Implementation of the Lean Approach in Sustainable Construction: A Conceptual Framework

by

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Student Declaration

I declare that while registered as a candidate for the research degree, I have not been a registered candidate or enrolled student for another award of the University or other academic or professional institution.

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ABSTRACT

There has been a growing awareness of the adoption of lean principles within UK construction organisations. The UK Government has recognised the importance of the construction industry in achieving the overall goals of sustainable development. Therefore, the Government has put several policies and strategies in place for achieving more sustainable construction. Assessment and performance improvement have been advocated by many researchers, and there is a substantial interest in performance measurement by construction organisations. Assessing the implementation efforts and benefits of lean approach in sustainable construction has become more critical to organisations in pursuit of continuous improvement. The inadequacy of many frameworks and tools developed to address this advancement in the area of lean and sustainability provided the motivation for this research. Therefore, the aim of this research was to develop a conceptual framework for assessing the implementation efforts and benefits of the lean approach in sustainable construction within contracting organisations.

The objectives of this study were to explore the process of implementation of the lean approach throughout all the levels of construction organisations, investigate the linkages between lean and sustainable construction, review the concept of lean and its application to sustainable construction, analyse the barriers and success factors, and to identify the benefits of lean in sustainable construction.

An exploratory method of investigation and study involving both quantitative and qualitative methodology was utilised in this research. An in-depth literature review and questionnaire survey was conducted among UK-based construction professionals on issues relating to sustainability and lean in order to identify the barriers, success factors and linkages between sustainability and the lean concept. The data collected were analysed with SPSS 19.0 version software using the percentile method, factor analysis, Kruskal Wallis test, Cronbach's Alpha reliability test and the Severity Index Analysis. A case study was also used with content analysis, in order to allow for a better understanding of the implementation process and drivers of lean at the organisational level.

The success factors in implementing lean and sustainability were subjected to factor analysis. A factor analysis of the data yielded two (2) critical success factors, which were labelled as management and resource factors and organisational culture factor. All the identified benefits of implementing lean construction were classified into economic, social, and environmental benefits. Also, the drivers of implementing lean were discussed and classified into internal and external drivers.

The research further revealed that reduction in waste is the most important benefit of synchronising lean and sustainability. The most significant barrier is resistance to change. The adoption of lean techniques will impact significantly on the realisation of sustainable construction as there are linkages between lean and sustainability. The developed framework of lean implementation process at the strategic level is made up of three sections, namely: policy and strategy deployment, assessments criteria, and the application and the implementation phase (with their respective sub sections). The framework highlighted the need to understand the implementation issues within a contracting construction organisation as well as the drivers of implementing lean. This study has theoretical, practical and methodological significance for successful lean implementation in contracting construction organisations in the UK.

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LIST OF ABBREVATIONS

AEC	Architecture, Engineering, and Construction
AHP	Analytical Hierarchy Process
ANOVA	Analysis of Variance
BIM	Building Information Modeling
BSC	Balanced Scorecard
CI	Continuous Improvement
CIB	Conseil International du Batiment
CIEF	Construction Industry Environmental Forum
CII	Construction Industry Institute
CIRIA	Construction Industry Research and Information Association
CLIP	Construction Lean Improvement Programme
CPN	Construction Productivity Network
CTP	Cost- Time-Profile
DETR	Department of the Environment, Transport and the Regions
DFMA	Design for Manufacturing and Assembly
DMAIC	Define, Measure, Analyse, Improve and Control
DPMO	Defects per million opportunities
DTI	Department of Trade and Industry
EFQM	European Foundation for Quality Management
EME	Extended Manufacturing Enterprise
ERP	Enterprise Resource Planning
IGLC	International Group for Lean Construction
ISIC	International Standard of Industrial Classification
JIT	Just-in-Time
KIVP	Knowledge Innovation Visible Planning
KMO	Kaiser-Meyer-Olkin

LC	Lean Construction
LCI:	Lean Construction Institute
LCI-UK	Lean Construction Institute UK
LEA:	The Lean Enterprise Architecture (LEA)
LIMA	Lean Implementation Assessment Framework
LPDS	Lean Project Delivery System
LPS	Last Planner System
MBNQA	Malcolm Baldrige National Quality Award
PCWE	Plan Conditions of Work Environment
PDCA	Plan-Do- Check-Act
PPC	Percent Plan Complete
PQASSO	Practical Quality Assurance System for Small Organisations
QFD	Quality Function Deployment
QUIP:	Qualitative Impact Protocol
R&D	Research and Development
RICS	Royal Institute of Chartered Surveyors
SMEs	Small and Medium Enterprises
SMED	Single Minute Exchange of Dies
SPSS	Statistical Package for the Social Sciences
TPM	Total Productive Maintenance
TQM	Total Quality Management
TVAL	Toyota Verification of Assembly Line
UK	United Kingdom
WRI	World Resources Institute
EFA	Exploratory Factor Analysis
CFA	Confirmatory Factor Analysis
KMO	Kaiser-Meyer-Olkin

PCA	Principal Components Analysis
PAF	Principal Axis Factoring

CHAPTER 1:INTRODUCTION

1.1 Background of the Study

The history of lean can be traced back to Henry Ford who was the first person to truly integrate an entire production process. He formed the flow production by combining interchangeable parts with standard work and moving conveyance. With wide acceptance by the public, Ford recorded more success. However, Kiichiro Toyoda, Taiichi Ohno, and others at Toyota revisited Ford's original thinking, and invented the Toyota Production System (Lean Enterprise Institute, 2013).

The concept of lean thinking came about in the early 1980s when the American car manufacturing industry realised that the Japanese were producing cars at a lower cost and better quality than any other country in the world. They found out that the Japanese built cars in less time, used half the space and recorded fewer defects than their American counterparts after making allowance for differences in different models (Lean Enterprise Institute, 2013).

In 1990, Womack e*t al*. presented the concept of lean in manufacturing. The principle of lean is mainly aimed at eliminating waste in process activities in order to reduce process cycles, improve quality, and increase efficiency. In the lean context, waste includes all forms of over production, over-processing, delay, excess inventory and motions, failure, and defects. Therefore, process variability such as those due to unstable processing, frequent and long breakdowns, and changeovers and material shortages highly contributes to process waste (Al-Aomar , 2011).

Lean production was developed by Toyota, led by Engineer Ohno. Ohno developed a simple set of objectives for the design of the production system: produce a car to the requirements of a specific customer, deliver it instantly, and maintain no inventories or intermediate stores unlike Ford who had an almost unlimited demand for a standard product (Howell, 1999). Lean production is defined as an approach to manufacture the right product with the right quantity through instant material supply while minimising wastes and maintaining flexibility to adapt to varying production requirements (Ikovenko, 2004).

Lean construction emerged due to the failure of current project management and results in significant improvement in terms of management and project deliverables (Koskela and Howell, 2002). Lean principles are traced from the Japanese car manufacturing industry. The term 'lean' was borrowed and developed from a range of industries and converted to a suitable form for use in the construction industry. Lean construction relies on the production management principles inspired by the Toyota Production System (Howell, 1999).

The emerging concept of lean construction is concerned with the application of lean thinking to the construction industry. The ideas of lean thinking within the UK construction industry seem to be predominantly targeted to improving quality and efficiency (Green 1999). Lean production management caused a revolution in the manufacturing world. Lean theory challenged the traditional notions about how to plan and manage work and achieved new levels of performance in return. Products were manufactured in less time, at lower costs, and with improved quality (Lean Construction Institute, 2003). The Lean Project Delivery System (LPDS) and the Last Planner System of Production Control were developed by Lean Construction Institute (LCI) where the principles pioneered in manufacturing were applied to construction (Pinch, 2005). LPDS's origins can be traced back to Lean Production Management which is a manufacturing approach brought into the limelight by Toyota Motor Company in the 1980s (Pinch, 2005).

In the quest for more sustainable construction, UK construction companies have been challenged to rethink construction using the principles and tools of lean (Department of the Environment, Transport and the Regions, 1998). Consequently, some of the innovative companies have been concerned with changing their work practices in line with this awareness. The Egan report "Rethinking Construction" (DETR, 1998) strongly suggests a change model i.e. the adoption of lean manufacturing principles in construction to address the challenges faced by the construction industry.

Sustainable construction most comprehensively addresses the ecological, social and economic issues of construction. The goal of sustainable construction is creating and operating a healthy built environment based on resource efficiency and ecological design. The principles of sustainable construction apply across the entire life of construction, from planning to disposal (Kibert, 2008). Sustainable development is now the stated policy which is applicable to industry, commerce, as well as local, national and international governments. Achieving sustainability requires us to live within the limit of the earth's capacity to provide materials for all human activities, and to absorb the waste and pollution that our activities generate (Halliday, 2008). There are many sustainability criteria such as energy efficiency, non-toxics or recyclability, preserving property value, flexibility, long service life, use of local resources, information dissemination, use of by-products, immaterial services, mobility consideration or supporting local economy (Koskela and Huovila, 1997). According to Koskela and Huovila (1997), the construction industry has to adapt to the new and emerging construction which has environmental and social dimensions. Similarly, construction businesses are expected to integrate into, and consider more fully, the issues valued by others at the national, regional and community level where the driving forces will be a mixture of political, social and market forces, requiring products which respond to genuine needs and concerns.

One of the priorities of lean construction is the elimination of waste as lean construction tools have evolved to contribute to sustainable construction. Similarly, sustainable construction focuses on the removal of waste from the construction process. Therefore, it could be said that both concepts share the same goal of waste reduction. However, organisations struggle to integrate the concepts (Koranda *et al.,* 2012).

The potential of lean to contribute to sustainable construction has been raised for discussion (Huovila and Koskela, 1998). Therefore, it is of utmost importance to examine the possibilities of lean contributing to sustainable construction. There have been many studies on lean and its application within construction at the project level with great benefits achieved in the studies. Most of these studies have investigated lean construction and sustainability separately (Koranda *et al.,* 2012; Marzouk *et al.,* 2011; Nahmens and Ikuma, 2009). However, studies that highlight the contributions of lean construction towards sustainability are few. The insufficiency of literature addressing this issue and the absence of research-based papers are assumed as a lack of awareness of the potential of lean construction as a means of achieving sustainability. This could also imply lack of general understanding of the relationship between sustainability and lean construction objectives. For instance, Forbes *et al.* (2000) proposed a framework for providing technical support for lean methods application in some environments in developing countries. Sacks *et al.* (2009) developed a research framework for the analysis of the interaction between lean and Building Information Modelling (BIM). However, there have been few studies investigating the impact of lean on sustainable construction in terms of developing a framework at the organisational level. For example, Al-Aomar (2011) developed a lean construction framework with six sigma rating. The focus was on categorisation and reduction of construction wastes. Similarly, Bommel (2011) developed a conceptual framework for analysing sustainability strategies in industrial supply networks. The focus was on innovation power of the 'focal' company and its supply network. In most of these studies, lean construction and sustainability initiatives were studied separately. There have been few organisation-wide studies of effects of lean construction on sustainable construction. Against this background, this study aims to examine the contributions of the implementation of the lean approach to achieving sustainability.

1.2 Research Aim and Objectives, Questions and Hypothesis

The aim of this research is to develop a conceptual framework for assessing lean implementation efforts and benefits of lean in sustainable construction within construction firms. The specific objectives are to:

1. Review the concept of lean and its application to sustainable construction
2. Critically explore and synthesise the linkage between lean construction and sustainability in the existing literature
3. Identify and prioritise the barriers and success factors in the implementation of lean construction and sustainability
4. Determine the core drivers of lean construction
5. Critically evaluate existing models/frameworks associated with the adoption, implementation, and monitoring of lean construction.
6. Develop a conceptual framework to assesses the implementation effort of the lean approach in construction firms
7. Test and validate the developed framework with domain experts

A set of research questions and hypotheses were developed through a review of relevant literature to guide the research. The research questions and research hypothesis examined in the study are given in Table 1.1.

Table 1.1: Research Objectives, Research Questions and Research Hypotheses

Research Objectives	Research Questions	Research Hypotheses
1. Review the concept of lean and its application to sustainable construction	I. What are the critical issues associated with the implementation of lean in sustainable construction?	
2. Critically explore and synthesise the linkage between lean construction and sustainability in the existing literature	II. Are there synergies and linkage between lean construction and sustainability, what are they? III. What are the benefits/impact of implementing lean in sustainable construction? IV. What is the level of use of lean tools and techniques/principles for enabling sustainability?	H1: There is agreement on the area of linkage between lean and sustainability among the respondents.
3. Identify and prioritise the barriers and success factors in the implementation of lean construction and sustainability.	V. What are the barriers and success factors in the implementation of lean and sustainability?	H2: The perception of the success factors in the implementation of lean and sustainability differs according to size of organisation. H3: The perception of the success factors in the implementation of lean and sustainability differs according to organisation's main business activities. H4: The perception of the barriers to the implementation of lean and sustainability differs according to size of organisation. H5: The perception of the barriers to the implementation of lean and sustainability differs according to organisation's main business activities.
4. Determine the core drivers of lean construction	VI. What are the core drivers of implementing lean?	

Research Objectives	Research Questions	Research Hypotheses
5. Critically evaluate existing models/frameworks associated with the adoption, implementation, and monitoring of lean construction	VII. What are the existing frameworks in-use for the lean approach in sustainable construction, if any?	
6. Develop a conceptual framework to assesses the implementation effort of lean approach in construction firms	VIII. Is there a need for developing a framework for assessing the implementation efforts of lean in sustainable construction?	
7. Test and validate the developed framework with domain experts	IX. Are the critical issues covered in the developed framework	

1.2.1 Research Programme

The research programme is made up of four stages as shown in Figure 1.1. The details of these four stages and the research approaches adopted to address the objectives of each stage are elaborated further in Chapter 4 and the findings of the stages are given in subsequent chapters (Chapter 5, 6, 7, 8 and 9).

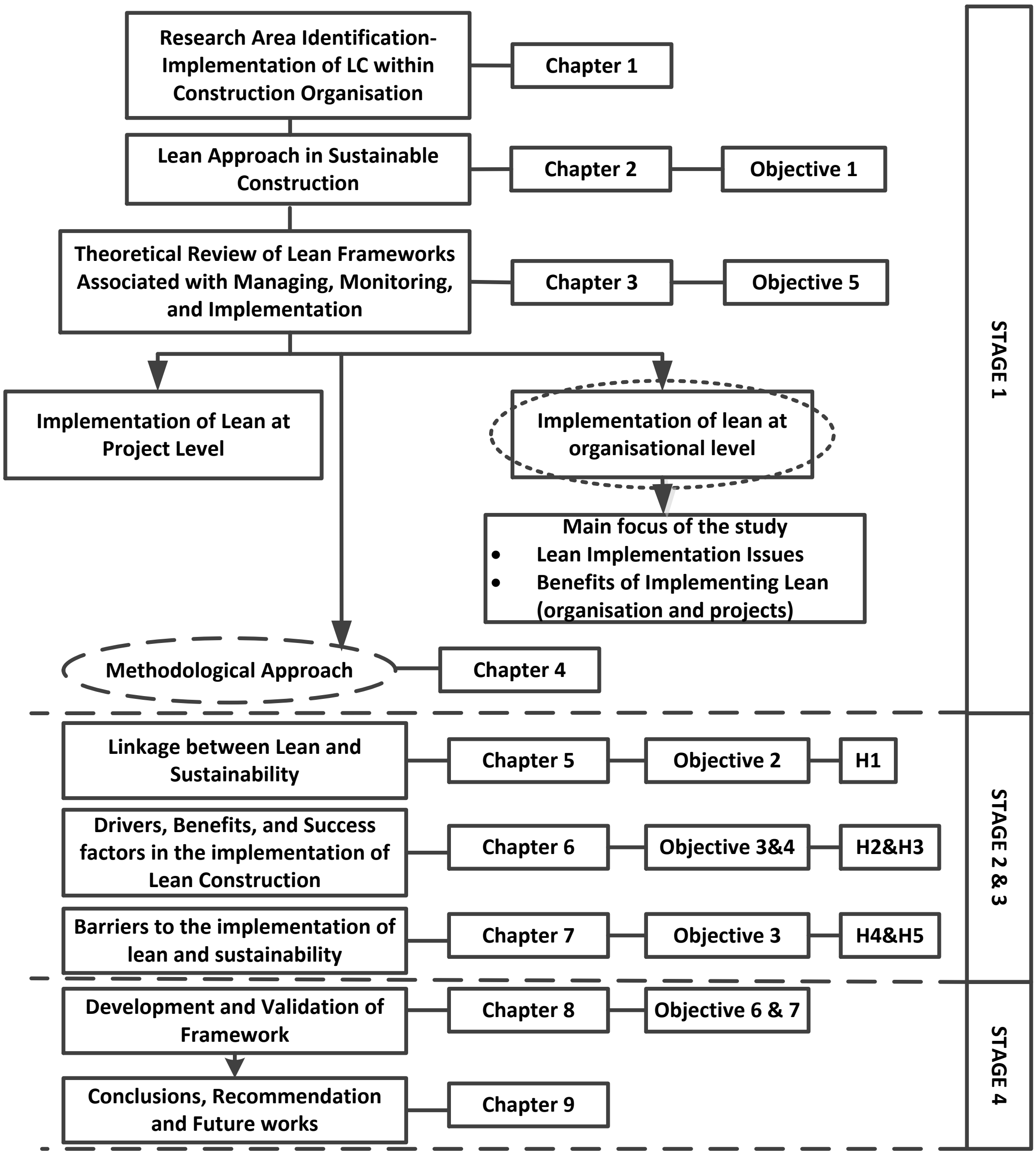

Figure 1.1: Research flow process, study focus and deliverables

1.3 Scope and Limitations of the Study

The scope of this study is the implementation of lean construction within construction organisations in the UK and its impacts on sustainable construction. The research cannot pretend to address everything within the domain of the study. As such, it is necessary to state the boundaries of knowledge and basic assumptions underlying the study.

Lean construction principles have been shown to contribute to sustainable construction and touted as a means of not only optimising construction costs but also reducing construction waste and its attendant impact on the environment (Koskela *et al*., 2002). While theoretical evidence abounds to support the perceived benefits of lean, very little empirical work has been done to quantify its actual use, cost and benefits in the construction industry. An important range of critical opinions pertaining to the human cost of lean production has been overlooked by construction researchers. Therefore, lean construction, which is independent of commercially vested interests, needs urgent experiential research (Green, 1999).

There are many studies on the subject of lean in relation to manufacturing and lean implementation on construction projects. However, very few studies and empirical work have been carried out in the aspect of organisational implementation of lean construction. As a result of this, it was challenging to develop the research questions and objectives. This limitation was overcome by informal discussion with experts at implementing lean and sustainability.

Due to volume of activities carried out by contracting organisations and sampling strategy adopted, the focus of the research was limited to contracting organisations that have implemented lean and are noted for their corporate sustainability concept adoption within their organisations. The rationale for choosing these organisations is given in Section 4.6.9.

The questionnaire survey conducted as part of the study (refer to Section 4.6.2) was based only on UK construction organisations with experience or expressed interest in lean construction and sustainability. This limitation could not be avoided as there is neither comprehensive, nor any standard, database of UK construction organisation involved in lean construction. Also, lean construction is evolving and as a result, the number of organisations involved is increasing, but not in a form that the overall number of these organisations can be determined easily. This limitation was overcome by the use of a qualitative approach (case study).

Furthermore, the responses obtained through the questionnaire survey were views of each respondent representing their respective organisation, and there might be differing views among respondents within the same organisation. This limitation was tackled by the use of a structured interview questions. Different personnel ranging from strategic to operational staff within the same organisation were interviewed in order to verify the results of the survey. It should also be noted that the results presented are based on the perception of respondents in organisations that have had experiences with lean management application.

1.4 Contributions to Knowledge

The concept of lean construction has been established in various studies. However, the understanding of the implementation issues of lean in the construction industry needs to be more emphasised. Therefore, the research intended to provide the following contributions:

- Awareness and understanding of the impact of the lean approach in sustainable construction
- Improved knowledge and understanding of implementation issues of lean construction
- Development of a conceptual framework for assessing lean construction implementation efforts and the benefits that can be derived from its adoption

It is expected that the developed framework will be beneficial to construction organisations because it will enable organisations to manage, measure, and evaluate the benefits arising from the use of lean construction techniques as sustainability is of increasing importance to the operation of a business. The outcome of this research will provide a knowledge base for companies intending to implement lean. It would also allow companies to evaluate the strengths and weaknesses of their lean implementation processes based on the impact assessment results. The framework can also be used as a standard business tool for assessing an organisation’s lean status and need.

1.5 Structure of the Thesis

The thesis consists of nine chapters, which have been organised in a logical manner in order to enable the reader to appreciate the thoughts of the author in achieving the objectives of the study. Figure 1.2 presents the overall structure of the thesis. The contents of each of these chapters are summarised as follows:

Chapter 1 provides the general introduction of the research theme and the nature of the problem investigated. The chapter provides a brief review of previous studies on lean construction and sustainable construction and identifies the research gap which the present study focuses on. The aim, objectives, and significance of the research are also stated in this chapter.

Chapter 2 examines the lean approach in sustainable construction through the review of literature. It also describes the nature of the construction industry and presents an overview of the UK construction industry and the need for sustainable construction, lean tools and techniques, and the benefits of lean in sustainable construction. The priorities of lean construction are also highlighted in this chapter based on a critical review of extant literature and gap analysis. Chapter 2 fulfils objective 1 of this research and also provides the basis for achieving the remaining objectives of the study (refer to Section 1.2).

Chapter 3 presents the theoretical review of existing lean frameworks associated with managing, monitoring and implementation. This chapter provides a review of the lean concept and organisational learning and the types and stages of lean organisation. It also presents a detailed review of existing lean frameworks and establishes the need for a more robust framework to assess the implementation of the lean approach in sustainable construction. Overall, Chapter 3 addresses objective 5 of the research (see Figure 1.1).

Chapter 4 establishes the epistemology framework in which the research was conducted. It also presents an overview of various research approaches and justifies the research methodology and methods employed in the study, as well as the rationale for selecting them. The sampling frame and methods of data analysis used for the study are also described in detail in this chapter.

Chapter 5 presents some of the findings of the questionnaire survey on the linkage between lean construction and sustainability. This chapter explores the linkage between lean construction and sustainability and examines the environmentally sustainable practices which are a natural extension of lean operational philosophy and techniques. The lean initiatives and eco-sustainability initiatives which have the potential to leap sustainability synergistically forward were also discussed. This chapter therefore addresses objective 2 of the research (refer to Section 1.2).

