspects/parts of a project
- ☐ Require upgrading/development, additional aspects need to be analyze, such as human factor
- ☐ Other opinions: Please specify

Time Overruns

Please answer the following questions in order to identify the most common factors that often causes and lead to project time overruns and regarding the frequency of time overrun experienced.

14. which of the following are among the most common influencing factors that often lead to project time overruns? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

- ☐ Lack of project funding
- ☐ Poor contract management
- ☐ Financing and payment of completed works
- ☐ Changes in site conditions
- ☐ Shortage of materials
- ☐ Imported materials and plant items
- ☐ Design changes
- ☐ Subcontractors and nominated suppliers
- ☐ Poor labour productivity
- ☐ Inadequate planning
- ☐ Material shortages
- ☐ Inaccuracy of material estimate
- ☐ Skilled labour shortage
- ☐ Inclement weather
- ☐ Other: Please specify

Lean Time Planning Techniques

15. Are you aware of the Last Planner System, which is a control system?

- ☐ Yes
- ☐ No: Please go to question 19

16. Do you use The Last Planner System?

- ☐ Yes: Please go to question 17
- ☐ No: Please continue with Question 20

17. After the last planner system (LPS) was adopted, have you seen/had cost performance index (CPI) improvement?

- ☐ Yes (% improvement)
- ☐ No (% decrease)

18. Do you use percent plan complete (PPC) as a measurement?

- ☐ Yes
- ☐ No

19. If you are not using the Last Planner System, then have you considered using it?

- ☐ Yes
- ☐ No: Please specify what reasons convinced you **NOT** to use it?

20. How do you currently structure weekly work plans?

- ☐ Build it on the Master schedule and form/create additional information
- ☐ Obtain and pick out from the master schedule
- ☐ Totally form/construct a modern work plan
- ☐ Other: Please specify

21. In order to accommodate uncertainties in the last phases of work, which of the following is your preferred technique in the planning phase?

- ☐ Set up and begin the process early (fast and quickly)
- ☐ Use of time buffers
- ☐ Utilizing resource buffers
- ☐ Other measures: Please specify

Open ended Questions:

22. If you have been using the Last Planner System, can you please say what it was that resulted in its adoption by your company? (Has it had an impact? Has it been useful? Do you find this effective?)

Please specify

23. If you use the Last Planner System, I'd like to explore its effectiveness. How have you measured its effectiveness? And how do you know it's been effective?

- ☐ Very good/Excellent
- ☐ Good
- ☐ Fair
- ☐ Very poor /Poor
- ☐ Other: Please specify

24. Are there any shortcomings that you can tell about?

- ☐ Yes
- ☐ No
- ☐ Other: Please specify

Production Control in Construction

25. For production control/management in construction, which of the following is the common/present most important problem?

- ☐ Out-of-date methods for production management/control
- ☐ Type of construction projects
- ☐ Attitude of people
- ☐ Other opinions: Please specify

26. Which factors hampers the effective controlling of projects?

27. For production management/control in your firm, what is the extent of utilization of lean construction or The Last Planner System?

- ☐ Testing on a number of works
- ☐ Not using it
- ☐ Completely utilized
- ☐ At Training level
- ☐ Other: Please specify

28. Based on your experience so far, how do you assess/evaluate the impact on production management of implementing The Last Planner System?

- ☐ Excellent, Very good: control and management gets better/increase significantly all over and everywhere in production
- ☐ Good, Average, Fair: Improvement/development can be seen and is visible

☐ Not applicable/Not working/Not practical: Does not assist to advance production control/management
☐ Other: Please specify

Planning Reliability

29. What should be done in order to guarantee that the real work on site would follow the plan and conform to it?

☐ Rely on the quality of the subcontractor's work
☐ Arrange an expert project management group
☐ Other: Please specify

Cost Management of Construction Projects

Cost Control Practices

30. Do you apply cost controls to your project?

☐ Always
☐ Frequently
☐ Rarely/do not use cost control during projects

Cost Control Techniques

31. For project Cost Control, which of the following control methods/techniques being used by you? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

☐ Project cost–value reconciliation
☐ Overall profit and/or loss
☐ Profit and/or loss on each contract at valuation dates
☐ Unit costing and Earned value analysis–
☐ Labour/plant/material (actual versus forecast reconciliation)

- ☐ Standard costing
- ☐ Program Evaluation and Review Technique (PERT/COST)
- ☐ Leading parameter method
- ☐ The application of principles of Value Engineering
- ☐ Other: Please specify

32. For Cost Control, which of the following software packages being used by you? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

- ☐ Microsoft Project
- ☐ Asta Power Project
- ☐ Project Costing System (PCS)
- ☐ Construction Industry Software (COINS)
- ☐ WinQS
- ☐ Microsoft Excel
- ☐ bespoke/inhouse systems
- ☐ Primavera Sure Trak
- ☐ Other: Please specify

Cost Overruns

Please answer the following questions in order to identify the most common factors that often causes and lead to project cost overruns.

33. Which of the following are among the most common influencing factors that often lead to project cost overruns? Please can you rank/order from the most important to the least important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

- ☐ Poor contract management
- ☐ Financing and payment of completed works
- ☐ Changes in site conditions
- ☐ Materials shortage
- ☐ Imported materials and plant items
- ☐ Design changes
- ☐ Subcontractors and nominated suppliers
- ☐ Price fluctuation,

- ☐ Inaccurate estimates
- ☐ Delays
- ☐ Additional work
- ☐ Materials cost increased by inflation
- ☐ Inaccurate quantity take-off
- ☐ Lack of experience of project location
- ☐ Lack of experience of project type
- ☐ Delays in design information
- ☐ Long waiting time for approval of drawings
- ☐ Poor site management and supervision
- ☐ Mistakes and discrepancies in design documents
- ☐ Changes initiated by designers
- ☐ Client requirements
- ☐ Weather
- ☐ Site conditions
- ☐ Late deliveries
- ☐ Economic conditions
- ☐ Problems in planning and design as main causes of change orders
- ☐ Other: Please specify

Quality Management and Control

34. Which of the following steps do you consider while doing quality management and control?

- ☐ Quality control and inspection: Quality control implemented in construction: The Specifications and contract drawings, Visual quality checks and Quantifable quality checks
- ☐ Quality assurance
- ☐ Total quality management (TQM)
- ☐ Quality management systems
- ☐ Other: Please specify

Quality schemes include the *EFQM Excellence Model* (the European foundation for quality management), *Malcolm Baldrige Quality Performance* (The Malcolm Baldrige National Quality Award (MBNQA)) and *Six Sigma.*

35. Which of the following Quality Tools have been used by you in order to improving quality and productivity? Please can you rank/order from the most important to the least

important (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

- ☐ Use of statistical methods/statistical process control (SPC)
- ☐ Quality control
- ☐ Quality circles
- ☐ Zero defects
- ☐ Total quality management (TQM)
- ☐ Baldrige
- ☐ ISO9000
- ☐ Continuous Process Improvement
- ☐ Reengineering
- ☐ Six sigma
- ☐ Lean Production
- ☐ Quality Assignments
- ☐ Other: Please specify

36. Which of the following factors leading to the problem of reduced and low quality?

- ☐ Variations (Project characteristics, Characteristics of client, Project organization factors)
- ☐ Variables causing time overruns
- ☐ Variables causing cost overruns
- ☐ Errors or omissions in construction work
- ☐ Other: Please specify

Sustainability Management and Control

Please answer the following questions regarding sustainable measurement and control.

37. Please describe/explain how do you manage and control sustainability?

38. Please tick which of the following factors do you consider regarding the sustainability?

- ☐ Sustainable indicators and benchmark: Please explain

☐ Sustainable assessment: Please explain

Development of the Measurement and Control Methods

The adaptation of lean principles with identified enablers is assessed where a combination of different lean principles and techniques will be considered as the main enablers to develop a new framework of construction process.

Please answer the following questions regarding each of the Plan, Implementation, and Monitoring/Control functions.

39. For Construction Planning efforts, which of the following methods have been used by you in your company?

☐ Short term planning
☐ Long term planning
☐ CPM (Critical Path Method)
☐ CCM (Critical Chain Method)
☐ LPS (Last Planner System)
☐ Crew level
☐ Buffer
☐ JIT (Just in time)
☐ Other: Please specify

40. For the acts of Implementation, which of the following methods have been used by you in your company?

☐ Six Sigma
☐ BIM
☐ LSS (Lean Six Sigma)
☐ 5 Why Analysis

- ☐ Kanban (JIT: Just in time)
- ☐ KanBIM
- ☐ LPS (Last Planner System)
- ☐ Other: Please specify

41. For the efforts and acts of Monitoring/Control, which of the following methods have been used by you in your company?