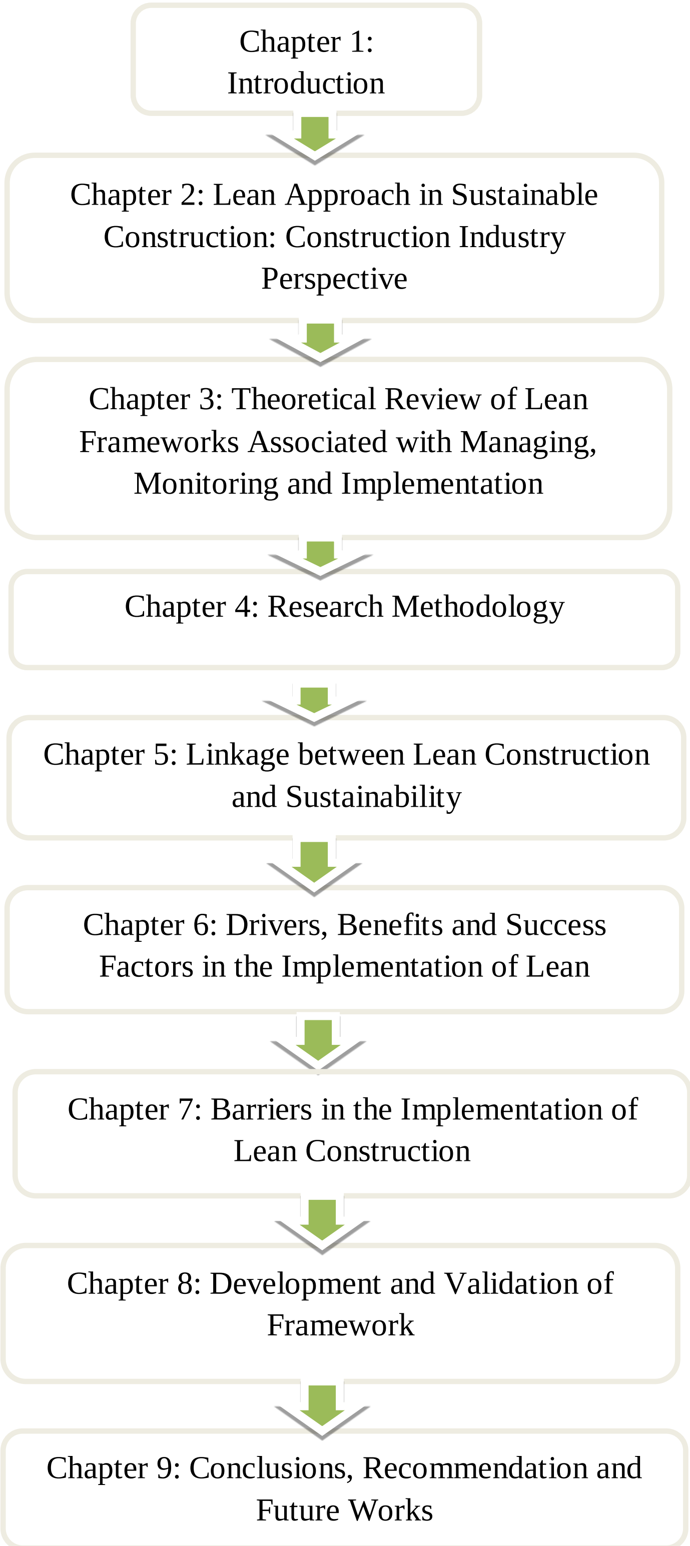

Figure 1.2: Structure of the Thesis

Chapter 6 presents the findings of the case study relating to drivers, benefits and success factors in the implementation of lean construction. The findings are further elaborated using some of the results from the questionnaire survey carried out as part of the research. The implications and inferences drawn from the findings are also elaborated in this chapter. This chapter addresses part of objective 3 and fulfils objective 4 of this research (see Figure 1.1).

Chapter 7 presents the findings of the questionnaire survey and the case study. The findings are on the barriers in the implementation of lean construction and sustainability. The questionnaire survey findings were further augmented by semi-structured interviews (case study approach). This chapter explores and elaborates the implications and inferences drawn from the findings. Overall, Chapter 6 addresses the remaining part of objective 3 of the research (see Figure 1.1).

Chapter 8 presents the Lean Implementation Assessment Framework (LIMA) developed for assessing the implementation efforts of lean construction in sustainable construction. This framework is the final output of this research. This chapter also presents the results of the semi- structured interviews carried out to refine and validate the LIMA framework. Overall, Chapter 8 addresses objective 6 and 7 (final objectives) of the research (see Figure 1.1).

Chapter 9 is the concluding chapter of the thesis which presents the key research findings. It summarises the overall research process adopted and presents the conclusions derived from the overall research findings, recommendations and suggestions for further research.

CHAPTER 2: LEAN APPROACH IN SUSTAINABLE CONSTRUCTION: CONSTRUCTION INDUSTRY PERSPECTIVE

2.1 Introduction

The need for a more sustainable approach or initiative such as lean has been stressed by the UK Government (DTI, 2006). The construction industry is seen as a major threat to sustainable development due to its negative environmental impact. Therefore there has been the need for widespread implementation of practices and approaches that would reduce the negative impact of construction activities on the environment. This has raised the awareness of the construction industry to adopt the lean approach. Thus the lean approach has been implemented within the construction industry as a means of improving construction activities and work place organisation.

This chapter focuses on the lean approach in sustainable construction through a review of literature centred on lean and sustainable construction in the wider context of the construction industry. This chapter also describes the nature of the construction industry and also presents an overview of the UK construction industry and the need for sustainable construction. A review of lean tools and techniques, benefits of lean in sustainable construction and the priorities of lean construction are also included in this chapter based on a critical review of extant literature and gap analysis. Chapter 2 fulfils Objective 1 and Research Question I of this research and also provides a basis for achieving the remaining objectives of the study (see Table 1.1).

2.2 Nature of the Construction Industry

Construction industry activities are concerned with the planning, regulation, design, manufacture, construction and maintenance of buildings and other structures (Burtonshaw-Gunn, 2009). The construction industry is defined by Druker and White (1996) as comprising new construction work, general construction and demolition work, the construction and repair of buildings, civil engineering, the installation of fixtures and fittings, and building completion work. In addition, the construction industry encompasses the building and the engineering sectors and also includes the process-plant industry. However the demarcation between these areas is often blurred (Ashworth, 2010).

Murdoch and Hughes (2008) stated that most of the people who study the construction industry do so from their respective point of view which is based on their professions. Because of this, there are many descriptions of the construction sector, drawn from different specialist disciplines. In a broad context, the term construction can include the erection, repair and demolition of things as diverse as houses, offices, shops, dams, bridges, motorways, home extensions, chimneys, factories and airports. Many different firms carry out specialist work relating to particular technologies, but a few firms are confined to only one building type or one technology. The industry and the issues that affect construction projects are difficult to comprehend fully because the relationships between the parts are not always clear and the boundary of the industry is unclear (Murdoch and Hughes, 2008). Barrie and Paulson (1992) affirmed that the construction industry must include general and specialty construction as there is no clear definition as to what the construction industry is. They further stated that to really understand the construction industry, one must extend its scope to include designers of facilities, material suppliers, and equipment manufacturers.

Meyers (2008) clearly identified a range of actors that can be included in a broad definition of the construction industry as suppliers of basic materials such as cement and bricks, machinery manufacturers who provide equipment used on site, such as cranes and bulldozers. Manufacturers of building components such as windows and doors, site operatives who bring together components and materials, project managers and surveyors who coordinate the overall assembly, developers and architects who initiate and design new projects, facility mangers who manage and maintain property, and providers of complementary goods and services such as transportation, distribution, demolition, disposal and clean-up.

According to Meyers (2008), the system of industrial classification used for statistical and government purposes favours a narrow definition of the construction industry that includes only firms that are involved with building and civil engineering. This categorisation is derived from the United Nations International Standard of Industrial Classification (ISIC). There are many interpretations given to the construction industry in the literature some of which are narrow or broad. The construction industry has been referred to as all firms involved directly in the design and construction of buildings (Morton, 2002). This description exempts the broad categorisation of the construction industry.

The areas of construction and their examples according to Meyers (2008) are infrastructure- water and sewage, energy, gas and electricity, roads, and airports, harbours, railways; housing- public sector/housing associations, private sector (new estates); public non-residential- schools, colleges, universities, health facilities, sports and leisure facilities and services (police, fire, prisons); private industrial- factories, warehouses and oil refineries; private commercial (and similar public private partnerships), schools/hospitals (where privately funded), restaurants, hotels, bars, shops, garages and offices; repair and maintenance- extension and conversions renovations and refurbishment, and planned maintenance (Meyers 2008).

It is important to clarify how this study perceives the construction industry. In the context of this study, the construction industry is considered as encompassing all the aforementioned descriptions. In other words, there is a broad definition of the construction industry.

2.2.1 Characteristics of the Construction Industry

Construction is mainly about coordination of specialised and differentiated tasks at the site level (Shirazi *et al*. 1996). Many studies have argued that construction is inherently a site-specific project-based activity (Cox and Thompson, 1997, Ren and Lin, 1996). However, Du Plessis (2007) argued that construction can be interpreted as the broader process of human settlement creation, everything related to the business of construction, and a comprehensive project cycle in addition to being a site level activity. This implies that construction can be interpreted in different ways other than just focusing on the site level activity.

The construction industry is one of the largest industries in most developed economies. A variety of statistics illustrates the importance of the construction industry to the national economy. In terms of output and contribution to employment, the construction industry in the UK is immense. According to the Office for National Statistics UK (2013), the construction industry contributed almost £90 billion to the UK economy (or 6.7%) in value added, comprises over 280,000 businesses covering some 2.93 million jobs, which is equivalent to about 10% of total UK employment. Therefore, construction is one of the largest sectors of the UK economy. The contracting industry is the largest sub-sector of the construction sector, accounting for about 70% of total value added generated by UK construction and almost 70% of the sector's jobs (Office for National Statistics UK, 2013).

The construction industry is generally characterised by low productivity, overruns in cost and schedule, errors, poor reputation, shortage of skilled labour and poor safety (Nash *et al.*, 2002; Health and Safety Executive, 2013). In particular, lack of safety is one of the chronic problems in construction, as is evident from the high accident rates. Although the construction industry only represents about 5% of employees in England, it accounts for 27% of fatal injuries to employees and 10% of major reported injuries (HSE, 2013). For example falls from height and trips appears to be the major cause of death and injuries to workers in the UK (specifically Britain) construction workplace. According to HSE (2013), slips and fall accounts for more than half of all major (56%) and almost a third of over seven day (31%) injuries to employees, making up 37% of all reported injuries to employees. The practice of subcontracting portions of project to special trade contractors by primary contractors is also one of the features of the construction industry (Dubious and Gadde, 2000).

The construction industry has several unique features which distinguish it from other industries; such features include the fragmented nature, one-off projects, and multi participants. According to Harvey and Ashworth (1993), there are certain characteristics of the construction industry which separate it from other industries. Thomassen (2004) also share the same view. The distinguishing characteristics include:

- The physical nature of the product (Harvey and Ashworth, 1993; Thomassen, 2004)
- The product is normally manufactured on the client's premises, i.e. the construction site (Harvey and Ashworth, 1993; Thomassen, 2004; Fellows *et al.*, 2002)
- Many of its projects are one-off designs and lack any prototype model being available (Harvey and Ashworth, 1993; Thomasen, 2004; Fellows *et al.*, 2002)
- The arrangement of the industry, where design has normally been separate from construction (Harvey and Ashworth, 193; Thomasen, 2004; Fellows *et al.*, 2002; Emmerson, 1962)
- The organisation of the construction process (Harvey and Ashworth, 1993; Thomasen, 2004)

- The methods used for price determination (Harvey and Ashworth, 1993; Thomasen, 2004)

Other characteristics of the UK construction industry include the rise of partnering, mergers and acquisitions, and combat of waste and cost using value management, lean construction, and other techniques (Fellows *et al.,* 2002).

2.2.2 Overview of the UK Construction Industry and Sustainability

Holton *et al*. (2010) stated that the UK construction industry is generally recognised as comprising four principal activities: building, civil engineering, materials and products, and associated professional services. Construction materials and products are the largest with an annual turnover in excess of £40 billion, accounting for approximately 40% of total construction output and 20% of the UK's manufacturing output. According to Langdon (2007), the British construction industry is the fourth largest in Europe, representing about 10% of the total output of work. It is exceeded only by Germany, France, and Italy with each having 32%, 14%, and 12% respectively.

The construction industry is the largest industry in the UK. It has the largest number of fatal injuries of main industry groups and it is also one of the most dangerous in terms of health and safety (Ashworth, 2010; HSE, 2013). In the last 25 years, over 2,800 people have died from injuries sustained as a result of construction work. The UK construction industry employs about 1.8 million people and contributes about 10% of its gross domestic product (Hughes and Ferret 2008, ONS 2013). Construction activities are responsible for over half of carbon emission, water consumption, landfill waste and 13% of the raw materials used and consume a vast amount of natural resources (BERR, 2010).

The construction sector in the UK and in other countries is under increasing obligation to adopt the principles of sustainability in their activities and policies (Brandon and Lombardi, 2005). Miyatake (1996) suggested that changes should be made in the way the construction industry undertakes their activities. The industry makes use of energy, material, and other resources to create buildings and civil engineering projects. The end result of all these activities is huge volumes of waste during and at the end of the facility's life. Therefore, changing this process into a cyclic process will bring increased use of recycled, renewed and reused resources, and a significant decrease in the use of energy and other natural resources.

The UK construction industry has been rising up to the challenge of sustainability as they are under increasing legal and commercial pressure to become more sustainable (Bennett and Crudgington, 2003). Due to the impact the construction industry has on the economy, society and environment, increasing the sustainability of construction has become a key aim of countries aspiring to follow the path towards sustainable development (Mustow, 2006). In view of this, the UK Government has been making progress towards more sustainable construction through a range of initiatives and policies (DTI, 2006). The drivers of sustainability identified in the literature include legislation, customer requirements, broad level support reputation, brand integrity, regulators, shareholders or investors expectations, increasing competitive advantage, business pressure, government policy and regulation, new client procurement policies, environmental concerns, long term survival of business, improved corporate image, cost savings/operational efficiency, enhanced relations with suppliers, peer pressure within the industry and increased realisation of the importance of construction image (Adetunji *et al;* 2003, Sustainable Construction Task Group, 2002; Yu and bell, 2007, Simpson *et al*. 2004).

2.3 The Concept of Sustainable Development and Construction

It is difficult to describe sustainable construction without defining or describing sustainable development. There are several definitions of sustainable development given in the literature (Glavic and Lukman, 2007). Sustainable development is a broad concept which has been adopted and interpreted in numerous contexts. Many authors have seen the concept as vague and fuzzy (Hill and Bowen, 1997; Brandon, 2000). According to Sage (1998), sustainable development refers to the fulfilment of human needs through simultaneous socio-economic and technological progress and conservation of the earth's natural systems. However, the most popular definition of sustainable development is the one given in the Brundant report, which is “development that meets the needs of the present without compromising that ability of future generations to meet their own needs” (Brundtland, 1987). This is often the most widely used definition of sustainable development.

There are some areas of agreement in the various definitions. Most of these definitions reflect that the goal of sustainable development is to enable humanity all over the world to satisfy their basic needs and enjoy a better quality of life without compromising the quality of life of future generations. The concept of sustainable development has been described in three dimensions: economic, social and environmental aspect. Sustainable development and social responsibility have become increasingly important strategic issues for companies in virtually every industry (Fiskel, 2006).

Sustainable development emerged from the natural sciences, where issues of yields, the earth's carrying capacity, and the intricate ecosystems of the environment were originally vocalised (Tregidga and Milne 2006). Sustainable development is generally associated with the achievement of increased techno-economic growth coupled with preservation of the natural capital that is comprised of environmental and natural resources. It requires the development of enlightened institutions and infrastructure and appropriate management of risks, uncertainties, and information and knowledge imperfections to assure intergenerational equity, and conservation of the ability of the earth's natural systems to serve humankind (Sage, 1998).

Generally, sustainable development concerns attitudes and judgment to help insure long-term ecological, social and economic growth in society. When applied to project development, it involves the efficient allocation of resources, minimum energy consumption, low embodied energy intensity in building materials, reuse and recycling, and other mechanisms to achieve effective and efficient short- and long-term use of natural resources (Ding, 2008).

Fiskel (2006) suggested that sustainable development in a changing global environment will require resilience at many levels, including human communities and economic enterprises. In the face of ever-increasing global complexity and volatility, it is essential to move beyond a simplistic "steady state" model of sustainability. Instead, we need to develop adaptive policies and strategies that enable societal and industrial institutions to cope with unexpected challenges, balancing their need to flourish and grow with long-term concerns about human and ecological well-being. In particular, addressing the challenge of global warming will require unprecedented international cooperation in both the development of alternative technologies and adaptation to climate change impacts (Fiskel, 2006).

The term sustainable construction has multiple definitions, variances in terms of scope and context as well as practices (Wyatt, 1994; Hill and Bowen, 1997; Bourdeau *et al.* 1998). Bourdeau *et al*. (1998) stated that sustainable construction practices are widely different depending on how the concept of sustainable construction is developed in various countries. Simply put, sustainable construction is the response of the building sector to the challenge of sustainable development (Huovila and Koskela, 1998). Sustainable construction is considered by this study as the application of sustainable practices and sustainable development principles to the activities of the construction sector and construction business strategies and practice.

The implementation of sustainable construction is still under-explored. A company aiming at sustainable construction must be aware of various stockholders who are influenced by sustainability decisions (Presley and Meade, 2010). The decision making process and the actors as well as the inter-relationship has to be understood when implementing sustainable construction (Rydin *et al.,* 2007). Construction Industry Environmental Forum (CIEF) (2009) suggests that sustainable construction is a solution for significant cost savings, to bring innovations and to enhance competitiveness for the long term survival of any organisation. Sustainable construction practices do not only provide increased market share and profitability but also bring many other intangible benefits. These benefits include visible brand name to the organisation in the industry, quality in construction, employee motivation and satisfaction, improved customer satisfaction, and compliments/awards from regulatory authorities and improved shareholder relations (CIEF, 2009; WRI report, 2006).

The benefits that can be achieved by applying sustainable construction according to Luther (2005) include the environmental, economic, social, health and community benefits. The environmental benefits are improved air and water quality, reduced energy and water consumption, and reduced waste disposal. The economic benefits are reduced operating cost, maintenance cost, and increased sales price and rent while enhanced health and occupants comfort, and reduced liability are the health and community benefit (Luther, 2005, CIEF, 2009).

The key issues of sustainable construction have been reviewed and this is presented in Table 2.1. These issues cut across the three aspects of sustainable construction

Table 2.1: The main issues of sustainable construction

	Key Theme	Principal Issues
Economic Sustainability	❖ Maintenance of high and stable levels of local economic growth and employment ❖ Improved Project Delivery ❖ Increased Profitability and Productivity ❖ Monitoring and Reporting Performance	Improved productivity Consistent profit growth Employee satisfaction supplier satisfaction Client satisfaction Minimising defects Shorter and more predictable completion time Lower cost projects with increased cost predictability Delivery services that provide best value to clients and focus on developing client business company reporting Benchmarking performance
Environmental Sustainability	❖ Effective Protection of the Environment ❖ Protecting and Enhancing Biodiversity ❖ Prudent Use of Resources ❖ Improved Energy Efficiency	Minimising polluting emissions Preventing nuisance from noise and dust by good site and depot management Waste minimisation and elimination Preventing pollution incidents and breaches of environmental requirements Habitat creation and environmentalimprovement Protection of sensitive ecosystems through good construction practices and supervision Green transport plan for sites and business activities Energy efficient at depots and cities Reduced energy consumption in business activities Design for whole-life costs Use of local supplies and materials with low embodied energy Lean design and construction avoiding waste use of recycled/sustainability sourced products water conservation waste minimisation and management
Social Sustainability	❖ Social progress which recognises the needs of everyone ❖ Respect for staff ❖ Working with local communities and road users ❖ Partnership working	Provision of effective training and appraisals Equitable terms and conditions Provision of equal opportunities Health, safety and conducive working environment Maintaining morale and employee satisfaction Participation in decision-making Minimising local nuisance and disruption Minimising traffic disruptions and delays Building effective channels of communication Contributing to the local economy through local employment and procurement Delivering services that enhance the local environment Building long-term relationships with clients Building long-term relationships with local suppliers corporate citizenship Delivering services that provide the best value to clients and focus on developing client business Contributing to sustainable development globally

(Adapted from Adetunji, 2005; Hill and Bowen, 1997; DETR, 2000; Sjostrom, 2001)

i.e. the environmental, social and economic aspects otherwise known as the triple bottom line (Cooper, 2002). The main themes as well as the principal issues have been adapted from Adetunji (2005) as this has been identified to capture all the aspects of sustainable construction.

2.3.1 Sustainability: Triple Bottom Line

The awareness of sustainability has increased significantly among government, industry, and the general public over the last two decades (Fiskel, 2006). There is a growing requirement for the construction sector in the UK and in other countries to adopt the principles of sustainability in their activities and policies (Augenbroe and Pearce, 1998; Brandon and Lombardi, 2005; Curwell, *et al.*, 1999; Department for Trade and Industry, 2006). Xing *et al.* (2009) noted that there exist sustainability assessment criteria but there is no single, robust methodology that can simultaneously quantify and assess all three dimensions (economic, social and environmental) of sustainable development.

The Royal Institute of Chartered Surveyors (RICS) (2009) stated that the principle of sustainability seeks to balance economic, environmental and social objectives, at global, national and local levels, in order to meet the needs of today, without compromising the ability of future generations to meet their needs. Sustainability is about securing our long-term future, by following the four main tenets of sustainable development which are: protection of the environment, prudent use of scarce resources, promotion of access to services for the benefit of all and production of a healthy local economy, including high levels of employment. Sustainability is of increasing importance to the efficient, effective, and responsible operation of business.

Sustainability is also defined as a continuous improvement process that involves managing processes in such a way that the environment will continue to support future activities as it presently does (Ehrenfeld, 2008). Sustainability is an inherently vague concept whose scientific definition and measurement still lack wide acceptance (Phillis *et al.*, 2001; Briassoulis, 2001). Although sustainability is a goal for international and national policy-makers, there is no measuring yardstick against which to assess practical policy (Hinterberger *et al.*, 1997; WCDE, 1987). According to Phillis *et al.* (2001), the need for a practical tool to assess sustainability is crucial to policy-makers if they are to secure future development. Since such a tool is not available, management by trial-and-error instead of management by knowledge and prediction is currently the only way to establish sustainable policies. In the past decades, scientists were waiting for important political issues to be raised by policy makers, while these are waiting for important ecological issues to be raised by the scientist (Brink, 1989). However, there is an increasing effort on bridging the challenges in the measurement of sustainability between scientists and policy makers (Richardson and Waever, 2012). In view of this, the IPCC has brought the global scientific community together in order to assess the available documentation of human influence on the global climate system and provides political leaders with guidelines concerning the consequences of setting different limits on the potential size of the resources available for human use (Richardson and Waever, 2012; IPCC, 2013).

Becker and Jahn (1999) argued that it is not possible to consider social or environmental sustainability in isolation, therefore sustainability is not a specific feature of the environment or of society, but refers to the viability of their relationship over long periods of time. As such, sustainability is concerned with stabilised and preserved patterns within social-ecological transformations in which the natural environment is a central dimension. Enhancement of sustainability can be realised by focusing on three aspects: minimising environmental impact, maximising economic benefits and minimising socio-cultural impact (Bourdeau *et al.*, 1998). According to Mihelcic *et al.* (2003), sustainability is the design of human and industrial systems to ensure that mankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health, and the environment. This is a well accepted definition of sustainability.

Elkington (1997) expands the concept of sustainability to be used in the corporate community, developing the principle of triple bottom line (Ding, 2008). According to Cooper (2002), triple bottom line refers to the three prongs of social, environmental and financial performance, which are directly tied to the concept and goal of sustainable development. They are highly inter-related and are of equal importance. The triple bottom line concept underlies the multiple-dimensional evaluation process of development. To conform to the concept, a business must deliver prosperity, environmental quality and social justice, to be sustainable. Furthermore, the triple bottom line concept has been expanded and used as an audit approach for sustainable community development (Rogers and Ryan, 2001). Effective sustainability measurement should consider the complete triple bottom line of economic, environmental, and societal performance (Bennett and James, 1999).

Mukherjee and Muga (2010) developed an integrated framework that allows reorganisation and integration of existing sustainability research in the architecture, engineering, and construction (AEC) industry, emphasising the perspective of decision-makers and stakeholders. They saw the need to develop an integrative framework (see Figure 2.1) that allows characterisation and classification of existing research and its relevance to sustainable design and construction.

Problem Solution Methods		**Problem Formulation Techniques → More Inter-disciplinary →**	
		Reductionist	Systemic
MORE COMPLEX	Reductionist	Design methods: • Static • Deterministic • Optimal • Exact and mechanistic • Simplicity rewarded **Activity Level**	Some inclusion of context • One or more elements considered • Emphasis on lean design • Emphasis on value engineering • Complexity acknowledged – if only qualitatively **System Level**
	Systemic	Long term system performance • Dynamic • Stochastic • Steady-state/ Equilibriums • Counter intuitive behaviors • Simplicity encouraged **Project Level**	The "inter-dependent web" • Multiple disciplines considered • Dynamic behavior critical • Complexity fundamental • No "correct answer" • What-if scenarios considered **Integrated Assessment of Sustainable Decision Making**

Figure 2.1: Sustainability as Method

(Source: Mukherjee and Muga, 2010)

The framework disambiguates the implications of the term "sustainability," and expresses it in terms of quantifiable metrics rather than conceptual constructs. The foundation of the framework relying on a problem classification method based in problem formulation and problem-solving methods allows seamless integration of top-down decision support for sustainability.

Koo *et al.* (2008) stated that a sustainability assessment model should have the capability to assess how present decisions for infrastructure development affect the future. This decision is based on reciprocal evaluations between rather oxymoronic values such as development against environmental protection, natural asset conservation, social and cultural value, and economical efficiency. Development of a sustainability assessment model at a practical level for physical infrastructure system development is still in its infancy.

Briassoulis (2001) stated that a systems approach consistent with the basic principles and requirement for sustainability has been proposed to consider strategic sustainable development planning at a company level. The approach thereby attempts to cover social and ecological sustainability on the basic principle level, translate the definition of sustainability to the institutional level, manage the strategic perspective through a step-by step approach whereby economic performance is taken into account regarding short-term and long-term risks, advocate the development of indicators that have this perspective, and show how various initiatives on this arena relate to such a sustainability perspective. However, the proposed synergy of the available tools does not adequately assist industry decision-makers (at company management level) who are required to assess and evaluate their operations in terms of internal and external impacts (Labuschagne *et al.*, 2005). According to Hockerts (1999), optimal decisions can only be made when the economic, social and environmental consequences are taken into consideration. A definite need has therefore been identified to develop a comprehensive framework of sustainability criteria that focuses on operational practices in the manufacturing sector, and more specifically the assessment of the sustainability performances of technological developments during project management (Warhurst, 2002).

2.3.2 Principles of Sustainable Construction

Research in sustainable construction has been carried out by many authors. This includes the development of framework for attaining sustainable construction (Hill and Bowen, 1997) and framework for implementing sustainable construction practice (Tan *et al.*, 2011). According to Kibert (1994a), the term 'sustainable construction' was originally proposed to describe the responsibility of the construction industry in attaining `sustainability'. The first International Conference on Sustainable Construction was held in 1994, with a major objective to assess progress in the new discipline that might be called 'sustainable construction' or 'green construction' (Hill and Bowen, 1997). Sustainable construction was proposed to mean `creating a healthy built environment using resource-efficient, ecologically based principles'. The term high performance, green and sustainable construction are often used interchangeably. However, the term sustainable construction most comprehensively addresses the ecology, social, and economic issues of a building in the context of its community (Kibert, 1994b). Wyatt (1994) has considered sustainable construction to include ‘cradle to grave’ appraisal, which includes managing the serviceability of a facility during its lifetime and eventual deconstruction and recycling of resources to reduce the waste stream usually associated with demolition. The principles are divided into the four main ‘pillars’ of sustainability - social, economic, biophysical, and technical- with a set of over-arching, process-oriented principles. These process-oriented principles suggest approaches to be followed in deciding the emphasis to be given to each of the four `pillars’ of sustainability, and each associated principle, in a particular situation (Hill and Bowen, 1997).

The Conseil International du Batiment (CIB) in 1994 defined the goal of sustainable construction as “...creating and operating a healthy built environment based on resource efficiency and ecological design.” Kibert (2008) stated the seven principles of sustainable construction according to the CIB are resource consumption reduction, reuse resources, use of recyclable resources, nature protection, toxics elimination, life cycle costing application and focus on quality. These principles apply to the entire life cycle of construction.

According to OGC (2000), sustainable construction is the set of processes by which a profitable and competitive industry delivers built assets (buildings, structures, supporting infrastructure and their immediate surroundings) which enhance the quality of life and offer customer satisfaction, offer flexibility and the potential to cater for user changes in the future, provide and support desirable natural and social environments and maximise the efficient use of resources.

The key themes for action by the construction sector have been benchmarked by the UK DTI (2004), and these include the following:

• Design for minimum waste;
• Lean construction and minimise waste;
• Minimise energy in construction and use;
• Eliminate pollution;
• Preserve and enhance biodiversity;

• Conserve water resources;

• Respect people and local environment; and

• Monitor and report i.e., use benchmarks, etc.

In order to achieve the aim of sustainable construction as listed above, it is imperative that potential and existing adverse environmental impacts due to construction and demolition activities are borne in mind by practitioners (Chen *et al.*, 2008). Figure 2.2 presents the five guiding principles of sustainable construction based on the main elements of sustainable construction i.e. the social, environmental and the economic element.

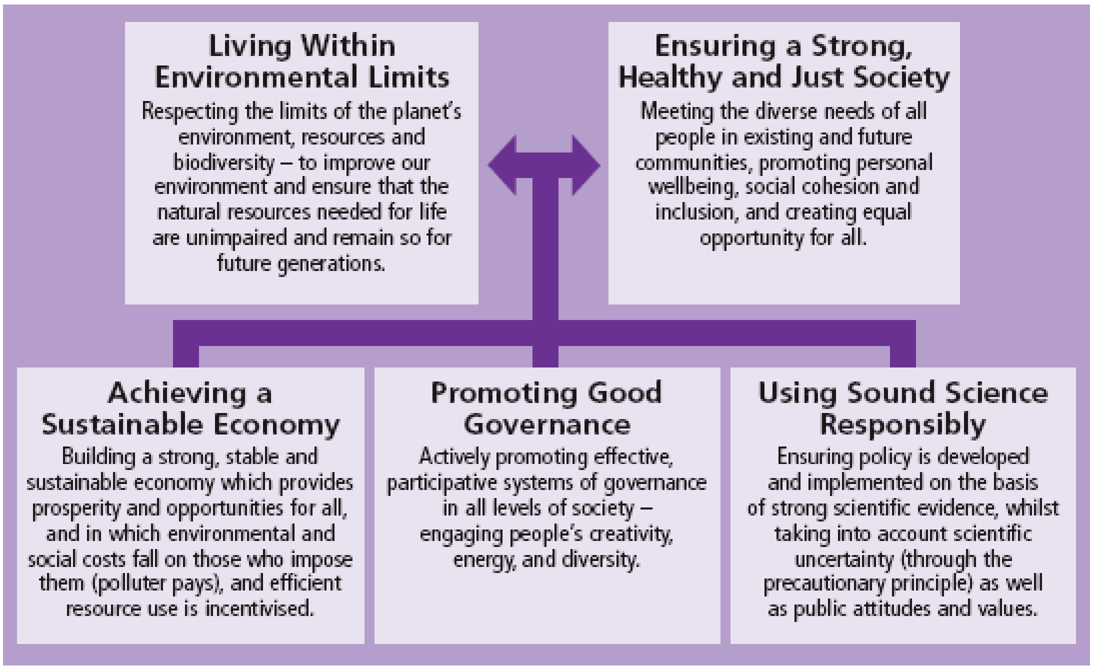

Figure 2.2: The Five Guiding Principles of Sustainable Development

(Source: DTI, 2006)

OGC (2000) stated that to move and to measure progress in a sustainable direction, a framework and a set of goals, are needed. The framework used is based upon the ten themes for action included in the strategy for more sustainable construction 'Building a Better Quality of Life'. These themes are re-use existing built assets, design for minimum waste, aim for lean construction, minimise energy in construction, minimise energy in use, do not pollute, preserve and enhance bio-diversity, conserve water resources, respect people and their local environment, and set targets.

2.4 The Concept of Lean Construction

Lean is a management philosophy focused on identifying and eliminating waste throughout a product's entire value stream, extending not only within the organisation but also along the company's supply chain network (Scherrer-Rathje, *et al*., 2009). Lean is achieved through a set of mutually reinforcing practices, including just-in-time (JIT), total quality management (TQM), total productive maintenance (TPM), continuous improvement (Kaizen), design for manufacturing and assembly (DFMA), supplier management, and effective human resource management (de Treville and Antonakis, 2006; Narasimhan *et al*., 2006; Shah and Ward, 2003, 2007). The concepts and principles of lean is to generally make the construction process leaner by removal of waste which is regarded as non- value generating activities (Koskela, 2000). Lean construction is a new production philosophy which has the potential of bringing innovative changes in the construction industry.

Shah and Ward (2007) pointed out that it is essential to differentiate between those studies considering lean from a philosophical perspective related to guiding principles or overarching goals, and those analysing the concept from a practical perspective as a set of management practices, tools, or techniques that can be observed directly. This is because the implementation of lean construction has been targeted towards some specific tools and principles without a full integration on different aspects such as supply chain, safety, planning and control, production design and management, culture and human aspects (Picchi and Granja, 2004; Alves and Tsao, 2007; Pavez and Alarcon, 2008). Framing an encompassing definition that covers all aspects of lean is seen as a difficult task (Petterson, 2009). Alves and Tsao (2007) stated that there are many denotations of lean when applied to construction. Therefore, this study deems it fit to scrutinise various definitions of lean as applied to construction. Table 2.2 presents various definitions of lean.

In the various definitions presented in Table 2.2, the common themes that are central to all the definitions are "customer", "value", and "waste". Therefore, it is essential that a broad definition of lean covers all the identified themes. Thus, in the context of this study, lean is defined as a philosophy and a production management-based system that uses tools and techniques to create a change in organisational culture and maximise value to the customer by identifying and eliminating waste, and pursuing perfection in the execution of a construction project.

Table 2.2: Definitions of lean

Sources	Definition
Manrodt *et al.*, (2008)	Lean is a systematic approach to enhancing value to the customer by identifying and eliminating waste (of time, effort and materials) through continuous improvement, by flowing the product at the pull of the customer, in pursuit of perfection
Ballard *et al.* (2007)	Lean is “a fundamental business philosophy – one that is most effective when shared throughout the value stream”
Lean Construction Institute (2012)	Lean construction is a production management-based project delivery system emphasising the reliable and speedy delivery of value
Radnor *et al.* (2006)	Lean is a philosophy that uses tools and techniques to create a change of organisational culture in order to implement the ‘good practice of process/operations improvement that allows the reduction of waste, improvement of flow, more focus on the needs of customers and which takes a process view’
Construction Industry Institute (2012)	“The continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and pursuing perfection in the execution of a constructed project.”
Shad and Ward (2007)	‘‘an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability.’’

Lean construction is similar to the current practices in the construction industry; both practices pursue meeting customer needs while reducing waste of every resource. However, the difference between the current practices and lean construction is that lean construction is based on production management principles, and it has better results in complex, uncertain, and quick projects. The adoption and application of some lean tools has faced a number of limitations, which is due to the nature of construction projects. One limitation to implementation of lean construction tools in the United States is the lack of investment in research from the construction industry (Howell, 1999). Paez *et al.* (2005) stated that the nature of the operation, planning, and execution are the key categories that emphasise the differences between manufacturing and construction. Due to these fundamental differences between construction and production processes, the tools of lean production cannot be directly used to manage construction processes and a new set of tools is required. The Last Planner system of production control, introduced in 1992, which emphasises the relationship between scheduling and production control, is the most completely developed lean construction tool (Ballard 2000). Howell (1999) stated that lean construction currently is still in early stage of development. However Salem (2005) stated that tools such as Last Planner have been tested in the field and refined over the last decade. Other tools such as visualisation, daily huddle meetings, 5S have not been extensively tested and concrete procedures for their implementation are being developed.

There are seven types of waste identified under lean: overproduction, overstocking, excessive motion, waiting time, delay and transportation, extra-processing, defect and rework. However, lean offers significant benefits in terms of waste reduction and increased organisational and supply chain communication and integration (Ogunbiyi *et al.*, 2013). The various methodologies for attaining lean production include just in time (JIT), total quality management, concurrent engineering, process redesign, value based management, total productive maintenance and employee involvement (Womack and Jones, 1996).

2.4.1 The Key Characteristics and Element of Lean Construction

Lean construction conceives a construction project as a temporary production system dedicated to three goals of delivering the project, maximising value, and minimising waste (Koskela, 2000). Lean construction had three initial sources of inspiration, the impact of which has been sustained by dissatisfaction with the practical accomplishments of project management (Koskela, 1999).

Hook and Stehn, (2008) stated that lean construction research has traditionally focused on a top-down (top-management initiated project performance) tool approach to improve construction projects. Theoretical and empirical proofs show that error-proofing and continuous improvement is statistically connected to worker motivation, and that workers follow standardised routines if they are visual and clear to workers (Abdelhamid and Salem, 2005; Hook and stehn, 2008). They stated further that workers do not take own responsibility to obtain standardisation in work and maintenance of equipment and tools.

Hook and Stehn, (2008) stated that the deep-rooted project culture in construction, e.g. including the production set up, the construction site and the temporary organisation, is stated to be a hindrance when applying lean principles. Hook and Stehn argued that the biggest challenge to achieving a long-term benefit of lean application in industrialised housing production (80 % of the work in a factory environment) is how to approach a lean culture.

OGC (2000) stated that the aim for lean construction is to work on continuous improvement, waste elimination, strong user focus, value for money, high quality management of projects and supply chains, and improved communications. Lean construction has been adopted by the construction industry as a means of supply chain improvement (Ballard and Howell, 2003; Green and May, 2005; Jorgensen and Emmitt, 2009). According to Hook and Stehn (2008), the adoption of innovative management practices, such as supply chain management and lean thinking, from a manufacturing context (based on continuous processes and relationships) to the discontinuous and project-based construction industry is, however, problematic.

According to Vrijhoef and Koskela (2000) construction supply chain is characterised by the following elements:

- It is a converging supply chain directing all materials to the construction site where the object is assembled from incoming materials. The "construction factory" is set up around the single product, in contrast to manufacturing systems where multiple products pass through the factory, and are distributed to many customers.
- It is, apart from rare exceptions, a temporary supply chain producing one-off construction projects through repeated reconfiguration of project organisations. As a result, the construction supply chain is typified by instability, fragmentation, and especially by the separation between the design and construction of the built object.
- It is a typical make-to-order supply chain, with every project creating a new product or prototype. There is little repetition, again with minor exceptions. The process can be very similar, however, for projects of a particular kind.

The four focuses of supply chain in construction according to Vrijhoef and Koskela (2000) are: interface between the supply chain and the construction site, supply chain, transferring activities from the construction sites to supply chain and integrated management of the supply chain and the construction site.

Eriksson (2010) carried out a study on how to increase the understanding of how various aspects of lean thinking can be implemented in a construction project and how they affect supply chain actors and their performance. The core elements of lean construction are investigated reflecting how the various aspects of lean construction can be grouped into six core elements: waste reduction, process focus in production planning and control, end customer focus, continuous improvements, cooperative relationships, systems perspective. Figure 2.3 shows the house of lean production, adapted from the works of Hook and Stehn (2008).

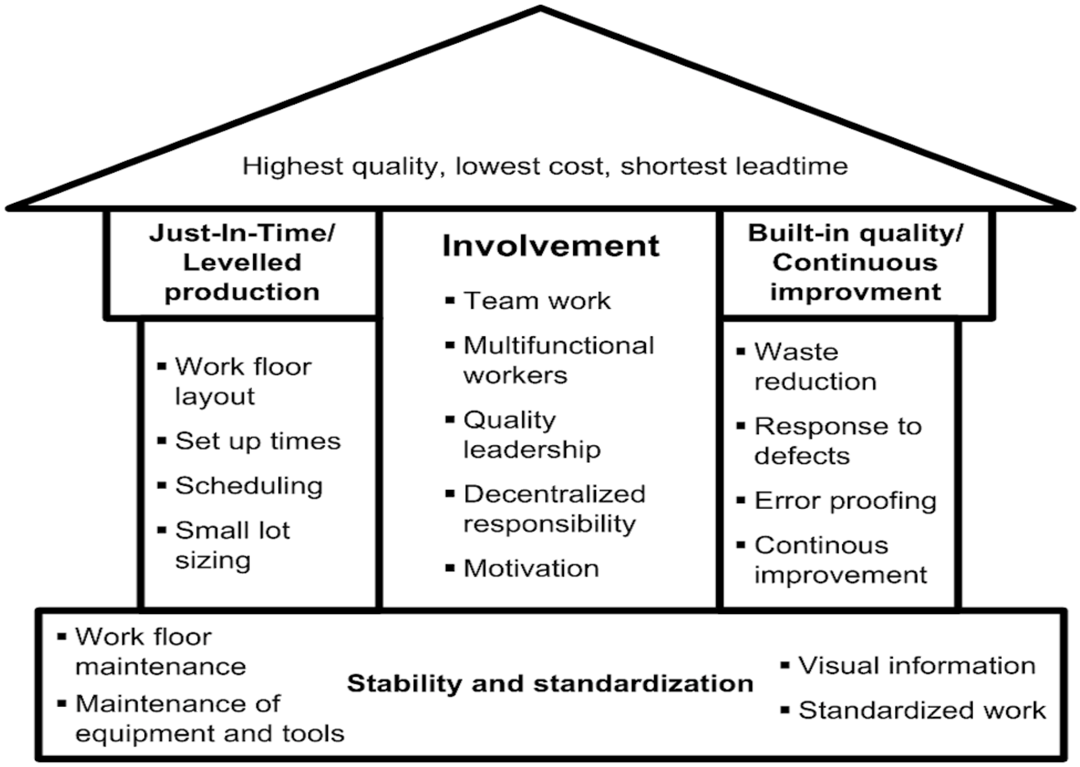

Figure 2.3: The House of Lean Production in the Context of the Literature Review, Representing a Lean Culture in Industrialised Factory Production

(Source: Hook and Stehn, 2008)

The common elements of lean according to Jorgensen (2006) and Womack and Jones, (2003) are:

- A focus on eliminating/reducing waste and sources of waste in relation to the delivery of artefacts or services that represent value to the end customer.

- End customer preference is adopted as the reference for determining what is to be considered value and what is waste.
- Management of production and supply chain from a (customer) demand pull approach.
- Approaching production management through focus on processes and flows of processes.
- An (at least to some degree) application of a system's perspective for approaching issues of waste elimination/reduction.

2.4.2 Lean Principles and Lean Thinking

Womack and Jones (2003) defined five lean principles to eliminate waste in organisations. Womack and Jones (1996) identified lack of strategic framework in translating lean production into other industries in their work. The guiding principles for creating a lean enterprise were then given to senior managers intending to make their organisation become lean after gathering case study materials of organisations considered to have adopted lean. The five lean principles identified are identify value from the customer perspective; map the value stream; achieve flow within the work process; achieve customer pull at the right time; and strive for perfection and continuous improvement (Picchi and Granja, 2004; Fewings, 2013; Hook and Stehn, 2008) These principles are referred to as the strategic approach term 'lean thinking'. Figure 2.4 represents the five lean principles described by Womack and Jones (1996) within which lean construction techniques can be successfully applied and the description of some of these lean techniques are given in Section 2.5.

The application of lean thinking in construction was pioneered by Koskela (2000) who suggested that construction production should be seen as a combination of conversion and flow processes for waste removal. The principles of lean is attributed to the manufacturing industry and was introduced to construction (Koskela, 2000). The application of the lean principles has been advocated in the UK, and several seminars and initiatives have been undertaken in an effort to encourage its uptake. The Construction Industry Research and Information Association (CIRIA), Construction Productivity Network (CPN), Construction Lean Improvement Programme (CLIP) and the Lean Construction Institute UK (LCI-UK) are some of the examples of institutions established. Seminars and conferences have been organised to tease out the main issues in the development and awareness of lean construction principles with real life case studies of some construction organisations presented (Construction Industry Environmental Forum, 2009). In spite of these efforts, there seems to be some barriers to the successful implementation of lean construction. Generally, the rate of lean implementation within the UK construction industry is relatively low and the application of lean in sustainable construction is still under explored (Mossman, 2009). Discussions relating to these principles are presented in the next Sub Sections in order to enhance the understanding of lean principles as applied to construction.