- ☐ LPS (Last Planner System)
- ☐ Commitment Based Planning
- ☐ 5S
- ☐ TPS (Toyota Production System)
- ☐ Other: Please specify

42. How do you Review your construction process?

- ☐ PPC (Percent Plan Complete)
- ☐ Other methods: Please explain

43. Do you measure reason for failure of the project process?

- ☐ Yes
- ☐ No

44. Do you root-cause analysis?

- ☐ Yes
- ☐ No

45. At the operational level, do you measure cost performance?

- ☐ Yes

☐ No

46. In assigning tasks, is shielding essential and important?

☐ Yes
☐ No

Waste

Waste in Production Process

For total improvement in lean production, the basic procedure is to recognize waste in the process therefore removing it. Wastes in production process are regarding the waste of overproduction of goods not needed, waiting by employees for procedure, unnecessary motions, transporting (or conveyance), overprocessing (or inappropriate processing), unnecessary inventory, and defects in products.

47. Regarding the following issues and operations related to waste in Iranian site, please can you rank/order from the most important to the least important?

☐ Improper excavation
☐ Wrong or improper welding
☐ Pouring Concrete
☐ Cutting of reinforcement
☐ General Waste
☐ Other: Please specify

Waste and Value-loss

48. In the following, the waste and value-loss that found and discovered on site are explained. Identification can be an excellent pointer and guide for the possible impact of the Lean Construction Philosophy. Please can you rank/order from the most important to the least important?

- ☐ Weather Conditions (Rain, Snow, etc)
- ☐ Soil Condition
- ☐ Long Distance Equipment Displacement
- ☐ Ground Preparation
- ☐ Material Shortage or Deficiency
- ☐ Maintenance (repairs)
- ☐ Breakdown of equipment
- ☐ Material Handling
- ☐ Other: Please specify

Types of Waste

As shown in the following questions and based on the present literatures, a number of wastes in the construction process of the construction projects were recognized, which can be eliminated by using the proposed construction process. The following wastes are the results of the literature review done by the researchers. The purpose of this study is to elaborate on the construction waste.

49. From the most important to the least important, please can you rank/order the following types of waste which are mostly relevant to the activities during the construction phase? (Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4 and Extremely unimportant – 5).

- ☐ Transport
- ☐ Over-production
- ☐ Delays
- ☐ Unnecessary movements
- ☐ Over-processing
- ☐ Construction defects
- ☐ Excess inventory
- ☐ Poor contractor briefing
- ☐ Insufficient pre-construction meetings
- ☐ Lack of project definition
- ☐ Poor technical knowledge
- ☐ Poor specification
- ☐ Construction changes
- ☐ Insufficient and unrealistic constraints of project time
- ☐ Insufficient and unrealistic constraints of project cost
- ☐ Inadequate involvement of other professionals and teamwork during the construction stage
- ☐ Lack of constructability review of construction

- ☐ Poor communication between construction team
- ☐ Making construction decisions on cost and not value of work
- ☐ Poor level of commitment to quality improvement
- ☐ Effect of standards and construction code on quality
- ☐ Other: Please specify

50. Since adopting the Last Planner System, what impact have you seen on waste on site?

- ☐ Significantly less waste
- ☐ Less waste
- ☐ Neutral / No change
- ☐ More waste
- ☐ Significantly more waste

51. By development and adopting new construction control, measurement and performance methods, how do you assess/evaluate the impact on waste on site?

- ☐ Significantly less waste
- ☐ Less waste
- ☐ Neutral / No change
- ☐ More waste
- ☐ Significantly more waste

52. By adopting the new methods, which of the mentioned wastes in this questionnaire do you think will be eliminated from the construction process? Please also write a list of other wastes that would be eliminated or reduced as a result of adopting the new methods and give your idea regarding the impact on construction works?

53. For improving the reliability of planning, can you rate the significance of the following mentioned techniques? Please order/rank from the most important (5) to the least important (1).

- ☐ Improve project planner's abilities

- ☐ Improve/develop the quality of material
- ☐ Employ specialist teams
- ☐ Improve/develop the quality of labour
- ☐ Learn from previous works and projects
- ☐ Other: Please specify

Training (continuous learning and training)

54. If you use the Last Planner System, what sort of training has your staff undertaken?

- ☐ In-house training
- ☐ Attendance at external workshops courses
- ☐ Online training/courses
- ☐ Other: please specify

Inhibiting Factors & Mitigating Measures

This section is regarding identifying top inhibiting factors of the project control effort of construction projects practitioners.

Based on the following list of the most important/common identified inhibiting factors, please answer the following questions. The following is a list of identified project cost and time control inhibiting factors and classification.

55. Please rate the level of importance for each of the following factors in affecting your ability to effectively control the time of your construction projects. Please rank/order the factors using a Likert scale from the most important to the least important, as either for example: Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4; Extremely unimportant – 5

- ☐ Inflation of prices
- ☐ Fluctuation currency/exchange rate
- ☐ Unstable government policies
- ☐ Weak regulation and control
- ☐ Unpredictable weather conditions
- ☐ Dependency on imported materials
- ☐ Low skilled manpower

- ☐ Risk and uncertainty associated with projects
- ☐ Unstable interest rate
- ☐ Lack of proper training and experience of PM
- ☐ Use of inappropriate software
- ☐ Inaccurate evaluation of projects time/duration
- ☐ Non-performance of subcontractors and nominated suppliers
- ☐ Project fraud and corruption
- ☐ Design changes
- ☐ Financing and payment for completed works
- ☐ Complexity of works
- ☐ Discrepancies in contract documentation
- ☐ Contract and specification interpretation disagreement
- ☐ Conflict between project parties
- ☐ Other: please include/add and rate other factors that you think should be among the factors put forward to them.

56. Please rate the level of importance for each of the following factors in affecting your ability to effectively control the cost of your construction projects. Please rank/order the factors using a Likert scale from the most important to the least important, as either for example: Extremely important – 1; Important – 2; Neutral / No change – 3; Unimportant – 4; Extremely unimportant – 5

- ☐ Inflation of prices
- ☐ Fluctuation currency/exchange rate
- ☐ Unstable government policies
- ☐ Weak regulation and control
- ☐ Unpredictable weather conditions
- ☐ Dependency on imported materials
- ☐ Low skilled manpower
- ☐ Risk and uncertainty associated with projects
- ☐ Unstable interest rate
- ☐ Lack of proper training and experience of PM
- ☐ Use of inappropriate software
- ☐ Inaccurate evaluation of projects time/duration
- ☐ Non-performance of subcontractors and nominated suppliers
- ☐ Project fraud and corruption
- ☐ Design changes
- ☐ Financing and payment for completed works
- ☐ Complexity of works
- ☐ Discrepancies in contract documentation
- ☐ Contract and specification interpretation disagreement
- ☐ Conflict between project parties
- ☐ Other: please include/add and rate other factors that you think should be among the factors put forward to them.

57. Most researchers often mention that there are problems faced by construction projects which should be eliminated in order to achieve project targets of cost, time and quality.

The following is a list of the main problems and challenges which exist in the construction industry. From the most important to the least important, please can you rank/order the following problems that faced by construction industry? Please also include other main problems that exist and affect the construction industry.

- ☐ Low productivity
- ☐ Poor safety
- ☐ Inferior working conditions
- ☐ Insufficient quality
- ☐ The presence of foreign competition
- ☐ A decline in skilled labour
- ☐ Waste
- ☐ Variability
- ☐ Change
- ☐ Uncertainty
- ☐ Variation
- ☐ Constraints
- ☐ Complexity
- ☐ Time over-runs
- ☐ The process-related problems, waste, absence of clear indicators of quantitative parameters and a lack of documented studies
- ☐ One-of-a kind projects, multi-level organisational structure, site production
- ☐ Projects lack the organisation which promotes cohesive partnerships, coordination and communication between multi-disciplinary professions, flexible contractual agreements and a customer focused objective
- ☐ Transition of method problem
- ☐ Delay in project delivery
- ☐ Errors in construction
- ☐ Stagnant productivity
- ☐ Budget overrun
- ☐ Project delay
- ☐ Low performance
- ☐ Poor performance
- ☐ Other: please also specify and include other main problems that exist and affect the construction industry.

58. The following is the list of the significant barriers to the successful implementation of LC in the UK. Please can you rank/order from the most important to the least important.

- ☐ Lack of adequate lean awareness/understanding
- ☐ Lack of top management commitment
- ☐ Culture and human attitudinal issues
- ☐ Time and commercial pressure
- ☐ Fragmentation and subcontracting
- ☐ Procurement and contracts
- ☐ Educational issues
- ☐ Lack of process based PMSs
- ☐ Financial issues
- ☐ Design/Construction dichotomy
- ☐ Structural and cultural barriers
- ☐ Other: please specify

Earned Value Method

59. The earned value method (EVM) is considered an advanced project control technique that provides a quantitative measure of work performance. At the assignment level, do you measure earned value or cost performance?

- ☐ Yes
- ☐ No

60. Please complete the consent form below.

1. General Information/Questions

Your main responsibility/position/Role:

Your years of experience:

Project types:

Location:

I, _____, of (position) _____, authorise Mahsa Heidar Barghi PhD researcher of/at the University of Birmingham to use my answer for the purpose of her research.

Print Name_____

Sign_____

Date_____

2. Please choose whether or not if you want to receive the following:

I do/do not wish to receive a report with the results of both questionnaires and interviews at the end of the survey process.

3. Please note that you may wish to withdraw from the survey at any time during the research without any negative consequences by simply notifying the decision to the researcher within 28 calendar days after the submission of the questionnaire or the day of the interview.