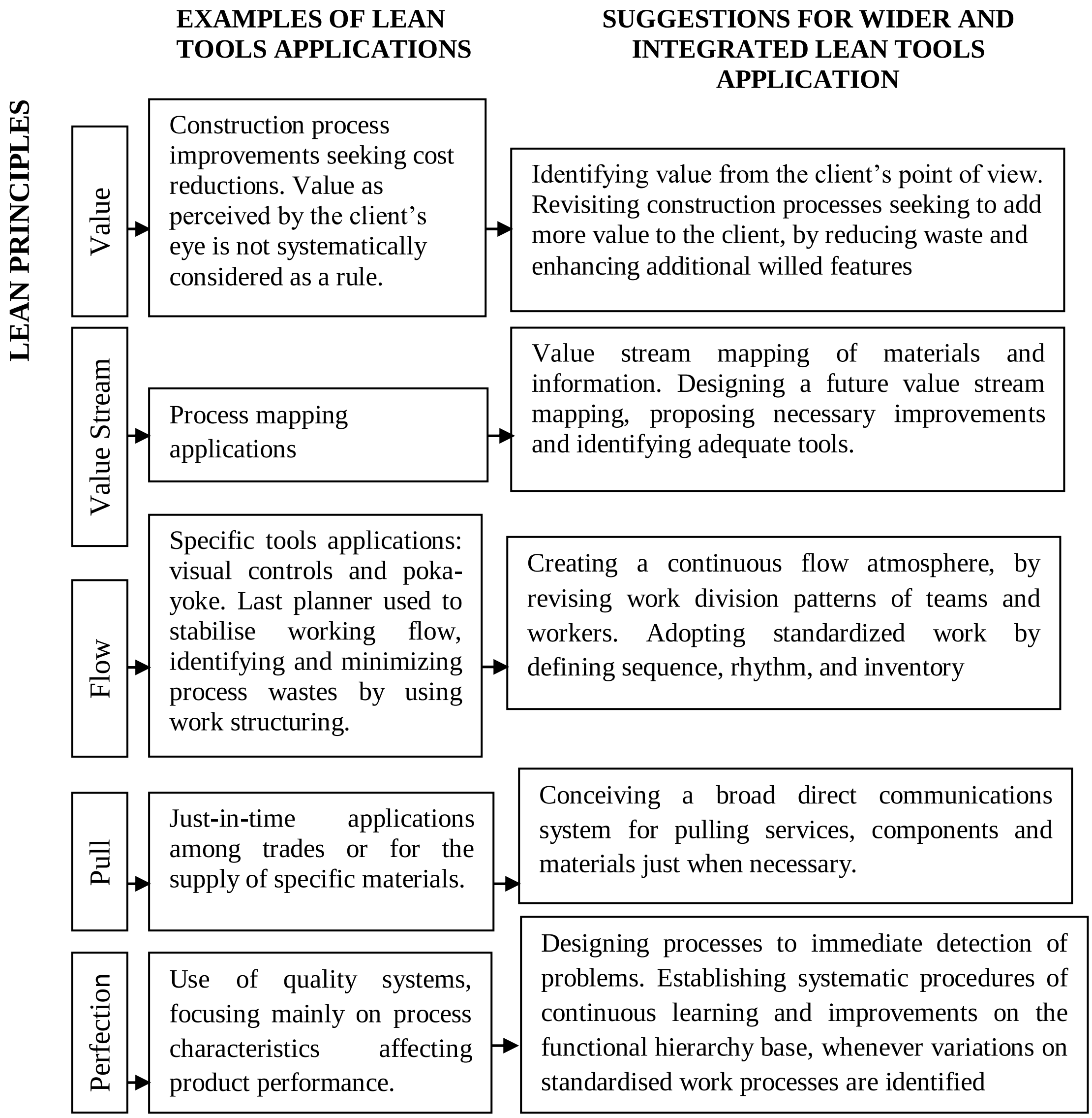

Figure 2.4: Examples of Lean Tools already Reported in Construction Implementation and Suggestion for wider and Integrated Application for Sector

(Source: Picchi and Granja, 2004)

2.4.2.1 Identifying Value

The principle of value in construction is considered from the point of view of the customer's perception i.e. specifying value from the customer's perspective. The definition of value in construction is subjective and complex. Koskela (2000) explored the use of the term 'value' and deduced that value can be related to either market value or utility value. This perception of value is supported by many other researchers as presented in lean construction papers. Value management and value engineering are the two methodologies used in gaining value knowledge about a building design. Value Management is described as, "Conceptualisation of production (from value viewpoint): As a process where value for the customer is created through fulfilment of his requirements" (Bertelsen and Koskela, 2002: 3). Value engineering refers to the analysis of technical building design to reduce cost but maintain fitness for purpose. Value management is concerned with understanding how the brief for a design can be developed so that a client's requirements can be captured in the design (Kelly and Male, 1993) thereby improving the value perception of the client. Ballard and Howell (1998) stated that value is generated through a process of negotiation between customer's ends and means. According to Lindfors (2000), value is the products or services that increase profit, decrease time and cost, and improve quality for the company and generate profit or value for the customer. Leinonen and Huovila (2000) mentioned three different kinds of value; exchange value, use value and esteem value. The first two can be translated directly into market value and utility value. The third value has a broader scope than only the product-customer perception. Marosszeky, *et al.* (2002) described the importance of working with project culture and values for achieving the desired level of quality. A model for reinforcing the manager's belief is applied, and it is concluded that each organisation tends to view quality from its parochial perspective due to the culture.

Value, as defined in Lean Thinking (Womack and Jones 2003), refers to materials, parts or products – something materialistic which is possible to understand and to specify (Koskela, 2004). Value may be divided into external and internal value (Emmitt *et al*., 2005) – external value is the clients' value and the value which the project should end up with, while internal value is the value that is generated by and between the participants of the project delivery team (contractor, architects, designers etc.).

Emmitt *et al.* (2005) stated that value is the end-goal of all construction projects and therefore the discussion and agreement of value parameters is fundamental to the achievement of improved productivity and client/user satisfaction. Emmitt *et al*. (2005) view value as an output of the collective efforts of the parties contributing to the design and construction process; central to all productivity; and providing a comprehensive framework in which to work. Value identification is vital in lean construction and must be established as client requires a product that fulfills its purpose, requirement and value for money (Ballard and Howell, 2004).

2.4.2.2 Value Stream Mapping

Mapping the value stream is the second principle of lean thinking. A value stream identifies every step necessary to create and deliver a product to the customer (Womack and Jones, 1996). The first step to understanding this is mapping the current state. Thus, identifying and mapping the value stream is a key requirement to implementing lean thinking. The value stream map is therefore an outline of operations that lead to valuable achievement of product and identifies alternative routes to maximise performance in the construction process (Dulaimi and Tanamas 2001; Forbes and Ahmed 2011). As noted by Fewings (2013), value stream entails all the value-adding steps required to design, produce and provide the product. In achieving an effective delivery process in a construction project, all the non-value adding activities must be minimised i.e. those activities that do not add value to the customer. The non-value adding activities consume resources such as time, space and money without adding value to the product (Forbes and Ahmed, 2011).

2.4.2.3 Achieving Flow in Processes

According to Fewings (2013), flow is a key process of perfecting and balancing the interconnected activities through which a product can be developed. The flow aspect has been suggested to be given more attention in construction instead of emphasising on the transformation aspect (Koskela and Howell, 2002). In managing flow, Koskela (2000) presented seven flows towards the perfect execution of a work package. These include space, crew, previous work, equipment, information, materials, and external conditions such as weather. It should be noted that each of these flows has its own nature and should be managed accordingly. Among these flows, the physical flow of materials is probably the easiest to deal with while the external condition is mostly the flow of unlikely things that may happen. According to Garnett *et al.* (1998), flow is strategically concerned with achieving a holistic route by which a product is developed. It attacks the fragmentation that is inherent in the construction industry by revealing it to be highly wasteful. The basic units of analysis in lean construction are information and resources flow.

2.4.2.4 Allowing Customer to Pull

Pull really identifies the need to be able to deliver the product to the customer as soon as the customer needs it at the strategic level. Pull is the ability to deliver the product to the client at the earliest possible time (Bicheno 2000). The principle of pull makes use of just in time applications to meet the client needs and subsequently customising and delivering them more predictably when the client requires them (Garnnet *et al.*, 1998). There are several risks and uncertainties associated with the delivery of construction project which may deter the delivery of a product to the client within the specified period and with minimum resources (Dulaimis and Tanamas, 2001).

2.4.2.5 Pursuing Perfection

This is a key concept at the strategic level because it defines the need for the way of working and organising to deliver construction products to become a way of life with an inherent culture. To achieve perfection means constantly considering what is being done, how it is being done and harnessing the expertise and knowledge of all those involved in the processes to improve and change it (Womack and Jones, 1996; Dulaimi and Tanamas, 2001). The principle of perfection involves producing exactly what the customer wants in terms of quality and quantity at the right time at a fair price and with minimum waste; the real target is zero waste (Bicheno, 2000). Perfection can be achieved through a continuous improvement in eliminating all forms of obstacles and non-value adding tasks along the flow process (Dulaimi and Tanamas 2001).

2.4.3 Three stages of Lean Construction

According to Green and May (2005), lean construction implementation efforts can be divided into three different stages, with an increasing degree of sophistication. Green and May (2005) are of the view that lean Stage 1 focuses on waste elimination from a technical and operational perspective. The responsibilities and focus are tied to managers rather than individual workers. Essential parts of this stage are: elimination of needless movements, cutting out unnecessary costs, optimising workflow, and sharing the benefits from improved performance (Green and May, 2005). The most important core element of lean construction is waste reduction (Green, 1999; Ballard and Howell, 2003; Jorgensen and Emmitt, 2008; Mao and Zhang, 2008). Fearne and Fowler (2006), Jorgensen and Emmitt (2008), and Mao and Zhang (2008) also stated that efficient transportation and stock holding of material, often termed just-in-time (JIT) delivery, is crucial for waste reduction in lean construction. According to Green and May (2005), another aspect of waste reduction is the off-site manufacturing of components and units. Pre-fabrication has many advantages similar to manufacturing industries, such as reducing material waste, shortening construction duration, improving work environment. Hence, increased pre-fabrication makes lean construction more similar to lean production in manufacturing industries.

Green and May (2005) stated that the Stage 2 focuses on eliminating adversarial relationships and enhancing cooperative relationships and teamwork among supply chain actors. The essential parts are cooperation, long-term framework agreements, workshops and facilitator. The workshops and facilitator role are needed in order to enhance good communication among the project participants which in turn improves integration and coordination (Pheng and Fang, 2005). Knowledge sharing and joint learning is important in enhancing continuous improvement. Therefore, the understanding of lean concept by projects participants must be improved (Green and May, 2005). This can be facilitated by relevant training in workshops where project participants meet periodically to exchange knowledge and experience and also jointly suggest ideas for the most visible problems in the workplace (Salem *et al.*, 2006). Aspects related to Stage 2, according to Eriksson (2010), are limited bid invitation, soft parameters, long-term contracts, collaborative tools, and broad partnering team. Lean Stage 2 does not go much beyond the concept of partnering since it is about eliminating waste derived from sub-optimisations and adversarial relationships through increased integration and collaboration.

Stage 3, according to Green and May (2005), is the most sophisticated because it involves a structural change of project governance. Its essential parts are information technology, pre-fabrication, Last Planner, bottom-up activities and emphasis on individuals, a rethink of design and construction, decreased competitive forces, long-term contracts, training at all staff levels, and a systems perspective of both processes and the product. Aspects related to lean Stage 3 are joint IT tools, pre-fabrication, Last planner, self-control, concurrent engineering, limited bid invitation, soft parameters, long-term contracts, special interest groups, training, suggestions from workers, coherent procurement decisions, large scale contracts, and properly balanced objectives. Only when striving to achieve Stage 3 is a radical change from other types of project governance required (Eriksson, 2010).

2.4.4 Priorities of Lean Construction

The main purpose of this section is to give a presentation of what lean construction priorities are. A review of contemporary literature on lean and a summary of benefits associated with lean as well as the stated purposes of the concept were carried out. Based on this, an evaluation of key themes of lean construction was made. Major citation databases (Science Direct, EBSCO, Elsevier, Scopus and ISI), and data sources (Emerald Journal and Lean Construction Journal) as well as Google Scholar were searched for articles containing the terms "lean construction" or "lean" in the article title and key themes.

The analyses in this section were accomplished on peer reviewed articles (Conference and Journal papers) in order to satisfy the research goals. The articles were gathered from different sources as listed above. In order to achieve a reliable analysis the unit of analysis was 'lean'. This presents a clear focus for the article searching. The literature searched covers decades of academic and industrial research, spanning from 1997 to 2013. This is because most of the works that are related to the main area of this research started in 1997 (LCI, 2012). The criteria for paper selection were based on relevance to the study, currency of the paper (in terms of the quality of the content) and the appropriateness of the key themes. The selected papers were read and the reviewed literature was then compared by listing the central theme of lean construction as presented by each author. The idea is that the purpose or priorities of lean construction should reasonably be the same for all authors and this consensus will indicate a reliability of the priorities.

Several papers were obtained from the search of the data sources published between 1997 and 2013. The most frequent keywords were identified and in order to ensure the reliability of analysis to be carried out the keywords were carefully tabulated under the appropriate theme as presented in Table 2.3. The number of papers from the overall search was reduced based on the aforementioned criteria.

This reduced the number of papers to 72, covering diverse and extensive research between 1997 and 2013. Table 2.3 presents the summary of the analysis. Based on the analysis shown in Table 2.3, productivity and performance, process tools and techniques, and sustainability and resource management are the most frequent themes that emerged.

Table 2.3: Priorities of lean construction

Year	Authors	Value Management	Waste Management	Environment, Health and Safety	Quality Improvement Initiatives	Productivity & Performance	Flow	Supply Chain Management	Cost Reduction	Change Management	Sustainability and Resource Mgt	Information Management	Process Tools/Techniques	Construction Project Management	Innovation	Research and Development	Operations Management
2013	Morrey *et al.*		x							x			x				
	Sarhan and Fox					x								x			
	Marhani *et al.*				x						x						
	Wu *et al.*			x							x						
	Fontanini *et al.*	x											x				
	Kemmer *et al.*										x			x			
2012	Sarhan and Fox					x											
	Nesensohn *et al.*														x		
	Koranda *et al.*										x			x			
	Anvari				x	x											
	Nahmens and Ikuma										x		x				
	Sacks *et al.*					x						x	x				
2011	Song and Liang					x											
	Bommel							x			x				x		
	Garrett and Lee	x	x			x					x		x	x			
	Jacobs					x											
	Anvari *et al.*		x			x											
	Tan *et al.*										x			x			
2010	Kim and Bae			x				x			x		x				
	Seed			x										x	x		
	Sacks *et al.*											x	x	x			
	Eriksson					x		x			x						x
	Al-Aomar	x				x											
	Elfving *et al.*					x							x	x			
2009	Wee and Wu				x	x		x	x								

Year	Authors	Value Management	Waste Management	Environment, Health and Safety	Quality Improvement Initiatives	Productivity & Performance	Flow	Supply Chain Management	Cost Reduction	Change Management	Sustainability and Resource Mgt	Information Management	Process Tools/Techniques	Construction Project Management	Innovation	Research and Development	Operations Management
2009	Alinaitwe					x											
	Alves *et al*.														x		
	Sacks *et al*.			x	x	x	x					x	x	x			
	Bae and Kim		x	x		x					x		x	x		x	
	Nahmens		x	x		x			x	x	x		x				
	Yu *et al*.	x				x					x		x	x			x
	Bergmiller and McCright			x		x					x						
	Mossman	x	x										x				
	Found			x		x					x						
	Salvatierra-Garrido *et al*.	x	x		x												
2008	Bae and Kim										x						
	Hook and Stehn					x											
	Jorgensen and Emmitt					x							x	x			
	Mao and Zhang					x	x						x	x			
	Senaratne and Wijesiri		x				x			x							
2007	Shah and Ward					x											
	Rivera and Chen					x			x								
2006	Salem *et al*			x		x								x			
	Kim and Park													x	x		
	Lapinski *et al*.										x						
	Achanga *et al*.					x											
	De Treville and Antonakis					x											
	de Miranda Filho													x			
2005	Riley *et al*.					x			x		x						
	Green and May					x				x				x			
	Paez *et al*		x			x								x			
	Pheng and Fhang					x								x			x
	Koerckel and Ballard					x					x				x		
2004	Arbulu and Ballard	x						x			x		x				
	Forbes and Ahmed	x			x	x		x	x				x	x			
	Emmitt *et al*.	x				x	x					x		x			

Year	Authors	Value Management	Waste Management	Environment, Health and Safety	Quality Improvement Initiatives	Productivity & Performance	Flow	Supply Chain Management	Cost Reduction	Change Management	Sustainability and Resource Mgt	Information Management	Process Tools/Techniques	Construction Project Management	Innovation	Research and Development	Operations Management
2003	Alarcon and Calderon					x						x		x		x	
	Thomassen *et al.*					x	x		x					x			
	Abdelhamid					x							x	x			
	Emmitt				x	x					x				x		
	Mastroianni and Abdelhamid	x								x			x	x			
2002	Liker and Lamb				x	x			x				x				
	Thomas *et al.*					x							x	x			
	Bertelsen					x							x	x			
	Ballard *et al.*					x	x						x				
	Freire and Alarcón	x					x			x			x	x			
	Alarcón *et al.*					x					x		x				
	Pasquire and Connolly					x				x			x				
2001	Dulaimi and Tanamas	x	x		x												
2000	Lantelme and Formoso					x											
1998	Huovila and Koskela										x		x	x			
1997	Tommelein	x				x					x		x				
	Number of Occurrence	10	7	6	6	46	6	6	7	7	22	6	28	29	7	2	3

The understanding of lean construction priorities among all stakeholders in the construction industry is essential in order to derive maximum benefit from lean construction implementation. Aside these, the dynamic, complex, and fragmented nature of the construction industry calls for a clear focus, and a resolution of the differing priorities of lean construction. The absence of a clearly defined priority of lean construction might impact a number of consequences for potential lean implementers, organisations, as well as researchers trying to explore the essence of the concept.

2.5 Lean Construction Tools and Techniques

Within a company, there are many lean tools and techniques that can be used. These tools and techniques include value stream, 5S, Just-in-Time, visual management, preventative maintenance, continuous improvement activities, kanban. The adoption of lean approach within a company has potential significance in terms of productivity, service delivery and quality which ultimately results in substantial cost savings.

Salem *et al.* (2005) in their study 'Site Implementation and Assessment of Lean Construction Techniques' carried out an evaluation on lean construction tools such as Last Planner, increased visualisation, daily huddle meetings, first run studies, 5S process, and Fail Safe for quality and safety. The effectiveness of the lean construction tools was evaluated through the lean implementation measurement standard and performance criteria. It was found that Last Planner, increased visualisation, daily huddle meetings, and first run studies achieved more effective outcomes than expected on the project. However, the results of implementation of 5S process and fail safe for quality did not meet the expectations of the tool champions and the research team. It was found that there is 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.

2.5.1 Last Planner System

Last Planner System (LPS) is a technique that shapes workflow and addresses project variability in construction. It is a system of production control that emphasises the relationship between scheduling and production control to improve flow of resources (Ballard, 2000; Fewings, 2013). The Last Planner is the person or group accountable for operational planning, that is, the structuring of product design to facilitate improved work flow, and production unit control, that is, the completion of individual assignments at the operational level (Ballard, 2000). People, information, equipment, materials, prior work, safe space and safe working environment are the seven flows required to come together at the workplace to enable construction transformation to flow. The Last Planner System (LPS) manages all seven flows by building relationships, creating conversations, and by securing commitments to action at the right level at right time throughout the process (Mossman 2008). According to Ballard and Howell (1994), the use of Lean-based tools like Last Planner reduces accident rates.

The aim of Last Planner System according to Ballard (1997) is to improve productivity by eliminating barriers to workflow. One of the main advantages is that it replaces optimistic planning with realistic planning by assessing the last planners' performance based on their ability to achieve their commitments (Salem et. al, 2005).

2.5.2 Increased Visualisation

According to Moser and Dos Santos (2003), the increased visualisation lean tool is about communicating key information effectively to the workforce through posting various signs and labels around the construction site. This is because workers can remember elements such as workflow, performance targets, and specific required actions if they visualise them. Salem *et al.* (2005) noted that increased visualisation tool makes operations and quality requirements clearer using charts, displayed schedules, painted designated inventory and tool locations. This tool is similar to the lean manufacturing tool, Visual controls, which is a continuous improvement activity that relates to the process control (Abdelhamid and Salem 2005).

2.5.3 Daily Huddle Meetings

Two-way communication is the key of the daily huddle meeting process in order to achieve employee involvement (Schwaber 1995, cited by Salem *et al.* 2005). With awareness of the project and problem solving involvement along with some training that is provided by other tools, employee satisfaction (job meaningfulness, self-esteem, sense of growth) will increase. This is a lean construction tool where a brief daily start-up meeting is conducted. This allows the team members to quickly give the status of what they have been working on since the previous day's meeting, especially if an issue might prevent the completion of an assignment (Salem *et al*., 2005).

2.5.4 First Run Studies

According to Ballard and Howell (1997), First Run Studies are used to redesign critical assignments, part of continuous improvement effort; and include productivity studies and review work methods by redesigning and streamlining the different functions involved. The use of video files, photos, or graphics to show the process or illustrate the work instruction is common with First Run Studies (Abdelhamid and Salem, 2005). The first run of a selected assignment should be examined in detail, bringing ideas and suggestions to explore alternative ways of doing the task. A PDCA cycle (plan, do, check, act) is suggested to develop the study (Forbes and Ahmed 2011). “Plan” refers to select work process to study, assemble people, analyse process steps, brainstorm how to eliminate steps, check for safety, quality and productivity (Salem *et al.*, 2006). “Do” means to try out ideas on the first run. “Check” is to describe and measure what actually happens. “Act” refers to reconvene the team, and communicate the improved method and performance as the standard to meet. This tool is similar to the combination of the lean production tool, graphic work instructions, and the traditional manufacturing technique, time and motion study (Abdelhamid and Salem 2005).

2.5.5 5S Process

The 5S process (sometimes referred to as the Visual Work Place) is about “a place for everything and everything in its place”. It has five levels of housekeeping that can help in eliminating wasteful resources (Kobayashi 1995; Hirano 1996): “Seiri” (Sort) refers to separate needed tools / parts and remove unneeded materials (trash). “Seiton” (Straighten or set in order) is to neatly arrange tools and materials for ease of use (stacks/bundles). “Seiso” (shine) means to clean up. “Seiketsu” (standardize) is to maintain the first 3Ss. Develop a standard 5S’s work process with expectation for the system improvement. ‘Shitsuke’ (sustain) refers to create the habit of conforming to the rules.

This tool is similar to the 5S housekeeping system from lean manufacturing (Abdelhamid and Salem 2005). The material layout is commonly used for acceleration of 5S implementation on the construction site. Spoore (2003) states that 5S is an area-based system of control and improvement. The benefits from implementation of 5S include improved safety, productivity, quality, and set-up-times improvement, creation of space, reduced lead times, cycle times, increased machine uptime, improved morale, teamwork, and continuous improvement (kaizen activities).

2.5.6 Fail Safe for Quality and Safety

The “Poka-Yoke” devices as new elements that prevent defective parts from flowing through the process were introduced by Shingo (1986). Fail safe for quality relies on the generation of ideas that alert for potential defects. This approach is opposed to the traditional concept of quality control, in which only a sample size is inspected and decisions are taken after defective parts have already been processed. This is similar to Visual inspection (Poka-Yoke devices) from lean manufacturing. Fail Safe can be extended to safety but there are potential hazards instead of potential defects, and it is related to the safety risk assessment tool from traditional manufacturing practice. Both elements require action plans that prevent bad outcomes. The logic of lean construction implementation requires a certain sequence of initiatives, which progressively reveal additional opportunities for improvement (Ballard, 1997).

2.5.7 Concurrent Engineering

Concurrent engineering has been defined as the parallel execution of different development tasks in multidisciplinary teams with the aim of obtaining an optimal product with respect to functionality, quality, and productivity (Rolstadås, 1995). Concurrent engineering goes beyond diagrams, charts, and algorithms. It demands a multidisciplinary team effort where information sharing and communication are key to identify ideas (Kamara, 2003). According to Gil *et al.*, (2000), the success in lean product process development relies on the involvement of all participants in the early design. Therefore, the relationship with client should not be overlooked as the client may facilitate concurrent engineering efforts that reduce the project’s cost. Partnering with subcontractors and suppliers can also influence the outcome of concurrent engineering efforts.

2.5.8 Value Stream Mapping

Value stream, according to Womack and Jones (1996), is “the set of all specific actions required to bring a specific product through the three critical management tasks of any business; the problem-solving task running from concept through detailed design and engineering to production launch, the information management task proceeding from raw materials to a finished product in the hand of the customers".