61. Please answer this question regarding the consent form provided in question 60 above.

☐ I authorise Mahsa Heidar Barghi PhD researcher of/at the University of Birmingham to use my answer for the purpose of her research.

Thank you very much.

I really appreciate your help.

Kind regards

Mahsa Heidar Barghi

B.2 Future Works

Interview: After identifying most of the main and common inhibiting factors of project control in practice that often lead to project cost and time overruns, interviews will be carried out to develop mitigating measures to help project managers better control their projects.

Develop Mitigating Measures: A list of mitigating measures will be developed for the top leading inhibiting factors. These mitigating measures will be classified as:

A) Preventive;

B) Predictive;

C) Corrective,

D) Organizational and

E) Other.

B.3 Interview

1. Please describe the type, value and time frame of your project.

2. How do you plan and which department does the planning, which planning system do you use, and how do you plan and control your production?

3. Is the cost mainly considered? How do you manage cost? How do you arrange and controlling the budget?

4. what are the criteria in assigning tasks to team?

5. How do you evaluate and measure your production plan?

6. How do you estimate the durations (for an activity or for a whole project)? (for processes/activities)?

7. If you use PPC (the number of tasks completed/the number of tasks assigned x 100%), do you identify reasons for failure on non completed tasks?

8. How will the use of the LPS and development of new methods will change the performance?

9.At the assignment level, do you measure earned value or cost performance? If you use an earned value or cost measures, does it have impact on your decision-making process in issuing tasks to your team?

10. Once you're on site, can you talk about the process? And if it's the construction phase, what's more important, and how does the construction company manage the construction process? And please explain whether the existing methods are efficient?

11. Proportion of projects that encounter time and cost overruns?

12. Do you believe that the site facilities have an impact on working conditions? And then its affect on the productivity?

13. Do you encounter issues with late access to the site?

14. During the construction phase, how do you plan?

15. How much waste and what waste do you encounter on your projects?

16. How are these managed during planning, construction and post construction?

17. How do you think this could be improved?

18. How easily do people in building industry comply/conform with new tools and technology?

19. Is planning and design, successful in terms of estimating the overall cost, execution time and quality of the construction project?

20. Are there any possibilities for improvement? Can lean construction contribute to that?

21. Do you consider Safety while doing a construction process? and please explain how do you avoid and eliminate risk and uncertainties and therefore increase safety while doing a construction work?

22. What are the critical success factors associated with time and cost as individual concepts of different project types and geographical regions?

Thank you very much.

I really appreciate your help.

B.4 Covering letter

Dear Sir or Madam: (respondent's name)

I am studying for a PhD in Civil Engineering at the University of Birmingham. I'm writing to ask for your help in completing a questionnaire survey on the area of "Lean Construction". I appreciate your help in this really important topic.

It would be highly appreciated if you could complete the online/attached questionnaire based on your experience/knowledge. Additionally, you may send the completed questionnaire to the email address below.

If you feel that a colleague may be better placed to complete the questionnaire, can I please ask you to pass it on.

Your participation and the information supplied will be treated as private and confidential. Summary of research findings will be available on request. If you have any questions regarding the questionnaire or the research, you may contact:

Please return the questionnaire to me at the latest by the end of June 2018, to help ensure completion of the analysis of the data and the report in time for submission.

Kind regards

Mahsa Heidar Barghi
PhD Civil Engineering
School of Civil Engineering
University of Birmingham
United Kingdom
Email:

B.5 Participant information sheet

Introduction to the questionnaire

Exploring project planning practice, the measurement and control methods, and the use of Lean Construction by the construction companies.

The construction projects are broadly understood as being unpredictable in terms of delivery within budget, on time and to the quality standards, which leads to low performances, such as cost and time overruns, low quality and inconsistent value generation.

Please write X beside your choice.

For the questions that you need to rank/rate, please can you rank/order from the most important (5) to the least important (1).

I have chosen the area of "Lean Construction" and the focus is on "Improvement of Construction Process" under the supervision of Professor Ian Jefferson.

The questionnaire survey is aimed at practitioners, Chief Planning Engineers, Construction Managers, Chief Executives, Managing Directors (Management Team, director/senior management), commercial managers, contracts managers, project managers, and quantity surveyors involved in managing the construction process. The questionnaire is designed to explore the application of lean principles in your organisation based on your experience.

Please answer the following questions in order to investigate present system of project planning, controls and measurement methods in practice at site.

Introduction to the interview

Exploring project planning practice, the measurement and control methods, and the use of Lean Construction by the construction companies.

The construction projects are broadly understood as being unpredictable in terms of delivery within budget, on time and to the quality standards, which leads to low performances, such as cost and time overruns, low quality and inconsistent value generation.

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surveyors involved in managing the construction process. The interview is designed to explore the application of lean principles in your organisation based on your experience.

Please answer the following questions in order to investigate present system of project planning, controls and measurement methods in practice at site.

B.6 Consent form

1. General Information/Questions

Your main responsibility/position/Role:

Your years of experience:

Project types:

Location:

I, _____, of (position) _____, authorise Mahsa Heidar Barghi PhD researcher of/at the University of Birmingham to use my answer for the purpose of her research.

Print Name_____

Sign_____

Date_____

2. Please choose whether or not if you want to receive the following:

I do/do not wish to receive a report with the results of both questionnaires and interviews at the end of the survey process.

3. Please note that you may wish to withdraw from the survey at any time during the research without any negative consequences by simply notifying the decision to the researcher within 28 calendar days after the submission of the questionnaire or the day of the interview.

B.7

CONSTRUCTION THE THIRD WAY (JOHN BENNETT)

Japanese control systems

The detailed planning that results in reliable quality in Japanese construction also ensures that projects always finish on time. This is possible partly because the programmes prepared at head office before work on site begins have slack built into them in various ways. When problems arise the slack is used to bring the work back onto programme. Thus, work is programmed on the basis of five normal working days each week; if necessary, work continues late into the night, seven days a week.

Each month's work is planned as four-week stages which leaves a few days each month to ensure that everything is exactly on target. When a problem is serious, a second shift may be worked; this may involve introducing a second subcontractor or, in an extreme case, a third. The aim is to keep the project exactly on programme or, when this proves impossible, to return it to the original programme as quickly as possible. The building must be completed exactly on the agreed date. It would be a matter of extreme dishonour and a great commercial embarrassment to any major contractor to complete a building even one day late; they would lose face and lose business. So everyone involved concentrates on doing whatever is necessary to complete all the required work exactly on time.

The importance of sticking to the plan is reinforced by the daily pattern of work.

As a result, an important feature of the Japanese construction industry is that it s possible to describe a typical day on site because procedures are standardized throughout Japan. The working day begins with the whole site workforce lined up in subcontractor teams. Then the workforce is briefed on the planned day's work by the project manager. The briefing describes the main processes, major deliveries, safety priorities, quality issues and any other points which need special attention. Having prepared for the day's work, the subcontractor teams move to their workplace where each team holds what is called a toolbox meeting. This decides exactly how the team will achieve their agreed day's work. As a result, when work

begins each worker knows exactly what he or she is to do during the day and where it fits into the overall plan. Each team continues its work until they have finished the agreed day's tasks.

B.8

SPSS PERFORMANCE IMPROVEMENT BY MAHSA HEIDAR BARGHI

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Kendall's W Test

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Descriptives

Round 3 of Delphi Questionnaire: Re-evaluating Weighted KPIs

SPSS Round 3 Final KPIs Results

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Descriptives

ROUND 4

NPar Tests

Kendall's W Test

Descriptives

APPENDIX C. SUPPLEMENTARY MATERIALS FOR CHAPTER 3

C.1

3.1 Data analysis and documentation

Based on literature review and according to the analysis of a study by Olawale and sun (2010), the following 20 factors were identified as the most common factors that often lead to project cost and time overruns, as shown in Table 3.1.

Table 3.1 Identified Project cost and time control inhibiting factors and classification (after Olawale & Sun 2010)

Factors
1) Inflation of prices
2) Fluctuation of currency/exchange rate
3) Unstable government policies
4) Weak regulation and control
5) Unpredictable weather conditions
6) Dependency on imported materials
7) Low skilled manpower
8) Risk and uncertainty associated with projects
9) Unstable interest rate
10) Lack of proper training and experience of Project Management (PM)
11) Lack of appropriate software
12) Inaccurate evaluation of projects time/duration
13) Non-performance of subcontractors and nominated suppliers
14) Project fraud and corruption
15) Design changes
16) Financing and payment for completed works
17) Complexity of works
18) Discrepancies in contract documentation
19) Contract and specification interpretation disagreement
20) Conflict between project parties

3.2 Expected outcomes

Expected outcomes of research are as follows: (1) In order to validate the Framework model development, external and internal validation and case studies were carried out. (2) Innovative features of the research are integration and combination of different techniques in my model development; and in RIBA. (3) Gap: In RIBA's Construction stage, there is a lack of lean principles; And in RIBA Plan of Work, there is a lack of lean principles, and sustainability principles in the construction stage.

Therefore, Time-Cost-Quality- and Sustainability measurement and control will be conducted in RIBA.