Paez *et al*. (2005) classified the operative techniques utilised in lean construction into three levels. The different levels are described below, and the classification is summarised in the Table 2.4.

1. Level One: Direct application of the techniques from lean manufacturing.

2. Level Two: Modification of the techniques taken from lean manufacturing.

3. Level Three: The all-in-all lean construction specific techniques.

Table 2.4: Classification of Lean Methodologies/Tools

Levels	Lean Construction Technique	Related Lean Manufacturing Technique
Level One	- Material Kanban Cards	- Kanban System
Level Two	- Visual Inspection - Quality Management Tools - Concurrent Engineering	- Visual Inspection (Poka Yoke Devices) - Multifunctional Layout - T.Q.M - Standard Operations -Single Minute Exchange of Dies (S.M.E.D.)
Level Three	- Last Planner - Plan Conditions of Work Environment (P.C.W.E.) - Daily Huddle Meetings	- Kanban System - Production Leveling - Toyota Verification of Assembly Line (T.V.A.L.)

(Source: Paez *et al*., 2005)

Several examples of the application of lean construction techniques were presented by Forbes *et al.* (2002). These include a Brazilian company which collaborated on a research programme with the University of Sao Paulo to improve the integration of design and production processes; VerticonConstrucao e Empreendimentos Ltda who used last planner on a 90 days construction project; and the application of the Last Planner Control System on a housing project in Quito, Ecuador.

Some of the benefits achieved are presented respectively: Communication and motivation among the design team influenced the integration of design features with process considerations directly, the implementation of lean construction and control procedures significantly improved production efficiency, in terms of buildability and production cost control and elimination of not only material waste, but non-adding value tasks as well. Additional benefits include a reduction in project duration from 90 days to 83 days, reduced rework. The last planner facilitated improved quality control and the application of lean methods, the Percent Plan Complete (PPC) and Performance Factor (PF) improved. It was proven at the construction site that look ahead planning enables one to keep current activities linked with the master pull schedule.

However, lean construction is not without its barriers. The lean approach maximises value delivered to the customer while minimising waste. The implementation of this philosophy is still facing difficulties due to the variability of construction processes and products. There are several barriers to the implementation of lean construction techniques. Ogunbiyi *et al.* (2011) presented a detailed list of barriers to the implementation of lean construction. These barriers have been classified as technological barriers, financial barriers, external barriers, and internal barriers such as human factor, culture factor, and learning factor (Bashir, *et al.*, 2010). The inability of some companies to sustain the benefits arising from the use of lean construction principles this way was attributed to lack of integration of lean construction implementation within their business strategy (Ogunbiyi *et al.*, 2011).

2.6 Benefits of Lean Construction

The theory of how lean production can work in a construction environment for the purpose of achieving the same benefits as derived in the automotive industry was initiated by Koskela in 1992. He reviewed the theory of lean production in terms of its constituent elements and its conceptual basis (i.e. what is a production philosophy?). Construction was defined as a production philosophy and the problems that practitioners would have in adopting the approach was identified (Koskela, 1992). The three layers of lean production identified by Koskela are as follows:

- A production method which was effective and waste free
- A general management philosophy
- A set of tools to continuously improve quality

Koskela (2000) further argued that construction production should not be seen as conversion activities but rather a process flow. Some of the benefits of adopting a process flow viewpoint include the removal of non-value adding activities such as waiting, transporting and inspection of material. Two important aspects were identified in the general management philosophy of lean production: the reorganisation of the work force to facilitate new operating processes, and the cultural changes that are required within the firm and individuals for the success of the lean production philosophy. It therefore, becomes imperative for a company intending to adopt a lean production philosophy to consider what the most suitable organisation structure would be for the new way of working. Similarly, it is essential for the company to adapt existing techniques to suit its own unique environment or create other tools and techniques to support its new operating and management structures. It should be noted that the tools and techniques are developed to support the other two aforementioned elements.

Shah and Ward (2007) stated that it is important to distinguish between those considering lean from a philosophical perspective related to guiding principles or overarching goals, and those analysing the concept from a practical perspective as a set of management practices, tools, or techniques that can be observed directly when scrutinizing studies addressing lean. Scherrer-Rathje *et al.* (2009) stated that despite the significant benefits lean offers in terms of waste reduction and increased organisational and supply chain communication and integration, implementing lean and achieving the levels of organisational commitment, employee autonomy, and information transparency needed to ensure its success is a daunting task. Not every company will be successful in its first attempt to get lean.

Scherrer-Rathje *et al*. (2009) carried out research on two lean implementation projects within a leading European manufacturer of food processing equipment. According to them, the first project, attempted in 1997, was a failure. The second project, launched in 2006, is currently viewed to be a success as measured in terms of management commitment, employee autonomy, information transparency, cultural fit, short-term performance improvement, and long term sustainability of lean efforts. According to Scherrer-Rathje *et al.* (2009) lean from a practical or operational perspective involves implementing a set of shop floor tools and techniques aimed at reducing waste within the plant and along the supply chain. Such tools and techniques include, for example, setup time reduction, kaizen (i.e., continuous improvement), six-sigma quality, visual displays (e.g., 5S), kanban, just-in-time supply systems, preventative maintenance, last planner, and first run studies (Mossman 2008; Shah and Ward, 2003; Ballard, 2000; White and Prybutok, 2001). Lean as a philosophy, however, considers the interrelationship and synergistic effect of these practices in order to improve overall levels of productivity and product quality, waste reduction outside of traditional manufacturing (e.g., R&D, accounting), integration and interaction across functional departments, and improved work force autonomy (Liker 2004).

Scherrer-Rathje *et al.* (2009), in their study considered lean success to occur if a company achieves the major strategic components of lean (management commitment, employee autonomy, information transparency, and cultural fit), successfully implements a number of practices to support the operational and tactical aspects of lean (e.g., JIT, one-piece work flows, continuous improvement, training programs), and provides evidence of performance improvements and sustainability of the lean programme in the long-term.

2.6.1 Lean Approach in Sustainable Construction

Lean construction is one of the strategies for improving the sustainability of construction. In other words, it is one method of achieving sustainable construction. The Lean approach in sustainable construction focuses on the removal of all forms of wastes from construction processes to allow more efficiency. Existing studies have suggested theories which reinforce lean as a method for optimising resources, improving safety, productivity, working conditions and overall, the social, environmental, and the economic bottom line (Nahmens and Ikuma, 2012). There are several forms of waste under the lean terminology: processes, material and poor safety are considered as potential wastes that hinder the flow of value to the client. Material waste elimination has been identified as the most efficient and cost effective approach to promote sustainable practise on construction sites. Similarly, the principles of lean construction focus on creating a sustainable change by stressing on efficient, waste-free and safe flow, storage and handling of materials to minimise cost, energy and resource consumption, and provide value for clients and end users (Nahmens and Ikuma, 2009).

One of the key issues of sustainability identified in the literature include climate change which is seen as one of the main threats to the environment as a whole (IPCC, 2007). Many studies have highlighted the contributions of lean construction towards the environmental aspect of sustainability. For example, Huovila and Koskela (1998) presented the minimisation of resource depletion, pollution and matching business and environmental improvement as the contribution of lean construction to sustainable development. However, the contribution of lean construction to sustainable development goes beyond the environmental aspect but also extends to the social and economic aspects. The different lean applications might have different results on the three pillars of sustainable development.

The lean impact has been described to cover the economic, social and environmental aspects of sustainable construction. One good example of this is the case study of the modular home building by Nahmens and Ikuma (2012) which was carried out to evaluate the use of lean construction to improve sustainability. Lean construction strategies serve as a platform for improvement in the delivery of the sustainable modular houses. Figure 2.5 presents the main effect of the application of the lean concept for the purpose of sustainability in the aforementioned example.

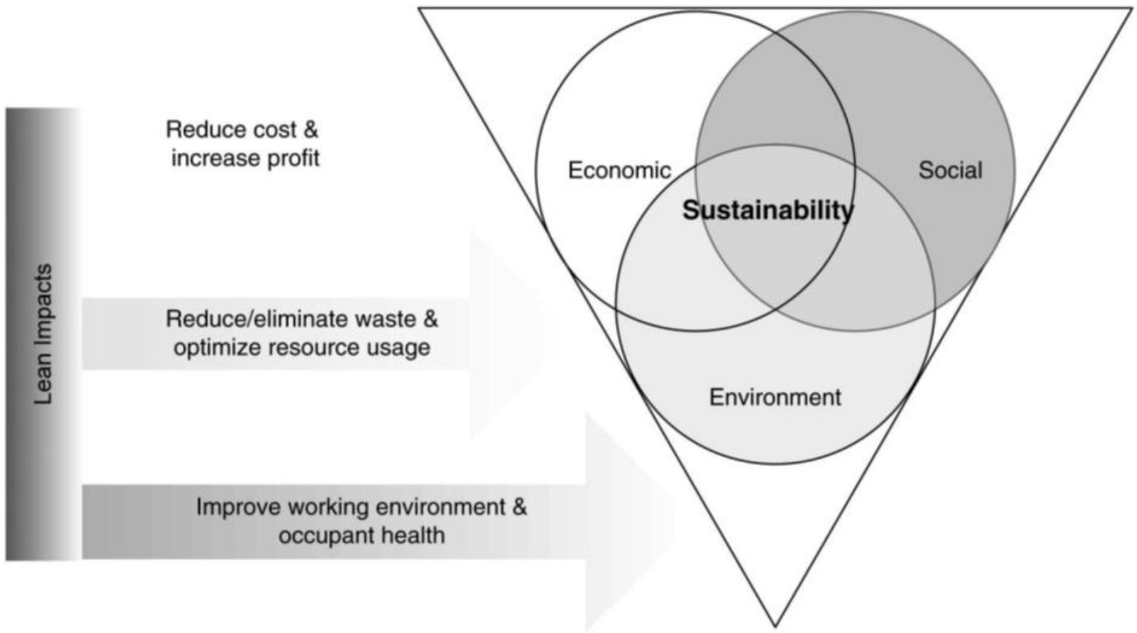

Figure 2.5: Conceptual Model: Effect of Lean on Sustainability

(Source: Nahmens and Ikuma, 2009)

As much as adopting the lean concept has been attributed to making a positive influence on sustainable construction in terms of improved safety, many researches have shown both negative and positive effects of lean on safety. However, in terms of sustainability, lean and safety influence economic sustainability by reducing costs and increasing productivity, environmental sustainability by reducing or improving materials and social sustainability by affecting the well-being of workers.

2.6.2 Sustainable Practice and the Lean Concept

According to Tan *et al.* (2011), sustainable construction practices include five major areas: compliance with sustainability legislation, design and procurement; technology and innovation; organisational structure and process; education and training; and measurement and reporting. The successful implementation of lean and sustainable concepts by an organisation depends on the level of commitment and knowledge of lean and sustainability by the organisation. The implementation of sustainability throughout the organisation including the organisation's project will yield more result than when implemented only on the project (Beheiry *et al*., 2006). Different organisation characteristics can influence the choices in sustainable construction practices. The selected sustainable construction practices should be consistent with the overarching strategy. The benefits of implementing sustainable practices include reduction of liability and risk; reduction of harmful impacts to the environment; prevention of pollution and waste (which can result in cost reduction); improvements in site and project safety (by minimising injuries related to environmental spills, releases and emissions); improved relationships with stakeholders such as government agencies, community groups, and clients (Christini *et al.*, 2004).

The benefits of implementing sustainable practices in construction can be grouped under environmental, economic and social aspects. Hall and Purchase (2006) stated that numerous sustainability and lean practices, such as productivity, safety, efficiency, and waste minimisation, are interconnected. The conceptual relationship between lean and sustainability has been presented in the literature. Lean practices can be adopted in a construction project at the design phase to reduce costs and enhance sustainability (Ogunbiyi *et al*., 2012; Bae and Kim, 2008). Despite the pressure on the construction industry to adopt the concept of sustainability to improve the current unsustainable pattern of project delivery, its uptake is relatively slow i.e. there is a slow adoption of sustainable practice in construction projects. Koranda *et al.,* (2012) developed a framework for implementing lean techniques and sustainability in a construction project as shown in Figure 2.6. This framework captured the major sustainability issues at project level, but does not capture the implementation of lean and sustainability at strategic level. However, lean can be positively applied to any aspect of an organisation's continued sustainability and provides a method for achieving organisational goals (Soltero, 2007). These goals may be related to cost reduction, quality improvement, reduction of environmental impact, and improvement in safety.

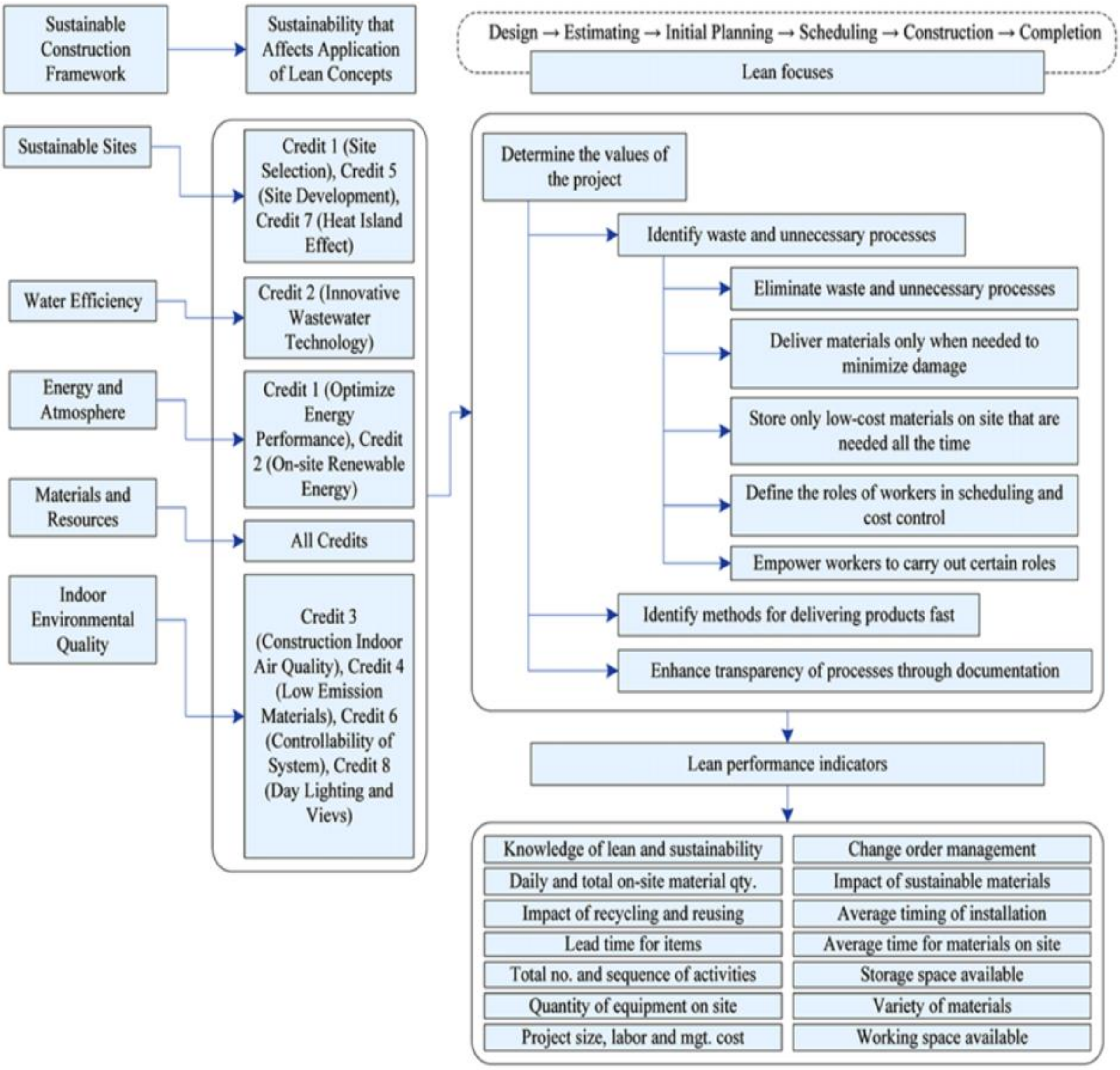

Figure 2.6: Framework for Implementing Lean Techniques and Sustainability in a Construction Project

(Source: Koranda *et al.*, 2012)

There is a need for leadership participation in the quest for attaining a more sustainable construction as the leadership role in construction organisation is one of the paramount factors that can provide an overall direction and vision towards the attainment of sustainable construction. Therefore, it is essential that leaders have full knowledge of the concept of sustainability to be able to guide their organisations effectively (Opoku and Fortune 2011). Likewise, top level leadership commitment has been identified as one of the success factors for the implementation of lean. This suggests that thorough understanding of the lean and sustainability concepts as well as principles are necessary for proper application in an organisation.

The availability of managerial tools and methodologies to measure and improve performance is becoming increasingly important as companies move toward sustainable construction and lean. Such tools include performance measurement and benchmarking, which can help construction companies to realise the benefits of lean and sustainable construction (Presley and Meade, 2010; Bhasin, 2008). Companies need to understand how key performance measures can guide and drive a firm's execution towards superior results in any area since performance measures enable an organisation to gauge whether progress is being made against targets (Bhasin, 2008). Therefore, the description of performance measurement and a review of existing lean frameworks are presented in the next chapter.

2.7 Summary

This chapter has drawn from literature on both lean and sustainability reflecting the principles of lean and sustainable construction. In relation to this study, lean has been defined to capture the common themes as presented in the various definitions. Better understanding of lean concepts by the construction industry can contribute to improvement in all aspects of sustainable construction. The concepts of lean and sustainable construction both seek to minimise waste during construction, but this is achieved through different approaches. The improvement through the reduction of waste is an important link between lean and sustainability. These two initiatives are both driven from top down within firms.

This Chapter also presents the nature of the construction industry, and an overview of the UK construction industry and sustainability. The unique characteristics of the construction industry are also discussed. The UK construction industry has been rising up to the challenge of sustainability as they are under increasing legal and commercial pressure to become more sustainable.

Lean practices can lead to environmental benefits; inversely environmental practices often lead to improved lean practices. The lean concept has a positive influence on sustainable construction in terms of improved safety. However, the contribution of lean construction to sustainable construction goes beyond the environmental aspect but also extends to the social and economic aspects. Lean implementation can exist at two levels strategic and operational, therefore the implementation issues can be viewed from both perspectives. The lean approach has delivered significant economic benefits to companies. Companies are under increasing pressure to deliver profit improvement and to operate their business in a responsible manner bearing in mind the activities' impact on society and the environment.

CHAPTER 3: THEORETICAL REVIEW OF LEAN FRAMEWORKS AND ORGANISATION PERFORMANCE MEASUREMENT

3.1 Introduction

The main goal of this chapter is to review and present the existing frameworks relating to lean implementation. Many researchers have made contributions to framework developments in the area of lean and more specifically in lean manufacturing. A few studies have developed frameworks in the area of lean construction. However, many of these frameworks lack a sound theoretical base, effective change management and completeness, and are not easily applicable. Nevertheless, these frameworks all have their advantages and disadvantages (i.e. area of strength and weakness). This chapter also presents the review of different approaches to evaluating and assessing an organisation performance. It then presents the common approaches to developing frameworks and the approaches in-use in organisations. Therefore, this chapter fulfils Objective 5 and Research Questions VII of the research study (see Table 1.1).

3.2 Process Improvements Methodologies

There are various methodologies for process improvement. These include Six Sigma, Lean, Lean Six Sigma, Agile Management, Re-engineering, and Total Quality Management (TQM). These improvement approaches are related to lean either based on their philosophy or principles. Most of the approaches to organisational improvement have been suggested to provide a significant contribution. Therefore a review of some of these approaches can contribute to the objective of this study. A brief description of some of these methodologies and the list of their common characteristics will be provided in order to determine if the approach is related to lean.

3.2.1 Total Quality Management

The drive for Total Quality Management (TQM) by many organisations is to improve quality, productivity, and competitive position (Hunt, 1992). TQM has been described by Besterfield (1995) as both philosophy and a set of guiding principles that represents the foundation of a continuously improving organisation. Ross and Perry (1999) explained the concept of TQM as a management strategy that seeks to embed awareness of quality in all organisational processes. TQM requires that organisations maintain quality standards in all aspects of the business. As such, the concept of TQM involves the integration of all functions and processes in an organisation to ensure that it achieves continuous improvement of its products and services to meet customer needs. The bottom line is that quality starts with understanding customer needs and ends when those needs are satisfied.

The TQM is based on Deming's 14 points (Saunders, 1995), and stands on a philosophy that entails six main areas:

- Managerial leadership and commitment
- Continuous improvement
- Total customer satisfaction
- Training and education
- Employee involvement and empowerment
- Reward and recognition

TQM is a programme that instils a climate of continuous improvement (kaizen) on a permanent basis towards products and services that customers will find more satisfying (Moody, 1997). TQM is similar to lean in some aspects; they can both be viewed as tools, practices, a culture or managerial principles, and both share the idea of continuous improvement through problem solving and employee involvement. The principles of TQM are customer focus, focussing on the process as well as on the result of the process, mobilising expertise of the workforce, prevention versus inspection, fact based decision making, and feedback or communication (Jablanski, 1992). Considering these principles, TQM can serve as very good support system or tool for lean.

3.2.2 Six Sigma

Six Sigma has been described by Pyzdek (2003) as a rigorous, focused and highly effective implementation of proven quality principles and techniques. It is also seen as a comprehensive and flexible system for achieving, sustaining and maximising business success (Pyzdek, 2003). Van Seaton (2010: 77) defined Six Sigma as a "rigorous application of principles-based continuous process improvement methods, tools, and a statistics-based analysis of processes" Six Sigma originated from the Motorola Corporation in the United States in the mid to late 1980s. Six Sigma has been noted as a powerful approach to achieve business process improvements in manufacturing, services and transactional industries (Hayler and Nichols, 2007). Motorola became popular as a quality leader and a profit leader using Six Sigma. The secret of their success became known to the public after winning the Malcolm Baldrige National Quality Award in 1988. Six Sigma is driven by understanding of customer needs, disciplined use of facts, data and statistical analysis, and diligent attention to managing, improving, and reinventing business process (Pande *et al.*, 2000).

Bicheno (2004) presented the specific methodology of Six Sigma as ‘DMAIC’ which is represented as follows;

- D- Define the problem

The voice of the customer, voice of the business, and value stream mapping provide critical input in this stage of the process. The “define’ stage starts with identification of problem that requires a solution and ends with a clear understanding of the scope of the problem and evidence of management support, who authorise the project to move forward through a commitment of resources (Shankar, 2009). Problems must be stated clearly and concisely. Likewise, the project’s purpose, scope, team members, resource requirements, and potential constraints must be defined. What is at stake must be clear to everyone involved, how and when the mission of the project is to be achieved, and who is responsible for what actions (Goldsby and Martichenko, 2005).