3.3 Significance / Benefits

The concept of lean construction has been introduced into the construction industry from manufacturing industry, which aims to increase value of the projects for customers and to eliminate construction wastes in order to achieve project targets of cost, time and quality, while reducing damage to environment (sustainable development). However, although some of lean construction techniques have been developed, there are still many of problems to apply these techniques in construction practices. The major reason for this may be due to lack of the implementation framework/guidelines/effective methodology, and control measures. This study will investigate lean construction techniques currently used in the industry and the principles of lean construction applications, particularly, the problems by using lean construction techniques regarding project planning, construction waste management, project changes, risk and uncertainty management etc. On the basis of findings from this research project, a new framework modelling and guidelines for the implementation of lean construction in construction industry will be developed and case study materials will be collected from the industry to test and validate the new development. The results produced from this research will provide useful information and guidance to the construction industry.

3.4 Summary of Project

Framework modelling by incorporating RIBA Plan has been developed. Control and measurement models of cost, time, quality and sustainability have been developed, which has completed after case study materials collected from industry.

Case study materials from the industry, was used to test the measurement models. These include LC implementation models for construction projects; Recent Implementation methods, tools techniques and models; Pilot studies to capture the LC initiatives in developed and developing countries; and, Conducting and evaluating the case study to validate the application and implementation of developed models.

The Data collection by questionnaire and interview survey, contacting selected respondents, observation and documentary analysis etc. was carried out to evaluate the proposed framework modelling. Measurement models of cost, time, quality and sustainability were undertaking.

The analysis of data was carried. Finally, the proposed framework modelling and the results of the data were discussed and evaluated.

The proposed control and measurement models were implemented in order to improve cost and time performance of construction projects.

External and Internal Validation and Case studies were carried out for validation.

APPENDIX D. SUPPLEMENTARY MATERIALS FOR CHAPTERS 4 AND 5

D.1

The goals/objectives of Value Engineering (VE) frequently come along with programs of cost reduction. This occurs once the manufactured goods/product has been completed and prepared in its initially considered shape, design variations.

Reaching successful Implementation (Approve and Move phase): enhancement in value or monetary saving can only be made following successful implementation of the program. A shift in the present managing methods is required, breaking the current norms. Team working and different stakeholders and skills. Some countries require Government support all through legislation. Shift in concept and idea, which is possible through shift and change in culture.

Improvement and innovation (new methods): The achievement and success of VE is directly joined/attached to communications (verbal and nonverbal), people and leadership skills. Improvement in techniques, replacement of materials, or changes in tolerance. Training is important. Value engineers must be trained. One of the important methods of value analysis is creativity or creative alternatives. Technology is adjusted toward the development of construction equipment, materials or methods. As some materials and resources might have a longer life at lower preservation cost, this result in a long-term life cycle saving. VE works best, if it starts early and Behavior/Manner/Habit change, as part of this is harder for people to accept. VE increase value but should not be considered as cost cutting, although it is about getting more for Less. Therein Countries require support of Government as VE is a demanding method to decrease life cycle costs and therefore is not easy. The difficulty concerned is in placing VE into exercise. Building projects are complex. Use of VE in the construction industry leads to the value improvement of the final product. The profits of VE enhance with work complexity. Every project contains risks. Health and safety is very important and should always be considered in every construction projects. VE is not essentially about cutting the cost. Considerable cost savings are achievable if only value engineering used to produce and create the maximum value in the design and planning phase, which are the first stages of the construction work. Results and consequences of applying VE correctly: lesser costs, improved quality, design times shortened, easier construction.

VE Recommendations: Modular / prefabrication construction: Benefits / Advantages: Cost effective, economical benefits and savings, on site troubles decrease. Value benefits: Speed (which results in cost savings such as decrease in usage of plant and groundwork and site troubles and in advance selling or letting, cash flow enhanced, quicker return on money), prearrange of work stages and phases, reduction in consultation and evaluation, quality improvement.

According to Mohd Arif Marhani et al. (2013), it was shown that there is a need for more holistic approaches to integrate LC key concepts with other significant aspects, such as health and safety, six sigma and EMS. From the literature review, it was discovered that by introducing health and safety and six sigma assessment to a construction project will facilitate the construction company in managing and assuring their health and safety risks, dealing with qualities and strategies, thus improving their performance. In addition, by incorporating EMS to the key concepts of LC, it would maximize the customer's satisfaction as well as minimising construction waste. The contractors should use "correct tool at the correct time" as most of the key concepts are interconnected between each others. To date, research conducted on standard procedure of LC key concepts is scarce; hence there is a need for a research to be conducted on this potential area. Furthermore, the potentials of integration of health and safety, six sigma and EMS to the key concepts of LC are remain unexplored.

D.2

The key to the project plan is a *work breakdown structure*. The planner must be able to provide a clear and accurate statement of the scope of work. A work breakdown structure (WBS) provides a rational subdivision of the work in hierarchical form down to the lowest level of discrete work packages from which estimates of resource requirements, durations, linkages and costs can be determined.

A WBS can provide the basis for a coding system by which any work package (activity) or any subgroup of activities can be identified. From the WBS a list of activities and precursor activities can be produced for the purposes of network analysis, from which programmes, resource charts and cost plans all flow.

A WBS provides a useful means of estimating the cost of a project. Estimates of costs are entered at the lowest level and 'rolled up' to successive levels. Once work is in progress the actual costs are entered at the lowest levels and rolled up to the higher levels. In presentational terms this works very well.

A work breakdown structure (WBS) provides a logical subdivision of the work from which programmes, resource charts and cost plans can be developed and presented at appropriate levels of operation. A primary function of a WBS is to identify the work packages; from the durations, resources and costs of each work package the programme, resource charts and cost curves for the whole project will be developed.

All unforeseen occurrences such as breakdowns, rejects, breakages, accidents, power cuts and materials shortages, affect the operation of the production plan.

One of the biggest advantages of preparing production plans is that the information is available to calculate the effect of disruptions and to rearrange the plan to reduce these effects to the minimum. Without the kind of information needed to produce the plan, it is virtually impossible to manage any form of production activity efficiently. It is, of course, still necessary to see that the plan is converted into a framework for day-to-day working, and this is done in the programming stage.

D.3

Project Monitoring and Control: The project manager must Measure performance; Control change; Minimize delays; Minimize extra costs; and Control and coordinate suppliers/ contractors.

All the companies that do not operate effective production control procedures will find frustration, boredom, long delays, poor quality, untidiness, and a bad accident record.

According to reference practical cost reduction, production control is not a technique: it is an attitude of mind towards the efficient organization of men, machines, and materials with the objective of producing a product of the right quality in the shortest time at the least cost.

Production control can be examined in four main sections: Planning; Programming; Scheduling; and Control.

All these stages are concerned with ensuring that the production activity continues efficiently on a day-to-day basis.

Project Control and Organisation: An important necessity for achieving the project objective is developing a timely realistic, and useful master project plan that incorporates the project's scope, cost, dependent activities, resource requirements, and resource availability.

Project control provides the information that is necessary for reporting on the project status both internally and to the owner. The principle project controls are estimating, scheduling, cost and change control.

Control is necessary at all interfaces between the project team and the owner, and between the project and its external environment.

The following criteria are most commonly used to measure a project's success: Client satisfaction; Performance to specifications in terms of output and quality; Budget performance; Schedule performance; Contractor and project team satisfaction.

Characteristics of successful projects are associated with the good management of planning, goal commitment, team motivation, technical competence, scope ad work definition and project control systems.

Poor project execution is associated with an unrealistic project plan, client/management changes, insufficient front end planning, and underestimating the project scope.

D.4

4.1 Control, Measurement and Performance Development of Construction Framework

4.1.1 Cost

Cost control should be carried out throughout the life cycle of the project. Control is fundamental to project management, of costs, design, specification, materials, timing etc.

Cost control is simply the prevention of waste within the existing environment. Cost reduction is the improvement of the environment. To reduce costs or rather the consumption of resources requires a constant appraisal of the whole company and not just production processes. Cost reduction should be a continuing process of improving productivity within the organization. Such a service should be provided in every organization.

Production control and costing: A cost is the financial value of a resource consumed. If we wish to record costs, there are two distinct types of data that we require:

1. Quantities of resources consumed
2. Resource values

The quantities of resources consumed have to be produced by the production control system. It is part of the feedback that provides three main items: man hours worked, materials used, machine operating hours.

To *control* cost is an obvious objective of most managers. The elements of any control system are:

- Observation;
- Comparison of observation with some desired standard;
- Corrective action to take if necessary.

A cost control system should enable a manager to observe current cost levels, compare them with a standard plan or norm, and institute corrective action to keep cost within acceptable bounds. The system should help to identify where corrective action is necessary and to provide pointers as to what that action should be.

The following systems and variants of them are in use in the construction industry. The selection of a system depends in part on the size and complexity of the contract, but more on the attitudes and level of sophistication of top management.

- By overall profit or loss
- Profit or loss on each contract at valuation dates
- Unit costing
- Systems based on the principles of standard costing
- PERT/cost

4.1.2 Quality

There are two essential ingredients for the achievement of quality standards: people and systems. While formal quality systems in construction can never in themselves fully compensate for the shortcomings of people, they can assist them in raising their performance to the standards required.