- M- Measure the performance or problem

Measurement here refers to assessment of the current state i.e. the problem (Goldsby and Martichenko, 2005). The purpose of the “measure’ stage is to gather baseline information about the process that has been identified as requiring improvement. The first step in this stage is to collect data and quantify the problem. The four necessary steps to be completed in this stage according to Shankar (2009) are:

- Understanding of the activities in the process by creating a process map of the current state
- Understanding where the risk lies in the process by performing a failure mode and effects analysis (FMEA)
- Determining how well the process meets customer expectations by calculating process capability
- Assessing the measurement system to ensure that reported data are accurate and there is no inherent variation due to the way in which data are collected.

- A- Analyse the cause of variation and defects

The “analyse” stage involves the identification of the cause and effect relationship between process performance and the process inputs (Goldsby and Martichenko, 2005; Shankar, 2009). The causes for performance gap measured in terms of CTQs are identified and solutions to the problems are generated. The best solution is then chosen to improve process performance.

- Improve

The ‘improve” stage involves taking necessary actions for correction, after the root cause of the problem has been identified. This stage offers the opportunity for competitive advantage when many companies in an industry are starting at a common problem

- C- Control

“Control” is the final stage of the DMAIC process, and it focuses on the aspect of improvements projects by avoiding complacency when the project is going well and goals are being met and taking corrective action when either the project strays or the environment changes. The main considerations in “control” phase of the DMAIC process is centred on issues of motivation and measurement.

3.2.3 Lean Six Sigma

The combination of the lean and six sigma initiatives by some companies have delivered significant results. However, achieving these results requires a level of organisational focus and maturity that involves the practice of lean, theory of constraint, and total quality management (Loubser, 2003). There exists common ground in terms of goals and tools adopted between lean and Six Sigma initiatives. Many world class companies have combined these two initiatives into an integrated approach at achieving excellence in all areas of business performance improvement and productivity such as cost, quality, responsiveness, and design innovation (Kaufman Global Group, 2003).
Table 3.1 presents the area of comparison between lean and Six Sigma.

Table 3.1: Area of Comparison

Area	Lean	Six sigma
Objectives	Reduce waste, improve value	Reduce variation Shift distribution inside customer requirements
Framework	5 principles (not always followed)	DMAIC (always followed)
Improvement	Many small improvements, a few low Kaizens. Everywhere, simultaneous	A small number of large projects One at a time.
Typical goals	Cost, quality, delivery, and lead time. Financial often not quantified	Improved sigma level (attempt six sigma 3.4 DPMO). Money saving
People involved in improvement	Team led by (perhaps) lean expert. Often wide involvement on different levels.	Black belts supported by green belts
Time horizon	Long term. Continuous, but also short term kaizen	Short term. Project bt project.
Tools	Often simple but complex to integrate	Sometimes complex statistical.
Typical early steps	Map the value stream	Collect data on process variation.
Impact	Can be large, system-wide	Individual projects may have large savings
Problem root causes	Via 5 why's (weak)	Via e.g. Design-Of-Experiments (strong).

(Source: Bicheno, 2004)

3.3 Lean Implementation Issues

Lean thinking principles have been applied majorly on site activities (i.e. at production level). However; it should be incorporated at the organisational level to guide senior managers in organising change (Womack and Jones, 1996). A study carried out by Sarhan and Fox (2012) revealed that there seems to be positive trends in the development of a lean culture among UK construction organisations. Lack of understanding of how to successfully apply lean thinking principles to specific construction processes was also revealed.

Lean thinking has become an important concept within the UK construction industry following the Egan report (1998). There has been significant improvement in the agenda for change in the UK construction industry. Few studies have been carried out in order to assess the current levels of awareness and implementation of lean thinking within the

UK construction industry. An example of such studies is the application of the Last Planner to a UK construction project. Last Planner is one of the lean tools and techniques perhaps its most developed. The tool was applied to a UK construction project to ascertain its value and its possible barriers. However, the study raised a number of important structural and cultural problems for the success of Last Planner in the UK (Johansen and Potter, 2003).

There is a further level of organisation in the construction industry where lean principles can be applied, namely the construction project. Lean principles can be implemented by adopting the Plan, Do, Check, Act cycle. Koskela (1992) identified a process for implementing lean construction:

1. Process – company's work should be viewed as process with a flow of key elements such as information and material depending whether it is a management process e.g. design management or an operational process e.g. constructing a floor slab.
2. Reduce non-value adding activities - each process should be examined to reduced non- value adding activities such as movement of materials to enhance the effectiveness and efficiency of value adding processes.
3. Develop a more effective operating strategy – having developed a more effective operating strategy, the organisation of the work force must be taken into account.
4. Change the organisation culture – the culture of the organisation needs to be changed to support lean construction. Tools need to be developed to facilitate key parts of the new process.

The implementation issues of lean such as barriers and success factors have been identified and discussed by many studies. These barriers need to be overcome in order for the construction industry to reap the benefits of implementing lean construction. Implementing lean construction requires action and good understanding of the drivers and techniques. The implementation of lean is believed to start on projects and spread throughout the organisation and suppliers (Howell and Ballard, 1998). The implementation of lean requires a change management strategy. There are four levels of change: event, system, behaviour and mental model.

A number of authors have argued that the construction industry has failed to adopt process improvement techniques such as total quality management (Shammas-Thoma *et al.*, 1998), supply chain management (Vrijhoef and Koskela, 2000) and just in time

(Low and Mok, 1999) that have improved performance in other industries. Organisations in lean transformation report an unexpected occurrence which calls for larger improvements (Senge *et al*., 1994). The construction industry should view implementing lean as a system. Howell and Ballard (1998) advised that "*implementing lean thinking will lead to change in almost every aspect of project and company management. No one step by step guide can be offered because change at the mental model level is a developmental process. Each principle driven action will reveal new opportunities hidden because people simply could not think in ways that made the change possible. Thinking causes action, action causes deep learning, and learning causes new thinking*".

3.4 Lean Concept and Organisational Learning

A lean organisation has been suggested to have two key features. First is transferring the maximum number of tasks and responsibilities to those workers who add value to the process. The second feature is an excellent defects detecting mechanism which not only identifies faults when they occur but feeds them into a process of analysis and correction to understand why the fault occurred and actions are taken to prevent it occurring again (Womack *et al.,* 1990). These features are important as they provide access to a deep-seated knowledge about the entire process, which is necessary for improvement.

The four stages of the lean maturity matrix have been presented by Hines *et al.* (2004). These are cells and assembly lines, shop floor, value stream, and value systems. Therefore, the evolution of the lean concept can be likened to organisational learning, both for the general lean movement and for firms who progress along this four-stage lean maturity matrix (Hines *et al.* 2004). The linkage between organisational learning and lean can be clarified through continuous improvement. Lean is sustainable when there is an embedded culture of continuous improvement within the organisation. Organisational learning has been described as the ways firms build, supplement and organise knowledge and routines around their activities and within their cultures and adapt and develop organisational efficiency by improving the use of the broad skills of the workforce (Dodgson, 1993). Organisational learning has also been defined by Fiol and Lyles (1985) as "the process of improving action through better knowledge and understanding". This reflects that a learning organisation promotes collective learning so as to enable the continuous capacity to adopt innovations and thereby change (Mohanty and Deshmukh, 1999).

3.4.1 Types and Stages of Lean Organisation (Organisational Learning)

Organisational learning can contribute toward lean sustainability. Continuous improvement, respect for people, customer focus, employee empowerment, information sharing and analysis and participation and teamwork have been suggested to be lean values (Womack *et al.,* 1990; Emiliani, 2007; Lakshman, 2006). Continuous improvement requires commitment to learning. An organisation cannot improve without new ideas, and new ideas generally come from learning. Organisational learning and continuous improvement augment one another, and the nature of relationship between organisational learning and continuous improvement is not a one direction process (Garvin, 1993; Sun and Ni, 2008).

Lean organisation has been classified into four types based on organisational learning (Hines *et al.,* 2004). These are:

- Knowing organisation
- Understanding organisation
- Thinking organisation, and
- Learning organisation

3.4.1.1 Knowing Organisation

The knowing organisation, according to McGill and Slocum (1993), is based on organisations efficiently repeating the way of doing business from other successful organisations. The business models of these successful organisations are viewed as the best templates and the organisation simply follows the model by setting up rules and policies.

3.4.1.2 Understanding Organisation

The second type of organisation is the understanding organisation. This is governed by a set of core values and management practices that are designed to clarify, communicate and reinforce the company’s culture. In this case, organisations stick to the established culture rather than considering changes (McGill and Slocum, 1993). As such they are often not open to further change and expanding their learning experiences. Hines *et al.* (2004) stated that an organisation named as the understanding organisation would usually respond “yes, we are doing lean” when discussing the application of lean with such firms, even if they are only applying it in limited islands of excellence on the shop-floor.

3.4.1.3 Thinking Organisation

The thinking organisation focuses on a set of problem-solving management practices in detecting obvious and potential problems in the business activity and attempts to deal with them immediately (McGill and Slocum, 1993). However, in the thinking organisation, these solutions may be criticised as being piecemeal and providing discrete and identifiable solutions, generally just within one business process (Hines *et al.*, 2004). Such firms also tend to assume that improvements should be based solely on improvements in quality, cost and delivery with the belief that improving these areas will create customer value. Kiernan (1993) suggested that the linear approach adopted by this type of organisation almost prevents the ability to step back and ask more fundamental, difficult and useful questions. Such questions may include: “should we be in the industry at all?” Such organisations are unlikely to achieve sustainable improvement against customer desired value attributes.

3.4.1.4 Learning Organisation

The learning organisation is suggested to allow the learning activities diffuse in the whole organisation with its philosophy of improving and developing every business experience. Such organisations seek to maximise the learning opportunities of employees, suppliers, customers and even competitors. Such an approach facilitates learning and reflects the idea of double-loop learning, which involves feedback for more effective decision making (Argyris, 1976). However, each change that occurs in this learning process is viewed as a hypothesis to be tested by checking the result of the experiment and the learning organisation learns how to undertake the experiment better the next time. This is linked to the active use of contingent strategy deployment using policy deployment (Hines *et al.*, 2000). The application of policy deployment takes into account the various contingent factors encroaching on an organisation such as their size, industrial sector, industrial dynamics and technology employed. Therefore, a unique contingent approach is created in the fourth lean stage using a range of tools drawn from diverse management approaches such as lean manufacturing, Six Sigma, marketing, agile manufacturing, system dynamics, theory of constraints, and revenue management (Hines *et al.*, 2004).

Garvin (1993) noted that a learning organisation must have a framework for management and measurement of the learning process along with the “meaning" of the process itself. Some of the characteristics of a learning organisation by Senge (1990) are as follows:

- There exists a shared vision that everyone agrees on.
- People discard their old ways of thinking and the standard routines they use for solving problems.
- Members think of all organisational processes, activities, functions and interactions with the environment as part of a system.
- People openly communicate with each other without fear of criticism or punishment.
- People sublimate their personal self-interest and fragmented departmental interests to work together to achieve the organisation's shared vision.

A learning organisation is suggested by Mohanty and Deshmukh (1999) to be an organisation skilled at creating. Acquiring and translating knowledge, and reforming the behaviour patterns of decision makers to reflect new knowledge and insights so as to evaluate total quality in every planned effort.

3.5 Review of Developed Lean Frameworks

Based on the review of literature some examples of developed frameworks are presented below.

3.5.1 Lean- A Framework

Hines *et al*. (2004) developed a framework for the development of lean concept. This framework is based on the work of McGill and Slocum (1993), using organisational learning theory to set a vision to help companies see where they can evolve in their lean thinking. Figure 3.1 presents the framework for the development of lean concept based on the strategic and operational level.

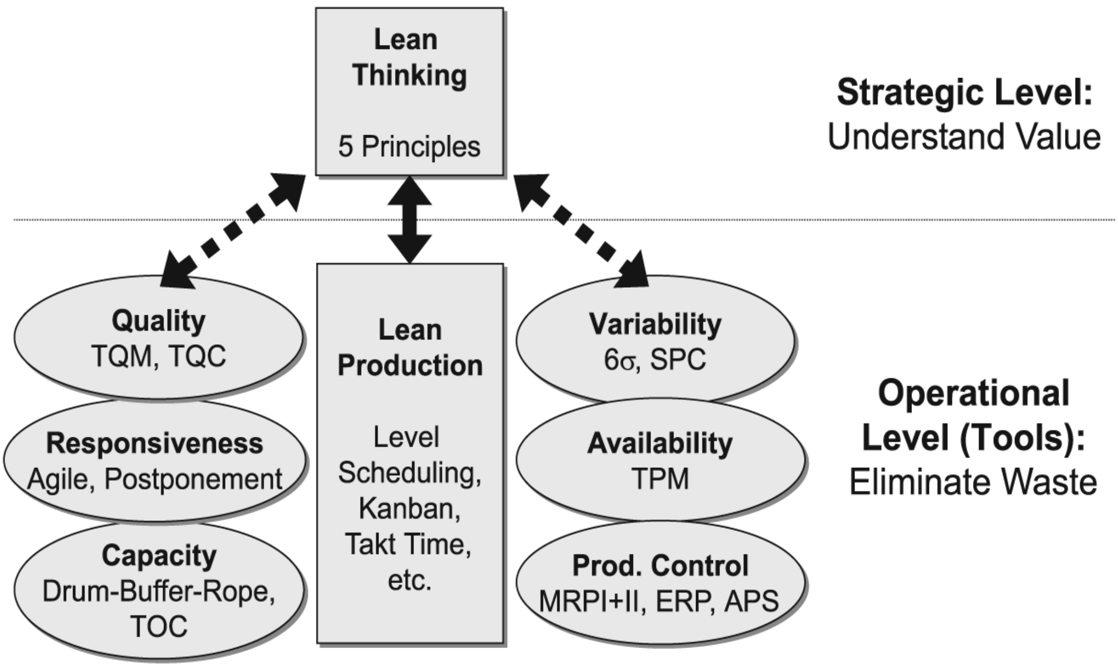

Figure 3.1: Lean- A framework

(Source: Hines *et al.,* 2004)

Lean exists at two levels: strategic and operational. The application of policy deployment takes into account the various contingent factors impinging on an organisation such as their size, industrial sector, industrial dynamics and technology employed. Based on the fourth lean value system stage, a unique contingent approach was created using a range of tools drawn from diverse management approaches such as the earlier lean manufacturing, Six Sigma, marketing, agile manufacturing, system dynamics, theory of constraints, and revenue management.

3.5.2 Lean Enterprise Architecture

The Lean Enterprise Architecture (LEA) framework for enterprise re-engineering in the design construction, integration and implementation of an enterprise using systems engineering methods was developed by Mathaisel (2005). The framework is shown in Figure 3.2 and is based on lean principles and system engineering methods. It uses a multi-phase approach which is structured on the transformation life cycle phases and portrays the flow of phases necessary to initiate, sustain and continuously refine an enterprise. However, the limitation of this framework is that it does not possess a definite process for defining performance requirements or improvement metrics system that are necessary for successful implementation of engineering process and architectural details (Mathaisel, 2005).

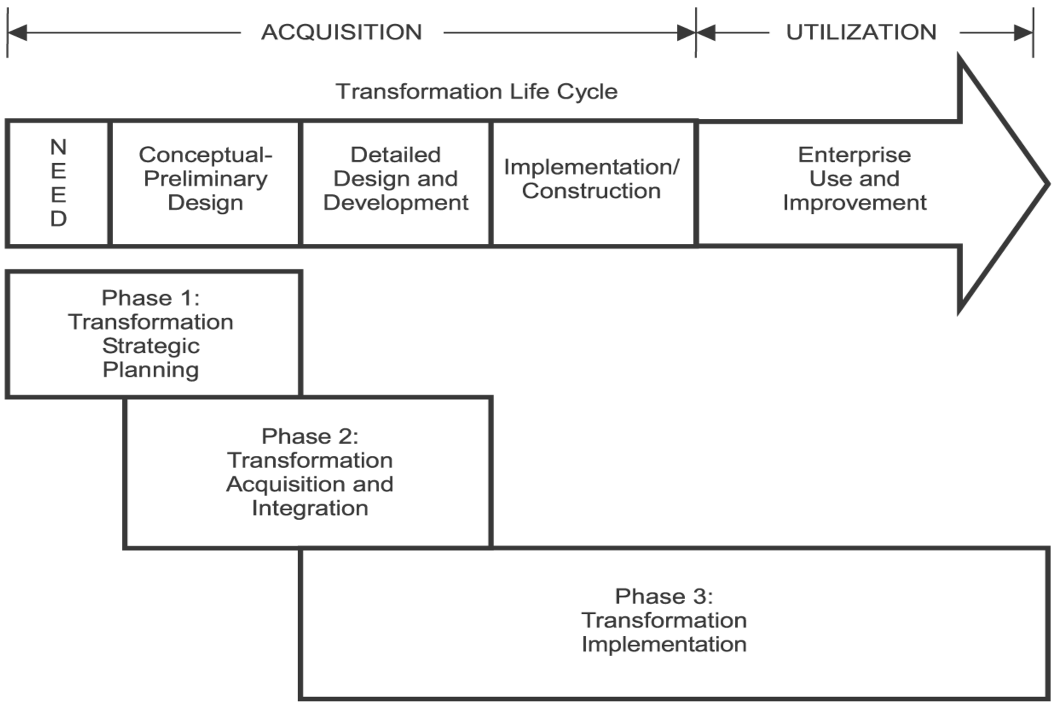

Figure 3.2: Lean Enterprise Architecture Framework

(Source: Mathaisel, 2005)

3.5.3 Conceptual Framework for Managing the Design Process

A conceptual framework for managing the design process was proposed by Huovila *et al.* (1997). Three different views of the design process were considered: design as a conversion of inputs into outputs; design as a flow of materials and information; and design as a value generating process for clients. The following are considered in development of the design model using the lean construction principles: reduce the share of non-value adding activities, increase output value through systematic consideration of customer requirements, reduce process variability, reduce cycle times, simplify by minimising the number of steps, parts, and linkages, increase output flexibility, increase process transparency, focus on complete process, build continuous improvement into the process, balance flow improvement with conversion improvement, and benchmark (Tzortzopoulous and Formoso, 1999).

3.5.4 Lean Assessment Tool

Salem *et al.* (2006) developed the lean assessment tool for construction projects. This tool was based on a checklist of lean construction practices. Figure 3.3 shows the lean assessment tool: Spider-web diagram. The lean assessment tool was based on the observation of six lean tools application on construction sites. The assessement was based on the initial and the expected outcome of the construction project.

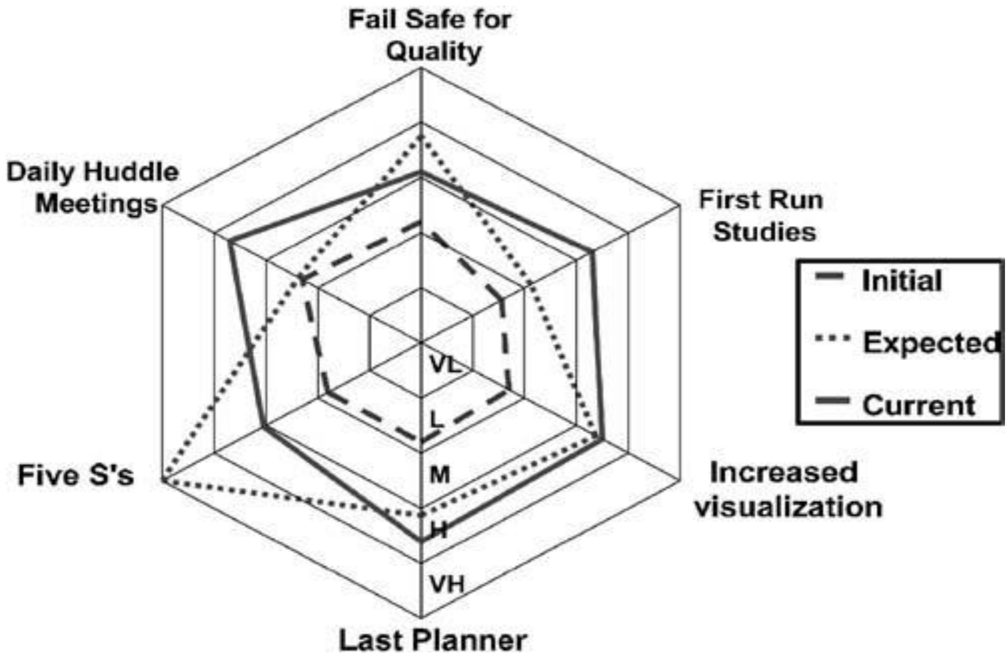

Figure 3.3: Lean Assessment Tool: Spider-web Diagram

(Source: Salem *et al*., 2006)

3.5.5 The Framework for Lean Product Lifecycle Management

The framework for lean product life cycle management was developed by Hines *et al.* (2006). This framework is a theoretical model comprising of six distinct stages which starts with the development and understanding of customer needs and established current product life cycle management status-quo. The developed framework described some of the fundamental steps required for effective lean overall process management. The approach adopted in the development of this framework outlined how a single projet can be managed more effectively from both technical and people based perspective. The six steps undertaken in the framework are understanding customer needs, value stream mapping, improving end-to-end technical process, improving end-to-end people process, developing the single project standard, and developing the complete process standard.

3.5.5.1 Understanding Customer Needs

The understanding of the customer needs was based on the first principle of lean thinking as defined by Womack and Jones (1996). The fundamental starting place for any lean process is to focus on customer needs. However, Hines *et al.* (2006) regarded the definition of customer needs given by Womack and Jones (1996) as narrow and broadened their definition of the customer voice to include a minimum of two types of customer; the external buyer or end-user of the product; and the internal buyer or end-user of the process under consideration

3.5.5.2 Value Stream Mapping

The mapping of the current state of a process and the development of a future state is an essential part of lean thinking and this is the second step in the developed framework. Hines *et al*., (2000) stated that a number of value stream mapping tools may be applied to the process but the most appropriate is the four fields mapping tools first described by Dimancescu (1992). These tools are used to describe an existing (or planned) project within four fields namely, cross functional participants or stakeholders, various phases (in this case for a request for quotation), flow chart of the detailed activities within the phases, and the standards by which these processes are performed.

3.5.5.3 Improving End-to-end Technical process

The third step of the developed framework suggests that the primary tool for improving the end-to-end technical part of the process is Quality Function Deployment (QFD) (Clausing, 1994). It should be noted that the third and the fourth steps in the framework should generally be undertaken concurrently as the technical and people aspects of successful project need to be applied together (Hines *et al.,* 2006).

3.5.5.4 Improving End-to-end People Process

The fourth part of the developed framework is the application of knowledge innovation visible planning (KIVP), a people centred approach developed by Japan Management Association Consultants (Tanaka, 2002). The focus on producing innovative products is on the people within the process.

3.5.5.5 Developing the Single Project Standard

The fifth step in the developed framework is developing the single project standard. The attempt to move from a single project theoretical-world environment to one that has repetitive cycles of product development, where any innovation in project management can be incorporated in the future was considered at this stage (Hines *et al.,* 2006).

3.5.5.6 Developing the Complete Process Standard

The development of the complete process standard is the final step of the developed framework. It is is concerned with moving from textbook theory to pratical real world solutions. According to Hines *et al.* (2006), majority of texts tend to concentrate on how products can be successfully brought to market and fail to address the fact that most firms are developing multiple products at any one time. This is worsened in literature on technical product development because they are dominated by examples from low variety and high innovation industries like the automotive sector.