Quality Assurance (QA) is a combination of two elements, quality plan and Quality Control (QC), to achieve an agreed quality objective. Quality Management (QM) requires the vital third element – improvement, ie learning from (expensively) acquired experience.

QA is needed to demonstrate that adequate systems and procedures are in place to ensure effective control of the project. QM is needed to ensure continuous improvement in the standards of products and services.

QC is required to build quality into the design, planning and execution of all stages of the project to ensure safe design, safe construction and safe plant operation. If short-cuts are taken in the areas of QC and QA, disastrous consequences may result, eg lengthy delays and associated high costs due to late delivery of wrong materials, design errors, defective construction or subsequent failure of the project, any of which may result in serious injury to personnel and even destruction of the project.

The implementation of QA and QM procedures in no way diminishes the responsibility of suppliers and contractors to achieve quality. The emphasis of the approach is on eliminating errors and deficiencies by better quality planning, training and organisation, rather than by inspecting to find faulty products. The clarification of the responsibilities of the various parties involved is a key benefit of this approach.

Quality Management: is a systematic way of guaranteeing that organised activities happen as they were planned. It is a management discipline concerned with preventing problems from occurring which, by changing attitudes and providing controls, make error prevention possible. The foundation and spearhead for *improvement* by prevention is the quality management system driven by management at all levels.

Quality Control: uses of statistical methods to understand variation and to distinguish between variation by chance and variation by cause.

Many additional quality tools have been developed, most of them rooted in statistics.

Quality Tools: These include Statistical Process Control (SPC), Quality Control, Quality Circles, Zero Defects, Total Quality Management (TQM), Baldrige, ISO9000, Continuous Process Improvement, Reengineering, Six Sigma, Lean Production. Recent quality management approaches: TQM, MBNQA. Quality Assignments: Cost and Time decrease/reduce.

4.2 Measurement Development

According to a study by Olawale, and Sun, (2014), regarding construction project control in the UK, which aimed to address the main deficiencies with the prevailing project cost and time control practices for construction projects, a list of good practice recommendations has been developed for the key project control tasks of planning, monitoring, reporting and analysing. Then, in order to evaluate the recommendations regarding improvement and to establish their degree of relevance, the Delphi method was used. After two rounds of Delphi, the recommendations are put forward as “critical”, “important”, or “helpful” measures for improving project control practice.

PCIM: Project Control and Inhibiting-Factors Management Model: According to a study, by Olawale, and Sun, (2013), the project control and inhibiting factors management (PCIM) model, is a new project cost and time control model, developed through a study involving extensive interaction with construction practitioners in the UK, which better reflects the real needs of project managers. A set of good practice checklist is also developed to facilitate implementation of the model.

Management Thinking in the Earned Value Method System and the Last Planner System: Management theory has been neglected in the construction industry, which has rather focused on best practices. The study by Kim, and Ballard, (2010), investigates the theories implicit in two prevalent project control systems: the earned value method (EVM) and the last planner system (LPS). The study introduces two fundamental and competing conceptualizations of management: managing by means (MBM) and managing by results (MBR). The EVM is found to be based on MBR. However, project control based on MBR is argued to be inappropriate for managing at the operational level where tasks are highly interdependent. The LPS is found to be based on the MBM view. The empirical evidence from literature and case study suggested that the MBM view is more appropriate to manage works when it is applied to the operation level where each task is highly interdependent.

Monitoring project duration and cost in a construction project by applying statistical quality control charts: The earned value is a leading technique in monitoring and analyzing project performance and project progress. Although, it allows exact measurement of project progress, and can uncover any time and cost deviations from the plan, its capability in reporting accepted level of deviation is not well studied. This study by Aliverdi, Naeni, and Salehipour, (2012), presented an approach to overcome this limitation by applying statistical quality control charts to monitor earned value indices.

Customer Earned Value: Performance Indicator from Flow and Value Generation View: The earned value method (EVM) is considered an advanced project control technique that provides a quantitative measure of work performance. However, the EVM is effective only under the assumption that every activity is independent. Literature shows that the EVM lacks the value generation view even working against the reliability of workflow. The goal of this research by Kim. Kim. and Cho (2016), is to propose a project metric system to supplement the EVM in terms of the workflow and value generation. The researchers suggest a new metric of customer earned value (CEV), which is defined as the budgeted amount of work completed and is used by the successors on a network. Through a hypothetical case study, this research investigates how the work-in-process between trades and schedule performance in each trade behave under different uncertainties. The result suggests that the proposed metrics can provide project managers with more relevant managerial information on project

progress as well as on the level of collaboration. The proposed system with the EVM would facilitate collaboration on project planning and control where variability and interdependency are involved.

Schedule and Cost Control in Dwelling Construction Using Control Charts: Methods to monitor the schedule and to control cost in dwelling construction projects are numerous and varied but commonly constitute an obstacle to a fast and agile response by construction managers, whose decisions require information to be comprehensive and summarized. A simple model to monitor these projects is proposed by Marrero et al. (2014), that can easily be implemented within control systems that are already in place. For the first time, process control charts are combined with cost control in dwelling construction in order to prevent overruns in terms of time and/or cost. The model facilitates the production supervision of construction contracts by regularly providing information on the work completed and the incurred cost of the production processes per period, through charting and/or summarizing this information in a manner consistent with statistical control charts. Finally, the manager can easily identify those processes which are off target by consulting control charts.

D.5

Chapter 5

5.1 Waste and Value-loss

In the past two decades, levels of waste in the construction industry have been identified as significant (Formoso et al., 1999). Moreover waste has been regarded as a key problem of construction that needs to be solved (Polat and Ballard, 2004). Since this time the drive to improve performance in the manufacturing industry by means of increasing productivity (Polat and Ballard, 2004; Lee et al., 1999) has seen the elimination of different types of waste in the process of production - as a direct consequence of implementing the Lean Production (Polat and Ballard 2004). On the other hand, Lee et al. (1999) suggested that traditional construction management practices frequently did not succeed in both recognizing and addressing waste production in the process of construction. This is related to the lack of management tools and techniques to determine waste and value. In light of these realities, the philosophy of lean construction has been shown to be an efficient approach in improving productivity through elimination of non-value adding activities, such as waste (Koskela 1992, Koskela 2000).

5.2 Performance Development

These improvements are a direct result of the observations of Sir Michael Latham in *Constructing the Team* (Latham, 1994), a report commissioned by government because of pressure from major clients to the construction industry.

Both Sir Michael Latham and later Sir John Egan in *Rethinking Construction* (Egan, 1998) concluded that a key factor in improving performance within the construction industry was through client (that is, ‘purchaser’) involvement. Egan proposed that, under committed leadership by the client, the industry should focus on the customer and that the process of procurement and the team of designers, suppliers and contractors should be integrated around the product. Major clients of the industry in partnership with leading consulting engineers, architects and contractors have adopted Egan’s best-practice proposals and committed

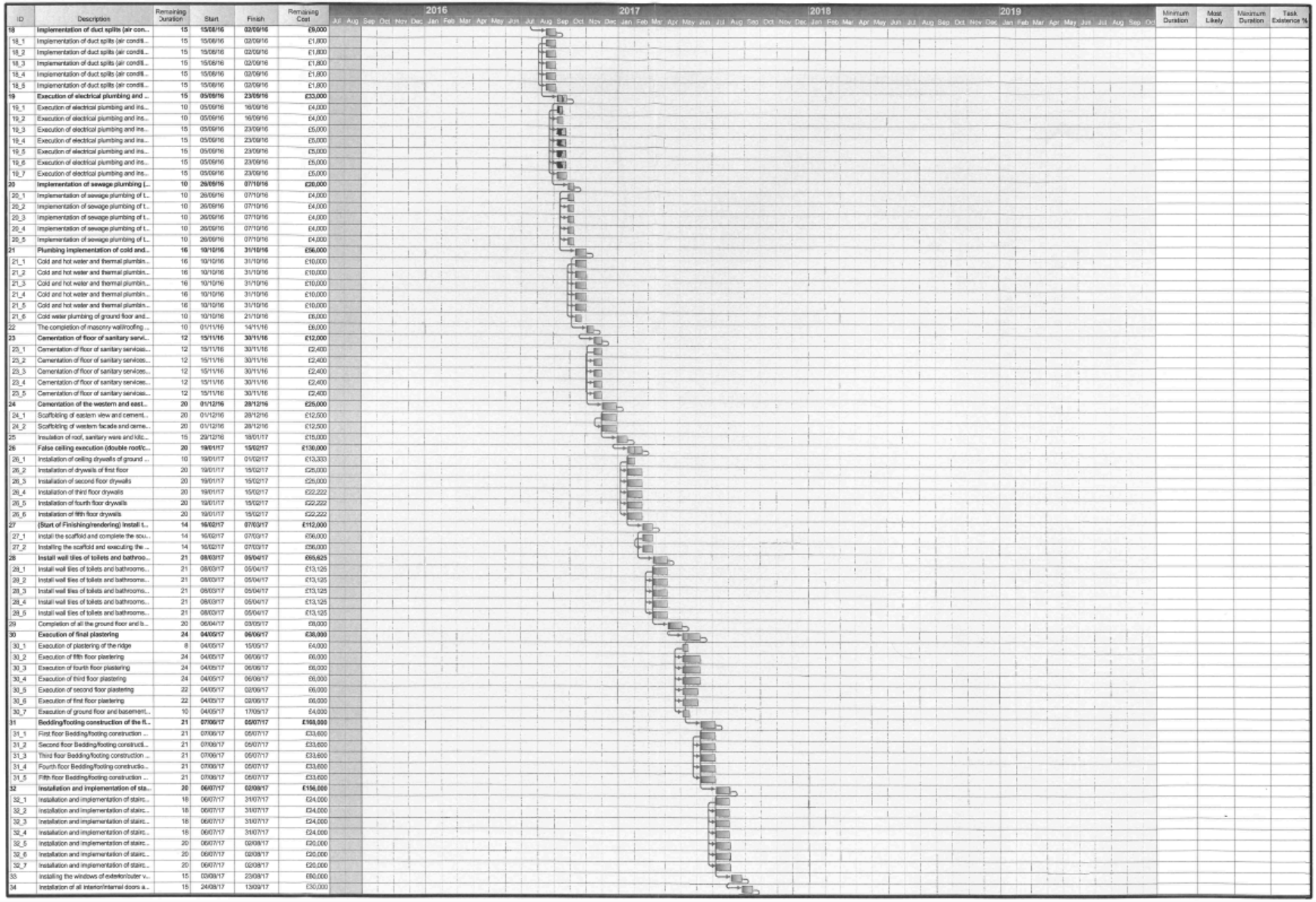
themselves to a series of projects to demonstrate, through published feedback on costs, time and productivity, the efficacy of these measures.

The experience underlying Latham and Egan was largely derived from the building industry rather than civil engineering. In civil engineering where large-scale excavation and earthmoving operations are common, where fitting in with the surrounding topography requires engineering decisions as the work proceeds, where the quantities of materials such as concrete and steel can be very large and where implementation of the actual design has its own safety issues, there is a strong case for empowering the A/E/PM to issue instructions, change quantities, approve working operations and even, if necessary, to suspend the works. In these circumstances the authority provided to the engineer under an ICE7 type of contract should be preferable to self-certification. Construction is a dangerous business. The construction industry can be considered as one of the largest and likely most important industries in the world.

PLAN OF PROJECT 1

Gantt Chart

ID	Description	Remaining Duration	Start	Finish	Remaining Cost	Minimum Duration	Most Likely	Maximum Duration	Task Existence %
0	Start	0	02/09/15	01/09/15	£0				
1	**Site mobilisation**	**7**	**02/09/15**	**10/09/15**	**£3,000**				
1_1	Security room installation	1	02/09/15	02/09/15	£3,000				
1_2	Contact with gas, water and electricity of...	6	03/09/15	10/09/15	£0				
2	**Excavation and excavation stabilisati...**	**7**	**11/09/15**	**21/09/15**	**£37,000**				
2_1	Surveying	1	11/09/15	11/09/15	£1,000				
2_2	Excavation by loader and power shovel	5	14/09/15	18/09/15	£19,000				
2_3	Construction and installation of eastern ...	1	21/09/15	21/09/15	£17,000				
3	**Foundation implementation**	**15**	**11/09/15**	**01/10/15**	**£93,000**				
3_1	Floor levelling and alignment of foundati...	2	11/09/15	14/09/15	£2,000				
3_2	Shuttering of foundation	4	15/09/15	18/09/15	£10,000				
3_3	Reinforcement of the foundation and ins...	7	21/09/15	29/09/15	£62,000				
3_4	Obtaining permission from an observer/...	2	30/09/15	01/10/15	£19,000				
4	**Implementation/run of the basement ...**	**15**	**02/10/15**	**22/10/15**	**£42,000**				
4_1	The implementation of basement colum...	4	02/10/15	07/10/15	£10,000				
4_2	The implementation of basement shear ...	3	08/10/15	12/10/15	£7,000				
4_3	Full implementation of the basement ro...	7	13/10/15	21/10/15	£20,000				
4_4	Obtaining permission from an observer/...	1	22/10/15	22/10/15	£5,000				
5	**Implementation of the roof of the gro...**	**15**	**23/10/15**	**12/11/15**	**£42,000**				
5_1	The implementation of the ground floor ...	4	23/10/15	28/10/15	£10,000				
5_2	The implementation of the ground floor ...	3	29/10/15	02/11/15	£7,000				
5_3	Full implementation of the ground floor r...	7	03/11/15	11/11/15	£20,000				
5_4	Obtaining permission from an observer/...	1	12/11/15	12/11/15	£5,000				
6	**Implementation of the roof of the first...**	**15**	**13/11/15**	**03/12/15**	**£42,000**				
6_1	The implementation of the first floor pilla...	4	13/11/15	18/11/15	£10,000				
6_2	The implementation of the first floor she...	3	19/11/15	23/11/15	£7,000				
6_3	Full implementation of the first floor roof...	7	24/11/15	02/12/15	£20,000				
6_4	Obtaining permission from an observer/...	1	03/12/15	03/12/15	£5,000				
7	**Implementation of the roof of the sec...**	**15**	**04/12/15**	**29/12/15**	**£42,000**				
7_1	The implementation of the second floor ...	5	04/12/15	10/12/15	£10,000				
7_2	The implementation of the second floor ...	3	11/12/15	15/12/15	£7,000				
7_3	Full implementation of the second floor r...	9	16/12/15	28/12/15	£20,000				
7_4	Obtaining permission from an observer/...	1	29/12/15	29/12/15	£5,000				
8	**Implementation of the roof of the thir...**	**18**	**30/12/15**	**22/01/16**	**£42,000**				
8_1	The implementation of the third floor pill...	5	30/12/15	05/01/16	£10,000				
8_2	The implementation of the third floor sh...	3	06/01/16	08/01/16	£7,000				
8_3	Full implementation of the third floor roo...	9	11/01/16	21/01/16	£20,000				
8_4	Obtaining permission from an observer/...	1	22/01/16	22/01/16	£5,000				
9	**Implementation of the roof of the four...**	**18**	**25/01/16**	**17/02/16**	**£42,000**				
9_1	The implementation of the fourth floor pi...	5	25/01/16	29/01/16	£10,000				
9_2	The implementation of the fourth floor s...	3	01/02/16	03/02/16	£7,000				
9_3	Full implementation of the fourth floor ro...	9	04/02/16	16/02/16	£20,000				
9_4	Obtaining permission from an observer/...	1	17/02/16	17/02/16	£5,000				
10	**Implementation of the roof of the fifth...**	**18**	**18/02/16**	**14/03/16**	**£42,000**				
10_1	The implementation of the fifth floor pilla...	5	18/02/16	24/02/16	£10,000				
10_2	The implementation of the fifth floor she...	3	25/02/16	29/02/16	£7,000				
10_3	Full implementation of the fifth floor roof...	9	01/03/16	11/03/16	£20,000				
10_4	Obtaining permission from an observer/...	1	14/03/16	14/03/16	£5,000				
11	Implementation of the roof of the ridge	1	15/03/16	15/03/16	£6,000				
12	**Carcassing/brickwork/framework**	**20**	**16/03/16**	**12/04/16**	**£164,000**				
12_1	Execution of basement masonry walls	20	16/03/16	12/04/16	£10,000				
12_2	Execution of ground floor masonry walls	12	16/03/16	31/03/16	£14,000				
12_3	Execution of first floor masonry walls	16	16/03/16	06/04/16	£28,000				
12_4	Execution of second floor masonry walls	16	16/03/16	06/04/16	£28,000				
12_5	Execution of third floor masonry walls	16	16/03/16	06/04/16	£28,000				
12_6	Execution of fourth floor masonry walls	16	16/03/16	06/04/16	£28,000				
12_7	Execution of fifth floor masonry walls	20	16/03/16	12/04/16	£28,000				
13	Installation and implementation of eleva...	10	13/04/16	26/04/16	£10,000				
14	**Installing the interior door frame (the ...**	**10**	**27/04/16**	**10/05/16**	**£8,000**				
14_1	Installing the interior door frame (the fra...	8	27/04/16	06/05/16	£1,600				
14_2	Installing the interior door frame (the fra...	8	27/04/16	06/05/16	£1,600				
14_3	Installing the interior door frame (the fra...	8	27/04/16	06/05/16	£1,600				
14_4	Installing the interior door frame (the fra...	10	27/04/16	10/05/16	£1,600				
14_5	Installing the interior door frame (the fra...	10	27/04/16	10/05/16	£1,600				
15	Earth wall and absorbent/leaching pit/so...	30	11/05/16	21/06/16	£7,500				
16	Implementation of basement walls isolat...	10	22/06/16	05/07/16	£5,000				
17	**Plastering of inside walls from the fir...**	**28**	**06/07/16**	**12/08/16**	**£26,667**				
17_1	Plastering of inside walls of the first floor	20	06/07/16	02/08/16	£5,000				
17_2	Plastering of inside walls of the second f...	20	06/07/16	02/08/16	£5,000				
17_3	Plastering of inside walls of the third floor	20	06/07/16	02/08/16	£5,000				
17_4	Plastering of inside walls of the fourth fl...	28	06/07/16	10/08/16	£5,000				
17_5	Plastering of inside walls of the fifth floor	28	06/07/16	12/08/16	£5,000				
17_6	Plastering of inside walls of the ridge	10	06/07/16	19/07/16	£1,667				