The limitation of this framework in relation to this study is that the framework appears to be partial or incomplete and was developed in the product development area. Also, the framework is yet to be tested in a number of different environments to ensure its robustness as a framework for the development of competitive advantage.

3.5.6 Framework for Describing Levels of Lean Capability

Jorgenson *et al.* (2007) presented a framework for describing levels of lean capability. This framework was based on litertaure review and experiences of some selected companies. The framework descibed the developemental stages that support lean capability development and lean sustainability. Five different levels of lean were identified which are: sporadic production, basic lean understanding and implementation, proactive lean culture, strategic lean intervention and lean in the Extended Manufacturing Enterprise (EME). The limitation of this framework in relation to this study is that it was conducted in a manufacturing environment.

3.5.7 Impact Assessment Framework

Hayes and Pisano (1994) stated that lean can be seen as an intended direction, not as a state or an answer to a specific problem. Therefore there shoud be a way to measure progress made in lean implementation effort. Based on this, Achanga (2007) developed a framework for assessing the impacts of implementing lean within SMEs at the conceptual design stage. This framework was targeted at designers of lean processes to enable them to adjust lean inputs so that costs of implementing are greatly reduced. According to the author, practitioners involved in the design of a lean process within companies tend to omit certain critical aspects of the fundamental ingredients within their palnning process in the implementation drive. Therefore, it was suggested that organisations should look at how best to design the entire lean implementation process at the conceptual stage of the prioject life cycle.

3.5.8 A Web-based Decision Support and Analysis Tool for Lean Manaufacturing Assessment and Implementation

The web-based decision support and analysis tool was developed by Chen *et al.* (2004). This tool was developed to assess the current level and possible improvement area of companies that are not thinking of lean manufacturing or have already been in the process of implementing lean manufacturing within their businesses. The framework has the capability of providing both qualitative and quantitative information to support decision makers on lean manufacturing implementation.

3.5.9 Cost-Time-Profile

Rivera and Chen (2007) proposed the Cost-Time-Profile (CTP) as a useful tool for the evaluation of the improvements achieved by the implementation of lean tools and techniques. The CTP can be used to assess the expected impact of a change in the production process.

3.5.10 The 4P Model of Lean

The 4P model of lean was developed by Liker (2004). The model comprises the "Toyota way" or TPS and incorporates the 14 key management principles. Continuous improvement and learning is at the top of the pyramid followed by development of people and partners, process orientation and long-term thinking at the base. According to Liker (2004) managing the 4P-model can be seen as a prerequisite for sustainable improvements. The 14 principles are classified under each of the 4P's as shown in Table 3.2.

Table 3.2: The 4P model of Lean

4P's	Principles
Philosophy	- Base management decision on a long term philosophy, even at the expense of short-term financial goals.
Processes	- Create continued process flow to bring problems to the surface - Use pull system to avoid over production - Level out the workload - Build a culture of stopping to fix problems, to get quality right the first time
People and partners	- Grow leaders who thoroughly understand the work, live the lean philosophy, and teach the lean philosophy to others. - Develop exceptional people and teams who follow the organisation's philosophy - Respect for the organisation's extended network of partners and suppliers by challenging them and helping them improve
Problem solving	- Go and see for yourself to thoroughly understand the situation - Make decision slowly by consensus, thoroughly considering all options; implement decisions rapidly - Become a learning organisation through relentless reflection and continuous improvement

(Adapted: Liker, 2004)

3.5.11 The Lean Project Delivery System

The Lean Project Delivery System (LPDS) is a conceptual framework developed by Ballard (2000) to guide the implementation of lean construction on project-based production systems. This framework was developed as a set of interdependent functions, rules for decision making, procedures for execution of functions and as implementation aid and tools. It is made up of five phases: project definition, lean design, lean supply, lean assembly and use. Each of the phases contains three modules and is represented as a triad. Each triad overlaps the succeeding triad to include at least one common module. For example the Project Definition phase includes purposes, design criteria and design concepts and overlaps with the Lean Design phase which includes design concepts, process design and product design. Also, two modules of Production Control and Work Structuring extend throughout the lifecycle of the project. Some important features of LPDS include downstream players in the planning process, conceptualising the project delivery as a value generating process, and creating a reliable workflow amongst the project participants (Ballard, 2000).

The domain of Lean Project Delivery is defined by the intersection of projects and production systems and is therefore fully applicable to the delivery of capital projects which include the formation of a temporary production system in the form of a project team that consists of owner, architects, engineers, general contractor and sub-contractors. The framework is particularly useful for project control. Figure 3.4 illustrates the LPDS system.

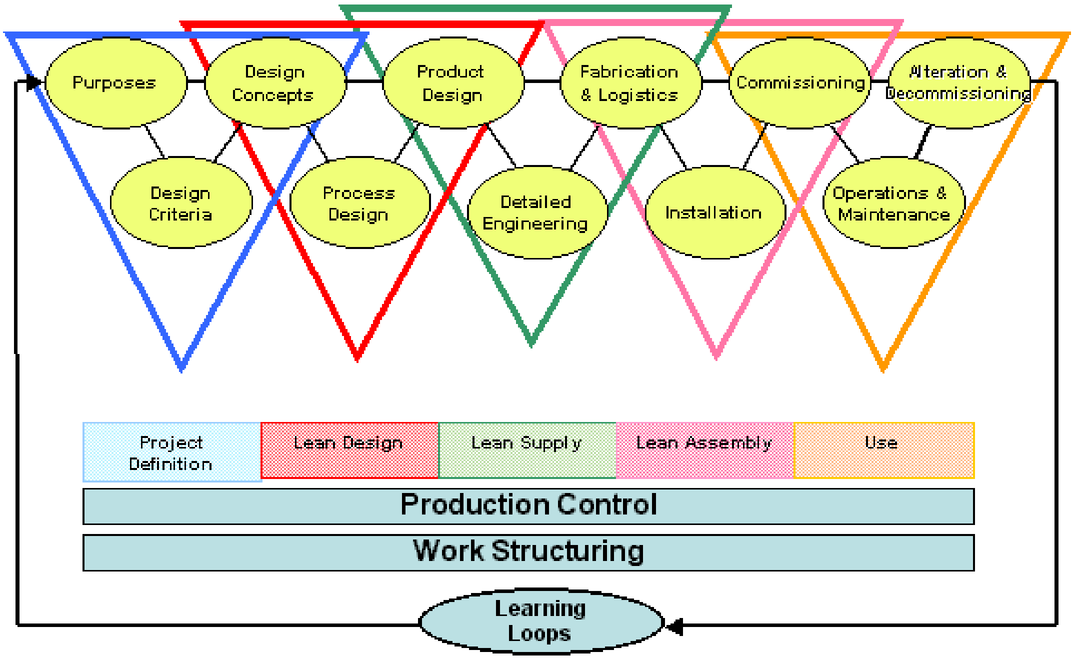

Figure 3.4: LPDS system

(Source: Ballard, 2000)

The review highlighted above presented and described various frameworks within the field of lean manufacturing and lean construction. These frameworks have focused majorly on the lean manufacturing implementation issues. They have not focused on how to address or measure the impact of lean in terms of assessing the benefits of implementing lean. Also, some of the frameworks were developed within the manufacturing environment and their uptake does not consider the strategy positioning and implementation.

As with many other initiatives originating in manufacturing, and being reconfigured for construction, the application of lean construction has faced challenges and requires significant research to complete the translation (Howell 1999). Furthermore, resistance was experienced from construction clients to adopt off-site prefabrication and incorporate lean production methods in the construction process (Pasquire and Connolly

2002). This was attributed to lack of methods to evaluate the benefits of such initiatives. Pasquire and Connolly (2002) further elaborated that if any change and improvement is to occur in construction, since it is not driven by crisis, it has to be driven by the realisation of the benefits of initiatives. Pasquire and Gibb (2002) presented a framework for realising the benefits of standardisation and pre-assembly, where the post-construction effect on the business was assessed by business performance indicators, such as the Construction Best Practice Programme – Key Performance Indicators (2002). The framework developed by Bassioni (2004) provides an alternative way of realising the effects of lean construction methods through the Construction Strategy Map. The causal relations depicted by each organisation in its strategy map offers such a link between lean construction methods and the final business results of the organisation. For example, if lean construction is deemed as a strategic option and driver to the overall business strategy of the organisation, it needs to be translated in the strategy map through the internal business process or learning and growth tiers. However, appropriate indicators need to be in place to measure the deployment of lean construction (Bassioni, 2004). Different ways of achieving this has been suggested in the literature. For example, Pasquire and Connolly (2002) described the impact on time, cost and quality indicators to demonstrate the benefits of off-site manufacturing. Diekmann *et al*. (2003) developed a questionnaire to measure an organisation's conformance to lean concepts, which is being adopted by the Construction Industry Institute (CII) in its pursuit for applying lean thinking in construction.

Based on the review of various frameworks and their limitations, the need to develop a self-assessment tool or framework with the capability of breaking down the strategic and management issues as well as benefits of implementing lean in construction organisations is justified. This will allow companies to focus on individual areas for improvement and pin-point necessary action to facilitate change in the implementation process.

3.6 Performance Measurement Systems and Process Performance Measures

There are several approaches to evaluating and assessing an organisation's performance. This includes the traditional approach and the systems approach. The adoption of a simple and well designed performance measurement system has been suggested to be essential to support the implementation of business strategies, such as the application of

LC concepts within construction organisations (Sarhan and Fox, 2013). Many studies have used the systems approach in the development of performance measurement and benchmarking (Castka *et al*., 2004). Yasin (2002) argued that the scope of benchmarking has expanded from a process and/or activity orientation towards strategies and systems. Examples of this management system include the Balanced Scorecard (BSC), the EFQM Excellence Model (formerly known as the European Foundation for Quality Management), the Malcolm Baldrige National Quality Award (MBNQA) model, the Practical Quality Assurance System for Small Organisations (PQASSO), the Big Picture (an organisational improvement framework and diagnostic tool for identifying strengths and weakness within an organisation or programmes of work), QFD, and the Investors in People (a national standard for improving organisational performance by training and developing people to achieve organisational goals). Eriksson (2010) suggested further research on performance indicators as performance measurement is an important aspect of both lean production (Wee and Wu, 2009) and lean construction (Freire and Alarcón, 2002).

Several studies have been carried out on performance measurement within the construction industry. Sarhan and Fox (2013) assessed the importance of the use of appropriate performance measures and its contributions to the application of lean construction concepts. The most common techniques used by UK construction organisations for performance measurement were identified and the results revealed that non-financial performance measures have not been properly and widely implemented, even though practitioners recognise the importance of their selection. The importance of performance measurement in the application of lean production concepts has also been discussed by Lantelme and Formoso (2000).

3.6.1 The Malcolm Baldrige National Quality Award

The Malcolm Baldrige National Quality Award (MBNQA) focuses on outputs that impact on the outcomes such as strategic quality planning, human resource utilisation, quality assurance of products and services, quality operation results and customer satisfaction (Baldrige National Quality Program, 2002). The MBNQA is a self-assessment process that focuses on outcome thereby allowing organisations to pay attention on what is important for them and putting processes and system in place that empower stakeholders to accomplish the ultimate goals and action plans. The lack of important areas such as innovation, marketing savvy, strategic positioning, and organisation design are critique of the MBNQA (Garvin, 1991). The MBNQA comprises criteria that require measuring of results, and can be used to identify dimensions of performance measurement. The criteria of the MBNQA Model include leadership, strategic planning, customer and market focus, information and analysis, human resource focus, process management, and business results (Baldrige National Quality Program, 2002).

3.6.2 Quality Function Deployment

The QFD is a well-established tool for providing excellence in product development (Clausing, 1994). It is mainly good at translating the voice of the customer into the requirements of the products, or the top level house of quality. QFD has evolved since its initial development in Japan in the late 1960s and early 1970s. The main drivers for the formation of QFD are to improve the 'quality design' and to provide manufacturing and field staff with the planned quality control chart (showing the points to be controlled within the production process) before the initial production run (Hill, 1994). Thus, QFD can be used as a management tool and has been widely used for decision making in terms of measurement, selection and evaluation with the purpose of determining customer needs, formulating annual policies, and benchmarking (Motwani *et al.*, 1996).

3.6.3 The Balance Scorecard

The Balanced Scorecard (BSC) is a management system which translates an organisation's strategy into performance objectives, measures, targets and initiatives. It is a widely accepted framework that offers feedback on internal business processes and external outcomes to continually improve organisational performance and results (Nudurupati *et al.*, 2007). It is based on four balanced perspectives: the financial perspective, customer perspective, internal perspective and the learning perspective (see Figure 3.5). These perspectives are linked together with the concept of cause and effect (Isoraite, 2008). The effectiveness of an organisation's strategy can be predicted by means of a well-structured balance scorecard based on its four perspectives.

The BSC is more focused on strategy and vision rather than control. Isoraite (2008) stated that there are many benefits and challenges to the balanced scorecard. The main benefit is that it helps organisations to translate strategy into action and also allows employees at all levels of the organisation to focus on important business drivers. This is achieved by defining and communicating performance metrics related to the overall strategy of the company. The primary challenge of this system is that it can be difficult and time-consuming to implement (Karanseh and Al-Dahir, 2012). The nine-step process for creating and implementing the balance scorecard as recommended by Kaplan and Norton (1996) are presented as follows:

1. Perform an overall organisational assessment.
2. Identify strategic themes.
3. Define perspectives and strategic objectives.
4. Develop a strategy map.
5. Drive performance metrics.
6. Refine and prioritise strategic initiatives.
7. Automate and communicate.
8. Implement the balanced scorecard throughout the organisation.
9. Collect data, evaluate, and revise.

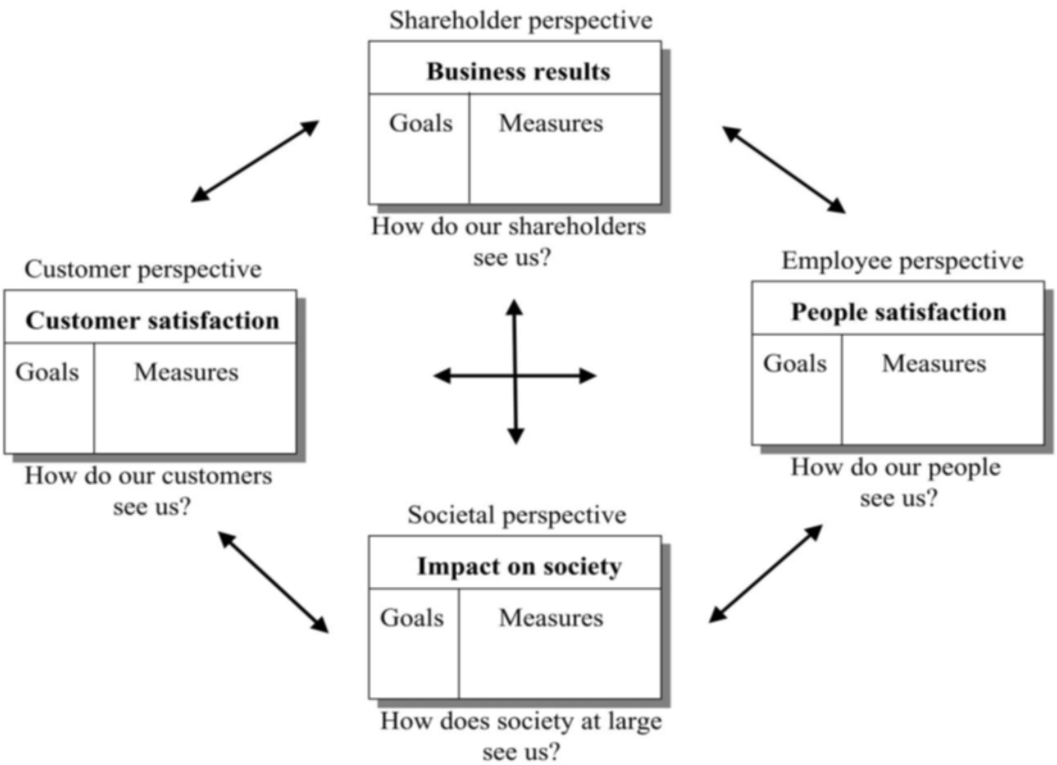

Figure 3.5: A Balanced Scorecard of Excellence Model

(Source: Kaplan and Norton, 1996)

3.6.4 EFQM Excellence Model

It is generally accepted that the establishment of an appropriate management system is essential for the success of an organisation. The EFQM model is a useful tool for many organisations, irrespective of size, sector, and structure or organisation maturity, to measure their path to excellence, understand the gaps and concentrate on improvements (EFQM, 2013). The EFQM is a non-perspective framework; its main aim is to provide a system perspective for understanding performance measurement. It places emphasis on self-assessment and improvement planning (Wongrassamee, 2003). The concept of the EFQM is based on nine criteria as shown in Figure 3.6. These nine criteria are grouped under the 'enablers' and the 'results'. The summary of the description of these nine criteria as given by EFQM (2013) is presented below:

3.6.4.1 'Enabler' Criteria

Leadership: This relates to the behaviours of the executive team and all other managers in how leaders inspire, develop, drive and clarify a statement of vision that proposes total quality and continuous improvement which the organisation and its people can achieve.

People management: This scrutinises how the organisation handles its employees and how it develops the knowledge and full potential of its people to improve its business processes and/ or services continuously.

Policy and strategy: This reviews the organisation's mission, values, vision and strategic direction. It also reflects how the organisation implements its vision and mission through the concept of total quality and continuous improvement.

Resources: This refers to how the organisation manages and utilises its external partnerships and internal resources effectively in order to carry out effective business performance as stated in its mission and strategic planning.

Processes: This reflects how the organisation designs, manages and improves its activities and processes in order to satisfy its customers and other stakeholders.

3.6.4.2 'Result' Criteria

People satisfaction: This investigates what the organisation is achieving in relation to its employees.

Customer satisfaction: This measures what the organisation is fulfilling in relation to its targeted customers.

Impact on society: This is concerned with what the organisation is achieving in satisfying the needs and expectations of local, national and international society as appropriate.

Business results: This examines what the organisation is achieving in relation to its planned business performance and in satisfying the needs of its shareholders.

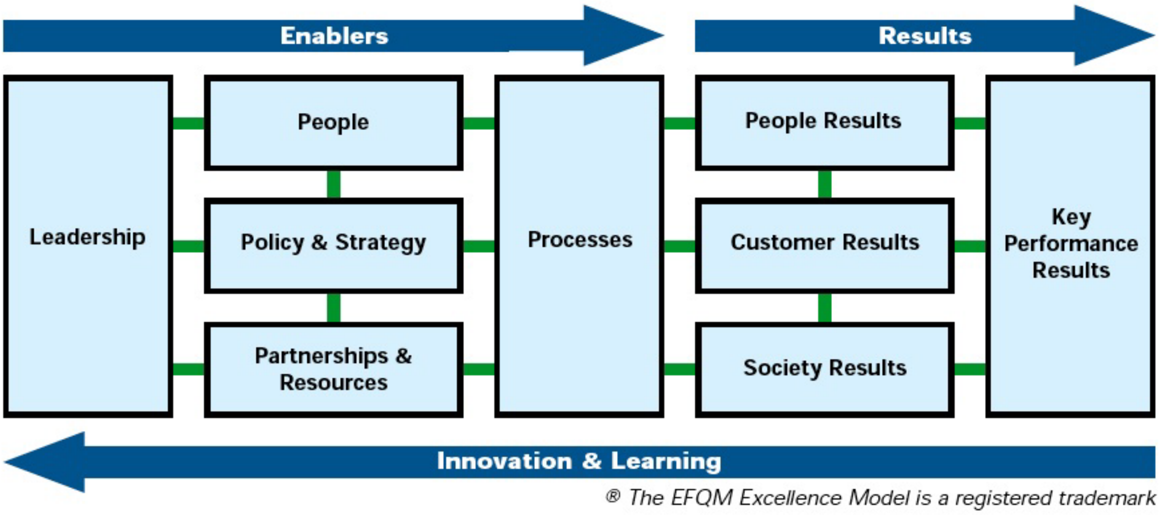

Figure 3.6: The EFQM Excellence Model

(EFQM, 2013)

3.6.5 Choice of Assessment Approach

According to Achanga (2007), lean impact assessment may be referred to as the evaluation of the effect of lean implementation on a business against the expected value-adds. Several arguments have been made for the need for a qualitative and quantitative impact assessment. Many lean frameworks have been developed by many authors using different approaches. Copestake *et al.* (2002) proposed a methodology which is known as the qualitative impact protocol (QUIP). Likewise, Tetumble (2000) presented a framework for evaluating Enterprise Resource Planning (ERP) projects using the Analytical Hierarchy Process (AHP).

Jorgensen (2010) asserts that assessment tools are critical to successful implementation of lean. Assessment tools serve as a roadmap that illustrates the company's current status among its important performance parameters. Therefore, it must accurately reflect the nature and complexity of what is being assessed. Jorgensen *et al.* (2007) stated that a lean assessment tool must include:

- A technical perspective, which reflects performance, methods, and tools in relationship to the given company's strategic "scope",
- Organisational perspective, which reflects management, organisational and human capabilities, culture, and learning.

Most studies have focused on a single aspect of lean and its performance implications and the relationship between implementation of lean and performance while fewer studies have investigated the simultaneous synergistic effects of multiple aspects of lean implementation and performance implication (Shah and Ward, 2003). In addition to being able to evaluate variables related to each of these perspectives, a lean assessment tool should be able to measure the relative balance between the two elements and the possible synergy created by focusing attention on both perspectives simultaneously. The majority of available assessment tools, however, address primarily or exclusively the technical perspective and only a select few refer to aspects of progressive lean development (i.e. elements associated with the organisational perspective). With regards to those tools that do include the organisational perspective of lean, even fewer consider the balance between the two perspectives and the potential synergy between them.

Finally, there do not appear to be any lean assessment tools that incorporate both perspectives while still emphasising the processes necessary for ensuring developmental progression of lean in the organisation. In general, the success of implementation of any particular management practice frequently depends upon organisational characteristics, and not all organisations can or should implement the same set of practices (Galbraith, 1977).

For the purpose of this study, the approach of self-assessment adopted is similar to EFQM excellence model. The choice of the EFQM approach arises as there appears to be some likely limitations when the BSC approach is considered. In relation to this study the aim is to develop a self-assessment tool for assessing the implementation effort and the benefits of the lean approach in sustainable construction in organisations. None of the assessment approaches that have been described above is directly related to the aim of this study but the BSC and the EFQM have laid down the rudiments in self-assessment. Therefore, this study deems it fit to follow the EFQM approach, because it allows the users to select the set of appropriate metrics to implement them and provides specific frameworks in which a company can establish a clear vision of its management processes and focus on improving its long-term performance. The EFQM also provides a basis for sustainable excellence and a holistic framework which covers the whole organisation and also provides the capability to track and measure progress through a robust scoring methodology. Moreso, the tool development approach of this study is similar to that of Adetunji (2005), who developed CONpass, a web based tool for assessing the implementation of sustainable construction. Castka *et al.* (2004) have also developed a TEaM model self-assessment and benchmarking tool for measurement of teamwork culture in organisations using an approach that is similar to the EFQM. The BSC and EFQM both focus on measuring and managing performance results, clarify the links between strategy, processes, and outcomes and highlight the importance of effective stakeholder management and integration, continuous improvement, and staff involvement (Atkinson *et al.*, 1997; Amaratunga *et al.*, 2000). The choice of BSC was ruled out based on: the failure of the BSC to highlight employee and suppliers' contribution; the role of community in defining the environment within the company; and the identification of performance measurement as two processes.