ID	Description	Remaining Duration	Start	Finish	Remaining Cost	Minimum Duration	Most Likely	Maximum Duration	Task Existence %
18	**Implementation of duct splits (air con...**	**15**	**15/08/16**	**02/09/16**	**£9,000**				
18_1	Implementation of duct splits (air condit...	15	15/08/16	02/09/16	£1,800				
18_2	Implementation of duct splits (air condit...	15	15/08/16	02/09/16	£1,800				
18_3	Implementation of duct splits (air condit...	15	15/08/16	02/09/16	£1,800				
18_4	Implementation of duct splits (air condit...	15	15/08/16	02/09/16	£1,800				
18_5	Implementation of duct splits (air condit...	15	15/08/16	02/09/16	£1,800				
19	**Execution of electrical plumbing and ...**	**15**	**05/09/16**	**23/09/16**	**£33,000**				
19_1	Execution of electrical plumbing and ins...	10	05/09/16	16/09/16	£4,000				
19_2	Execution of electrical plumbing and ins...	10	05/09/16	16/09/16	£4,000				
19_3	Execution of electrical plumbing and ins...	15	05/09/16	23/09/16	£5,000				
19_4	Execution of electrical plumbing and ins...	15	05/09/16	23/09/16	£5,000				
19_5	Execution of electrical plumbing and ins...	15	05/09/16	23/09/16	£5,000				
19_6	Execution of electrical plumbing and ins...	15	05/09/16	23/09/16	£5,000				
19_7	Execution of electrical plumbing and ins...	15	05/09/16	23/09/16	£5,000				
20	**Implementation of sewage plumbing (...**	**10**	**26/09/16**	**07/10/16**	**£20,000**				
20_1	Implementation of sewage plumbing of t...	10	26/09/16	07/10/16	£4,000				
20_2	Implementation of sewage plumbing of t...	10	26/09/16	07/10/16	£4,000				
20_3	Implementation of sewage plumbing of t...	10	26/09/16	07/10/16	£4,000				
20_4	Implementation of sewage plumbing of t...	10	26/09/16	07/10/16	£4,000				
20_5	Implementation of sewage plumbing of t...	10	26/09/16	07/10/16	£4,000				
21	**Plumbing implementation of cold and...**	**16**	**10/10/16**	**31/10/16**	**£56,000**				
21_1	Cold and hot water and thermal plumbin...	16	10/10/16	31/10/16	£10,000				
21_2	Cold and hot water and thermal plumbin...	16	10/10/16	31/10/16	£10,000				
21_3	Cold and hot water and thermal plumbin...	16	10/10/16	31/10/16	£10,000				
21_4	Cold and hot water and thermal plumbin...	16	10/10/16	31/10/16	£10,000				
21_5	Cold and hot water and thermal plumbin...	16	10/10/16	31/10/16	£10,000				
21_6	Cold water plumbing of ground floor and...	10	10/10/16	21/10/16	£6,000				
22	The completion of masonry wall/roofing ...	10	01/11/16	14/11/16	£6,000				
23	**Cementation of floor of sanitary servi...**	**12**	**15/11/16**	**30/11/16**	**£12,000**				
23_1	Cementation of floor of sanitary services...	12	15/11/16	30/11/16	£2,400				
23_2	Cementation of floor of sanitary services...	12	15/11/16	30/11/16	£2,400				
23_3	Cementation of floor of sanitary services...	12	15/11/16	30/11/16	£2,400				
23_4	Cementation of floor of sanitary services...	12	15/11/16	30/11/16	£2,400				
23_5	Cementation of floor of sanitary services...	12	15/11/16	30/11/16	£2,400				
24	**Cementation of the western and east...**	**20**	**01/12/16**	**28/12/16**	**£25,000**				
24_1	Scaffolding of eastern view and cement...	20	01/12/16	28/12/16	£12,500				
24_2	Scaffolding of western facade and ceme...	20	01/12/16	28/12/16	£12,500				
25	Insulation of roof, sanitary ware and kitc...	15	29/12/16	18/01/17	£15,000				
26	**False ceiling execution (double roof/c...**	**20**	**19/01/17**	**15/02/17**	**£130,000**				
26_1	Installation of ceiling drywalls of ground ...	10	19/01/17	01/02/17	£13,333				
26_2	Installation of drywalls of first floor	20	19/01/17	15/02/17	£25,000				
26_3	Installation of second floor drywalls	20	19/01/17	15/02/17	£25,000				
26_4	Installation of third floor drywalls	20	19/01/17	15/02/17	£22,222				
26_5	Installation of fourth floor drywalls	20	19/01/17	15/02/17	£22,222				
26_6	Installation of fifth floor drywalls	20	19/01/17	15/02/17	£22,222				
27	**(Start of Finishing/rendering) Install t...**	**14**	**16/02/17**	**07/03/17**	**£112,000**				
27_1	Install the scaffold and complete the sou...	14	16/02/17	07/03/17	£56,000				
27_2	Installing the scaffold and executing the ...	14	16/02/17	07/03/17	£56,000				
28	**Install wall tiles of toilets and bathroo...**	**21**	**08/03/17**	**05/04/17**	**£65,625**				
28_1	Install wall tiles of toilets and bathrooms...	21	08/03/17	05/04/17	£13,125				
28_2	Install wall tiles of toilets and bathrooms...	21	08/03/17	05/04/17	£13,125				
28_3	Install wall tiles of toilets and bathrooms...	21	08/03/17	05/04/17	£13,125				
28_4	Install wall tiles of toilets and bathrooms...	21	08/03/17	05/04/17	£13,125				
28_5	Install wall tiles of toilets and bathrooms...	21	08/03/17	05/04/17	£13,125				
29	Completion of all the ground floor and b...	20	06/04/17	03/05/17	£9,000				
30	**Execution of final plastering**	**24**	**04/05/17**	**06/06/17**	**£36,000**				
30_1	Execution of plastering of the ridge	8	04/05/17	15/05/17	£4,000				
30_2	Execution of fifth floor plastering	24	04/05/17	06/06/17	£6,000				
30_3	Execution of fourth floor plastering	24	04/05/17	06/06/17	£6,000				
30_4	Execution of third floor plastering	24	04/05/17	06/06/17	£6,000				
30_5	Execution of second floor plastering	22	04/05/17	02/06/17	£6,000				
30_6	Execution of first floor plastering	22	04/05/17	02/06/17	£6,000				
30_7	Execution of ground floor and basement/...	10	04/05/17	17/05/17	£4,000				
31	**Bedding/footing construction of the fi...**	**21**	**07/06/17**	**05/07/17**	**£168,000**				
31_1	First floor Bedding/footing construction ...	21	07/06/17	05/07/17	£33,600				
31_2	Second floor Bedding/footing constructi...	21	07/06/17	05/07/17	£33,600				
31_3	Third floor Bedding/footing construction ...	21	07/06/17	05/07/17	£33,600				
31_4	Fourth floor Bedding/footing constructio...	21	07/06/17	05/07/17	£33,600				
31_5	Fifth floor Bedding/footing construction ...	21	07/06/17	05/07/17	£33,600				
32	**Installation and implementation of sta...**	**20**	**06/07/17**	**02/08/17**	**£156,000**				
32_1	Installation and implementation of stairc...	18	06/07/17	31/07/17	£24,000				
32_2	Installation and implementation of stairc...	18	06/07/17	31/07/17	£24,000				
32_3	Installation and implementation of stairc...	18	06/07/17	31/07/17	£24,000				
32_4	Installation and implementation of stairc...	18	06/07/17	31/07/17	£24,000				
32_5	Installation and implementation of stairc...	20	06/07/17	02/08/17	£20,000				
32_6	Installation and implementation of stairc...	20	06/07/17	02/08/17	£20,000				
32_7	Installation and implementation of stairc...	20	06/07/17	02/08/17	£20,000				
33	Installing the windows of exterior/outer v...	15	03/08/17	23/08/17	£60,000				
34	Installation of all interior/internal doors a...	15	24/08/17	13/09/17	£30,000				

ID	Description	Remaining Duration	Start	Finish	Remaining Cost	Minimum Duration	Most Likely	Maximum Duration	Task Existence %
35	Installation of elevator room and items r...	10	14/08/17	27/09/17	£40,000				
36	Completion of the wiring of all units and ...	10	28/09/17	11/10/17	£15,000				
37	Installing thermal packages and connect...	20	12/10/17	08/11/17	£21,000				
38	Installing splits inside the floors and con...	15	09/11/17	29/11/17	£18,000				
39	Completion of all stone installation work...	25	30/11/17	05/01/18	£12,500				
40	Getting power, water and gas and sewa...	30	04/01/18	14/02/18	£25,000				
41	Elimination of defects/troubleshoot of all...	15	15/02/18	07/03/18	£5,000				
42	Perform painting of all units and ground ...	60	08/03/18	30/05/18	£50,000				
43	Install all the valves and sanitary items i...	30	31/05/18	11/07/18	£10,000				
44	Installing the cabinets of all units	25	12/07/18	15/08/18	£62,500				
45	Re-test the water and electricity and se...	25	16/08/18	19/09/18	£8,000				
46	**Finishing touches**	**100**	**20/09/18**	**06/02/19**	**£70,000**				
46_1	Painting and finishing touches	100	20/09/18	06/02/19	£70,000				
47	**Final defect remove and cleaning**	**20**	**07/02/19**	**06/03/19**	**£3,000**				
47_1	Defect remove and cleaning	20	07/02/19	06/03/19	£3,000				
48	Completion of the project	0	07/03/19	06/03/19	£0				



Normal, Critical

ORACLE

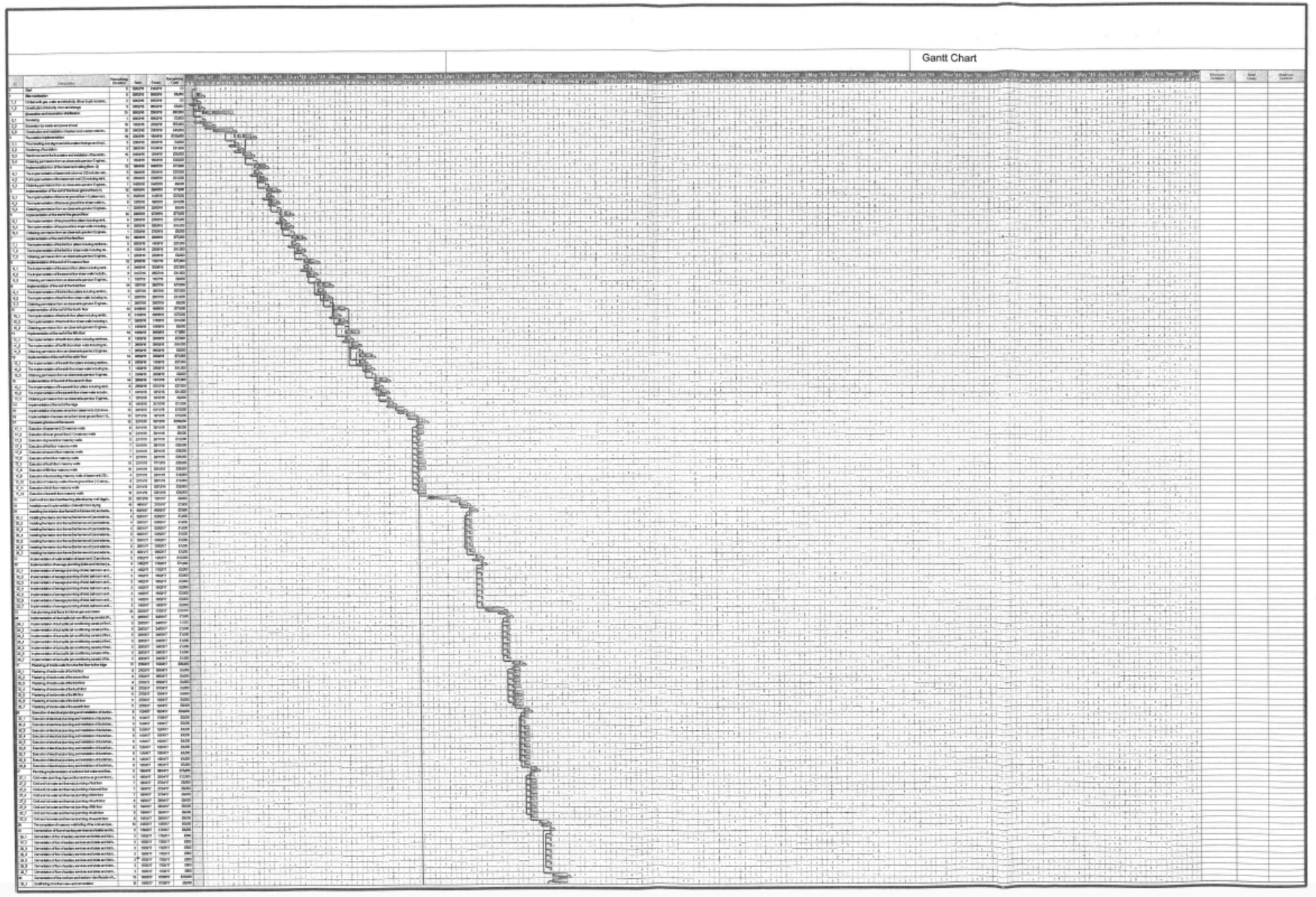
PRIMAVERA RISK ANALYSIS

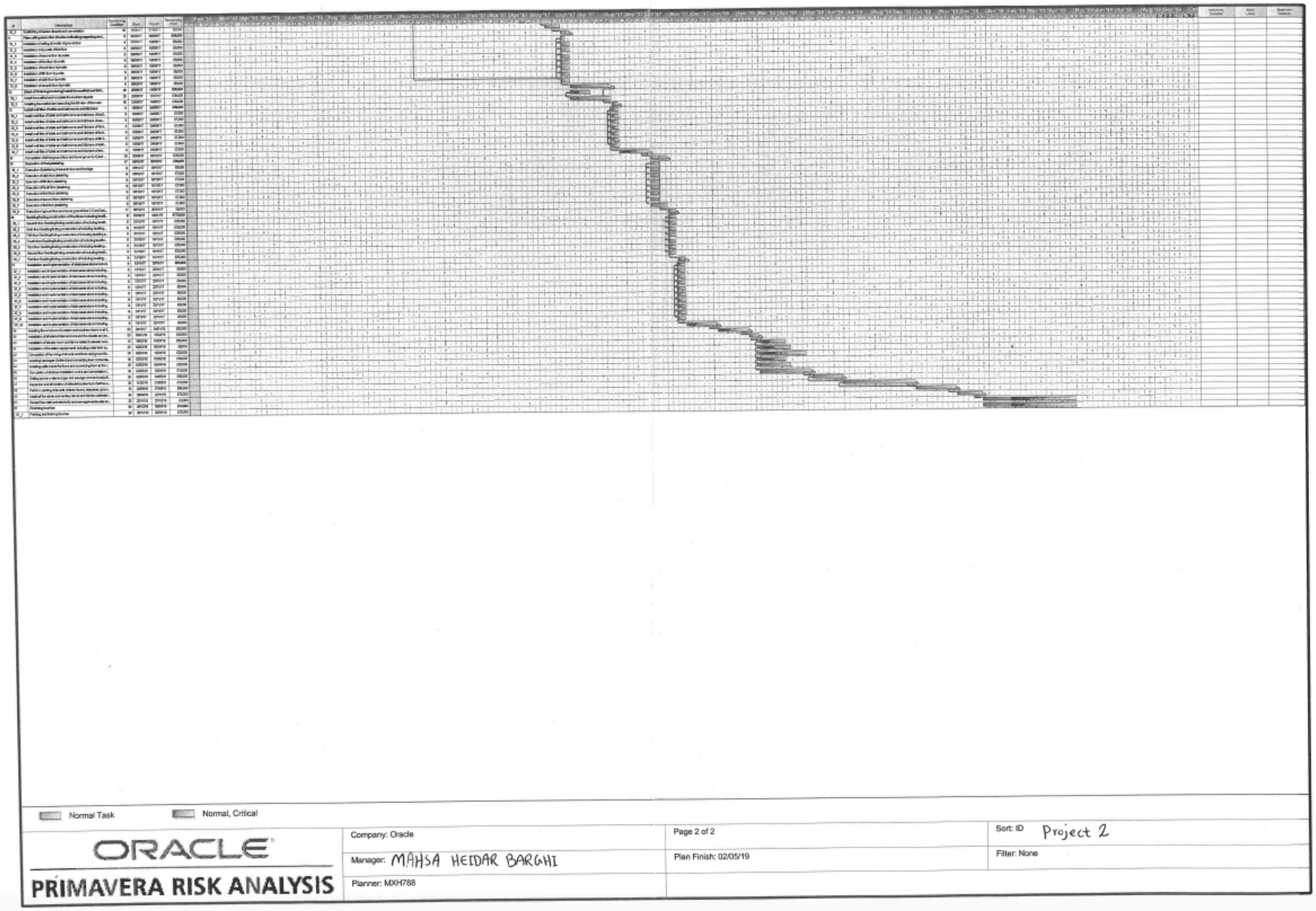
Company: Oracle | Page 3 of 3 | Sort: ID project 1

Manager: MAHSA HEIDAR BARGHI | Plan Finish: 06/03/19 | Filter: None

Planner: MXH788

PLAN OF PROJECT 2


Gantt Chart


Normal Task
Normal, Critical
ORACLE
PRIMAVERA RISK ANALYSIS
Company: Oracle
Manager: MAHSA HEIDAR BARGHI
Planner: MXH788
Page 2 of 2
Plan Finish: 02/05/19
Sort: ID Project 2
Filter: None