3.7 Summary

This chapter has presented the review of various lean frameworks and the different types of performance assessment measurement. It also presented a brief description of some of the process improvement techniques associated with lean as well as types of lean organisation. The implementation of lean requires a change management strategy. Continues improvement requires commitment to learning, an organisation cannot improve without new ideas, and new ideas generally come from learning. Lean organisation has been classified into the knowing organisation, understanding organisation, thinking organisation and learning organisation.

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

This chapter presents the research methodology adopted to achieve the aim and objectives of this study. It is essential that the epistemological premise on which a study stands is established in the attempt to discuss the research methodology and research methods employed in carrying out the research of this nature. This chapter is divided into two parts. The first part is centred on research design, research methodology, justification of the research methodology and the research approach. The second part of the chapter describes the four stages of the research study, the sampling procedure, data collection methods, measurement scales and data processing procedures as well as the methods of data analysis employed for the study. The first stage involved a thorough review of literature. The second stage used a questionnaire survey approach, while the third stage adopted a case study approach. The final stage focused on developing a framework for assessing lean construction implementation effort and the benefits of lean in sustainable construction, resulting from the combination of all the methods adopted.

4.2 Research Design

Choosing an appropriate research methodology and research method are two different things. Therefore the clarity of these two terminologies are essential for the purpose of this study. Research methodology refers to the understanding of the research and the strategy chosen to answer the research question (Greener, 2008). It also refers to a system of explicit rules and procedures, upon which research is based and against which claims for knowledge are evaluated (Frankfort-Nachmias and Nachimias, 1996). Research methodology has been defined by Fellows and Liu (2008) as "the principle and procedures of the logical thought process which are applied to a specific investigation". Research method, on the other hand refers to specific activities designed to generate data, for example questionnaire, interviews, focus groups and observation (Greener, 2008).

The construction industry is one of the most important sectors in any country. Its activities include design, manufacturing and construction, and hence has numerous stakeholders. The new areas for research presented by the construction management include a hybrid of natural science and social sciences (Dainty, 2008; Love *et al*., 2002). This research study focuses on lean construction and sustainability within the construction industry (refer to section 1.2). Lean construction (LC) related research is still under explored. Research studies in LC have been criticised for being built on weak theoretical foundation to some extent (Green, 1999, Jorgensen and Emmitt, 2008). There are various examples of research methodologies and methods chosen by many other researchers in similar areas of study. For example, Howell and Ballard (1994) have adopted a qualitative methodology to examine the implementation of LC to reduce inflow variation; Eriksson (2009) has chosen a combination of qualitative and quantitative methods for their LC related research studies through the use of case studies and a survey. Ballard *et al.* (1996) have choosen a qualitative paradigm, using a case study approach for their LC related studies. On the other hand, Chang and Sun (2007) have used a survey method to collect data to explore the correspondence between TQM and learning organisations. Similarly, Sacks *et al.* (2009) have done an extensive literature review to investigate Building Information Model (BIM) based on lean production and lean construction principles. In addition, the research method categories with definition in relation to IGLC research studies has been presented by Jacobs (2011) as shown in Table 4.1. This was based on the analysis of reseearch papers presnted in IGLC conferences between 1996 and 2009.

The selection of the most appropriate research method must be driven by the research questions and the current body of knowledge in the area researched as well as the data accessible to the researcher (Reiter *et al.,* 2011). Many researchers have made the choice of a single method while some have used a mixed method approach for their research studies. The most important thing is that no matter what the choice may be, the method chosen should be appropriate to achieve the aim and the objectives of the research study in question. Therefore, it is necessary to describe the research design, strategies and methods adopted in achieving the aim and objectives of this study in relation to the research paradigm.

Table 4.1: Research Method Categories with Definiton in Relation to IGLC Research Studies

Research Methods	Definition	Applied in this study
Theoretical research	Theoretical research provides detailed descriptions and explanations of a phenomenon studied rather than providing and analysing statistics	In this study lean researchers created an inquiry around the phenomenon of lean theory in construction
Case study	Case Study research is a type of qualitative research and is based on an in-depth investigation of a single individual, group, or event to explore causation in order to find underlying problems.	In this study lean researchers applied lean theory on projects in the construction field
Action research	Action research is a type of qualitative research and is a reflective process of progressive problem solving led by individuals working with others in teams or as part of a ―community of practice‖ to improve the way they address issues and solve problems.	In this study lean researchers engaged in problem solving methods in an attempt to improve construction processes.
Structured interviews	Structured interviews, another form of qualitative research, ask people questions during an interview process. The interviewer usually has a framework of themes to be explored.	In this study lean researchers interviewed various players within the construction field.

(Source: Jacobs, 2011)

4.3 Research Paradigms and Perceptions

It is important to clarify the structure of inquiry and methodological choices adopted in a study. Therefore, an exploration of various research paradigms is necessary in order to adopt the paradigm that best fits the focus of this study. The term research paradigm was first used by Kuhn (1970: 182) who presented it as "universally recognised scientific achievements that for a time provide model problems and solutions to a community of practitioners". According to Easterby-Smith *et al.* (1991), deciding on suitable methodologies and research methods depend on research paradigms and their assumptions.

A research paradigm, as suggested by Denzin and Lincoln (1994), is the philosophical stance taken by the researcher which provides a basic set of beliefs that guides action. Weaver and Olson (2006: 460) defined paradigm as "patterns of beliefs and practices that regulate inquiry within a discipline by providing lenses, frames and processes through which investigation is accomplished". Research paradigm has been classified or represented based on various views. The three generally accepted paradigms are positivism, interpretivism and the critical theory (Cupchik, 2001; Guba, 1990; Smith, 1989).

Research paradigm has been referred to as research methodology by Neuman (2006) and has been classified into three approaches of positivist social science, interpretive social science, and critical social science. Neuman (2006) stated that positivist and interpretive approaches are the most commonly used in social research but positivist is the oldest and the most widely used approach, while critical social science is less commonly seen in scholarly journals. These approaches are different ways to observe, measure, and understand social reality in the world (Neuman, 2006). These three approaches are described differently by other authors. For example, Alvesson and Skoldberg (2009) described the three approaches as positivism and post-positivism, social constructionism, and critical realism. These approaches cut across the dividing line between qualitative and quantitative methods of research. Another way of classification is based on the ontological and epistemological models and axiological and rhetorical assumptions have been added.

According to Creswell (1998), researchers make claims philosophically (knowledge claims) about these assumptions: what knowledge is (ontology), how we know it (epistemology), what values go into it (axiology), how we write about it (rhetoric), and the processes for studying it (methodology). Ruona and Lynham (2004) presented a research philosophical framework as shown in Figure 4.1. This framework includes the ontology, epistemology and the axiology. This was referred to as 'the net' that contains researcher's epistemological, ontological and methodological premises (assumptions) (Denzin and Lincoln, 1994).

Amaratunga *et al.* (2002) also commented on two schools of thought: positivism (quantitative) and phenomenological (qualitative) paradigms. Phenomenological inquiry uses qualitative and naturalistic approaches to inductively and holistically understand human experience in context-specific settings. This approach tries to understand and explain a phenomenon, rather than search for external causes or fundamental laws (Amaratunga *et al.*, 2002).

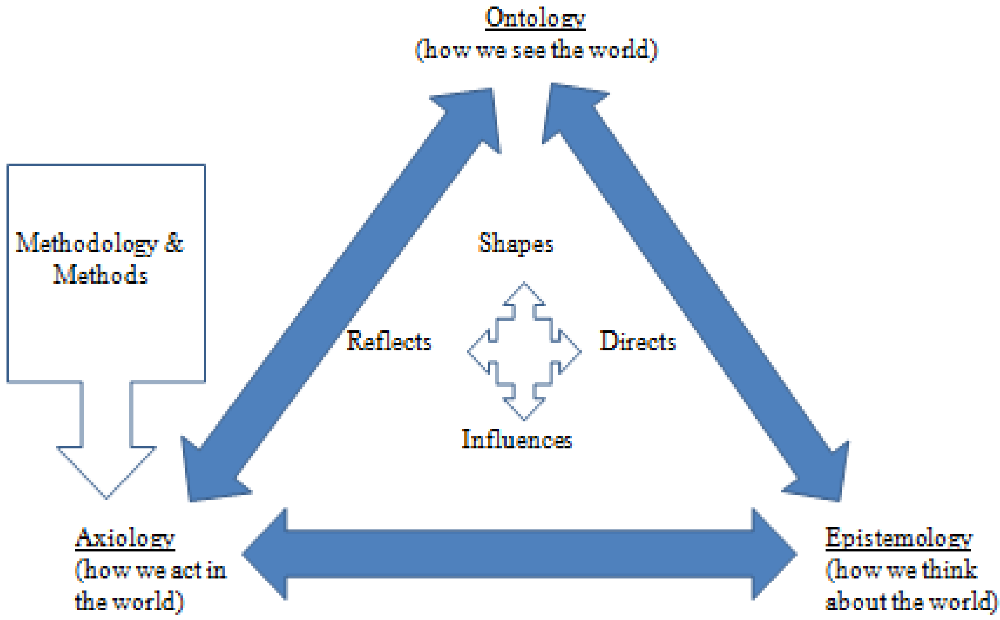

Figure 4.1: The Research Framework

(Source: Ruona and Lynham, 2004)

According to Ritchie and Lewis (2003), ontology deals with the study and nature of the social world. A major debate is on the existence of a social reality and how such should be represented. The three unique positions are realism, materialism, and idealism. Alvesson and Skoldberg (2009) stated that in realism, the task of science is to explore the realm of the real and how it relates to the other two domains, namely the actual and the empirical. This is supported by Ritchie and Lewis (2003) who claimed that realism is the existence of an external reality regardless of people's believe or knowledge of it. Materialism maintains the existence of a real world but ascribes reality to only the material features. From the standpoint of idealism, it is only through the human mind and socially constructed meanings that reality can be known (Ritchie and Lewis, 2003). Creswell (2007) has also described four paradigms; post-positive (which is also called quantitative) constructivism, advocacy (where researchers believe that inquiry needs to be intertwined with politics and a political agenda) and pragmatism.

According to Silverman (2005), positivism and interpretivism are opposing views in epistemology. Positivism involves the utilisation of empirical methodologies extracted from natural sciences and used to understudy phenomenon (Berg, 2009). Positivism encourages the explanation of relationship between variables which are operationally defined in any given research and is the most common model used in quantitative research (Silverman, 2005). Positivism argues that natural science approaches are suitable for social issues since some law-like regularity determines human behaviour. Interpretivism, on the other hand, believes that natural science approaches are unsuitable for social inquisition because the regularities which control human behaviour do not have law-like properties (Ritchie and Lewis, 2003). The three broad categories of the research paradigm based on the underlying research epistemology: positivist, interpretive and the critical social sciences are considered for further discussion in the next section.

4.3.1 Positivist Social Science

According to Neuman (2006), positivist social science refers to the approach of natural sciences and there are various versions of positivism. So, positivism has a long history with science but is also associated with many specific social theories. Common examples are its link to the exchange theory frameworks, structural-functional, and rational choice (Neuman, 2006). Feyerabend (1981) described positivism as any interpretation of science (and of theoretical knowledge in general). According to Alvesson and Skoldberg (2009), the key concepts in positivism include theory and data, verification and falsification, law-like statements, inductions and deductions. Hence, positivism has several similarities with data-oriented methods. The task of the researcher is basically that of gathering and systematising data. It follows that the main thrust of positivism is quantitative, but there have also been cases of qualitative positivism (Alvesson and Skoldberg, 2009). Neuman (2006) stated that quantitative data, use of experiments, surveys, and statistics are preferred under positivism. Positivist researchers seek rigorous, accurate measures and objective research, and they test hypotheses by cautiously analysing numbers from the measures. The characteristics of positivistic research include formal propositions, quantifiable measures of variables, hypothesis testing, and the direct drawing of conclusions about a phenomenon from the sample to a stated population (Orlikowski and Baroudi, 1991).

4.3.2 Interpretive Social Science

Neuman (2006) stated that interpretive social science is related to hermeneutics, a theory of meaning which originated in the nineteenth century. Interpretivist approach usually means that data is collected with a focus on how people interpret the social world and social phenomena, thereby enabling different perspectives to be investigated and explored (Matthews and Ross, 2010). Field research and participant observations are often used by interpretive researchers. According to Alvesson and Skoldberg (2009), in social constructionism, which is another description of interpretive social science, reality is socially constructed. The approach is not dominantly theory-oriented; rather the focus is on revealing how social phenomena are socially constructed. This is further supported by Porter and Lopez (2005) who described constructionism as anti-individualist and anti-reductionist. It insists on the ontological difference between products and producer, between discourse and speaker. It questions the link between people and the short-lived products of their social activity (Porter and Lopez, 2005). An interpretive approach is associated with symbolic interactionists and it is often called a qualitative method of research. Contrary to an essentialist orientation view, constructionist orientation assumes that reality is created by people's interactions and beliefs (Neuman, 2006).

4.3.3 Critical Social Science

Critical social science mixes nomothetic and ideographic approaches. It agrees with most of interpretive social science criticism of positivism, but also disagrees with the interpretive approach on some points (Neuman 2006). Alvesson and Skoldberg (2009) listed the point of agreement as the emphasis on underlying patterns, in view of commonality of social science, and in its search for some kind of scientific laws. However, there has been disagreement on some points. Critical researchers believe interpretivism approach is too subjective and relativist in nature, as to take people's ideas more important than the actual condition (Neuman 2006). Critical realism bridges the gap between quantitative and qualitative research, and has no bias toward either of these types of research (Alvesson and Skoldberg, 2009). While some realists argue that social structures are real existing things with causal power, many others claim that real social structures do not have causal power; rather, the social world is concept-dependent i.e. made of discursive structures (Porter and Lopez, 2005). According to Neuman (2006), critical social science sees the current state of every society as an on-going process rather than an unchanging social order. Thus, the main drive of critical social science approach is not for studying the social world but to bring changes to it. Critical realism and interpretive social science have been presented as two possible alternatives to positivist's conception of science (Alvesson and Skoldberg, 2009).

4.3.4 The Chosen Paradigm

It has been deemed essential in this study to take a clear philosophical stance which is commensurate with the personal style of the researcher, the style of the research, and the potential for effective learning about the area of concern of this study as suggested by Johnson and Duberly (2000). As discussed (in Section 4.3), the paradigms most commonly utilised in research are positivist, postpositivist, interpretive, and critical social theory. The positivist paradigm arose from the philosophy recognised as logical positivism and it is based on rigid rules of logic and measurement, truth, absolute principles and prediction (Halcomb and Andrew, 2005; Cole, 2006; Weaver and Olson, 2006). The positivist philosophy argues that there is one objective reality. It also assumes that objective reality can be captured, observations are free from situational constraints (i.e. they are universally generalisable), inquiry is value-free, and that causality is linear in that there are no causes without effects or effects without causes.

Subsequently, valid research is demonstrated only by the degree of proof that corresponds to the phenomena that study results stand for (Hope and Waterman, 2003). However, such inflexible beliefs did not have the capacity to accommodate the investigatory the aspects of this study that dealt with the social and human experiences. Consequently, the interpretive paradigm was also incorporated into the research design. The qualitative methodology shares its philosophical foundation with the interpretive paradigm which supports the view that there are many truths and multiple realities. Positivism is not sufficient where the area under study concerns individual responses to particular aspects of lean implementation. One of the objectives of this research was to determine the drivers for adopting lean in organisations. This was difficult as the conditions or motives for adoption were never the same. For example Galliers and Land (1987) presented decision making as a typical example of a real world situation that would be very difficult to simulate especially in an organisational setting where the objects under study are people. This type of paradigm focuses on the holistic perspective of the person and environment.

Additionally, the interpretive paradigm is associated more with methodological approaches that provide an opportunity for the voice, concerns and practices of research participants to be heard (Cole, 2006; Weaver and Olson, 2006). Furthermore, Cole (2006) argued that qualitative researchers are “more concerned about uncovering knowledge about how people feel and think in the circumstances in which they find themselves, than making judgements about whether those thoughts and feelings are valid”.

The paradigm chosen for this study is the combination of both positivism and interpretivism as this is the most appropriate approach to elicit information concerning the general and internal perceptions and motivations of individuals/organisations and the resultant benefits of the implementation of lean construction. The combination of the two approaches otherwise known as pragmatism is possible (Cupchik, 2001). Positivism and interpretive social science approaches have been widely used by many researchers under an epistemological context where both qualitative and quantitative methods of research have been effectively combined (Ritchie and Lewis, 2003).

4.4 Choice of Research Methodology and Research Methods

In broad terms, ‘research design’ describes the ways in which the data will be collected and analysed in order to answer the research questions posed and so provide a framework for undertaking the research (Bryman and Bell, 2003). As discussed in Section 4.4, the choice of research methodology and method should be appropriate for the research aim and objectives. The two common research methodologies within the research paradigms are the qualitative and the quantitative. The combination of these two methodologies otherwise known as the mixed method can aslo be a choice. Denscombe (2010) summarises the characteristic feature of a mixed method approach to be the use of qualitative and quantitative approaches within a single research project. The choice of this approach is based on the assumption that value can be achieved in bringing the two types of approach together having considered the very different ontological and epistemological bases of the two paradigms (Ritchie and Lewis, 2003).

4.4.1 Quantitative Research

Quantitative research has been defined by so many authors. It is defined by Creswell (1994) as an inquiry into a social or human problem, based on testing a hypothesis or a theory composed of variables, measured with numbers, and analysed with statistical procedures, in order to determine whether the hypothesis or the theory holds true. Creswell (2007) stated that the investigator primarily uses post-positivist claim for developing knowledge when the quantitative approach is adopted (i.e., cause and effect thinking, reduction to specific variables and hypotheses and questions, use of measurement and observation, and test of the theories), employs strategies of inquiry such as experiments and surveys, and collects data on predetermined instruments that yield statistical data. The use of experiments, statistics, content analysis, social survey and structured observation has been identified as quantitative techniques (Bryman, 1998). It has been noted by many authors that quantitative methods ignore social and cultural influences and assume a value-free and objective report (Denzin and Lincoln, 1994). Additionally, it has also been pointed out that a purely statistical logic can make the development of hypotheses a small matter and can fail to help in generating theory from data (Glaser and Strauss, 1967). Based on this shortcoming of quantitative method, an alternative method of research that is capable of exploring the underlying 'real world' environment and to include the hard to define factors which influence actual human behaviour (qualitative method) is usually proposed.

4.4.2 Qualitative Research

According to Denzin and Lincoln (2000), qualitative research involves the studied use and collection of a variety of empirical materials-case study, personal experience, introspective, life story, interview, artefacts, cultural texts and productions, observational, historical, interactional, and visual texts that describe routine and problematic moments and meaning in individuals' lives. Shank (2002: 5) defines qualitative research as "a form of systematic empirical inquiry into meaning". The word 'empirical' in this definition implies that inquiry is grounded in the world of experience. According to Walsham (1993), the validity of generalisation in qualitative research does not depend on statistical inference but on the plausibility and cogency of the logical reasoning used in describing the results from the cases and in drawing conclusions from them. Denzin and Lincoln (2000) argued that qualitative research involves an interpretive and naturalistic approach. This reflects that researchers study things in their natural settings while trying to make sense of them and interpret phenomena in terms of the meaning people bring to them. The several types of qualitative designs found in the literature include ethnography, action research and grounded theory (Tierney, 1996; Schall *et al*, 2002; Huxham and Vangen, 2000; Parry, 1998). Further discussions relating to each of these qualitative designs are provided in Section 4.6.6.

4.4.3 Qualitative and Quantitative Methodologies (Mixed Method)

There has been much debate whether quantitative and qualitative approaches can be combined in social research. Many arguments have been put forward by so many authors that the approaches are so different in their philosophical and methodological origins that they cannot be effectively blended (Ritchie and Lewis, 2003). Similarly, Knight and Ruddock (2008) argued that quantitative and qualitative research are themselves rooted in particular ontological and epistemological foundations (i.e. objectivism and constructivism, and positivism and interpretivism respectively). However, many other authors suggest that value can be achieved in bringing the two types of approach together having considered the very different ontological and epistemological bases of the two paradigms (Ritchie and Lewis, 2003). Kaplan and Duchon (1988) maintained that quantitative data can be used as supplementary evidence for an interpretive study and that the adoption of both qualitative and quantitative methods offers a richer contextual basis for interpreting results. According to Janetzko (2001), the combination of qualitative and qualitative can be complementary; the use of either quantitative or qualitative can have its own pros and cons. The differences between the two methodologies (quantitative and qualitative) are presented in Table 4.2.

Table 4.2: Quantitative vs. Qualitative Methodology

	QUANTITATIVE RESEARCH	QUALITATIVE RESEARCH
Purpose/objective	To measure various views and options in a chosen sample Primary purpose is to determine cause- and-effect relationships To quantify data and generalise results from a sample to the population of interest	To provide insight into the settings of a problem Primary purpose is to describe on going processes To gain understanding of underlying reasons and motivations
Setting hypothesis	Precise hypothesis is stated at the start of the	Hypotheses are developed during the investigation; questions govern the

	investigation; theories govern the purpose of the investigation in a deductive manner	purpose of the investigation; theories are developed inductively
Variable types	The independent variable is controlled and manipulated	There is no specific independent variable; the concern is to study naturally occurring phenomena without interference
Data collection method	Objective collection of data is a requirement. Closed ended questions, questionnaire surveys experiments	Participant observation, semi-and unstructured interview, focus groups, in-depth discussion and discourse analysis. Objective collection of data is not a requirement; data collectors may interact with the participants
Research design	Research design is specified before the start of the investigation	Research design is flexible and develops throughout the investigation
Data analysis	Data are represented and summarised in in numerical form	Data are represented or summarised narrative or verbal forms
Validity and reliability	Reliability and validity determined through statistical and logical methods	Reliability and validity determined through multiple sources of information (triangulation)
Sample frame	Samples are selected to represent the population	Samples are purposefully selected or single cases are studied
Study of behaviour	Study of behaviour is in the natural or artificial setting	Study of behaviour is in the natural setting
Statistical analysis	Use of design or statistical analyses to control for threats to internal validity	Use of logical analyses to control or account for alternative explanation
External validity	Use of inferential statistical procedures to demonstrate external validity (specifically, population validity)	Use of similar cases to determine the generalisability of findings (logical generalisation) if at all
	Rely on research design and data gathering instruments to control for procedural bias	Rely on the researcher to come to terms with procedural bias
	Phenomena are broken down or simplified for study	Phenomena are studies holistically, as a complex system
Strengths	Data can be easily generalised Variable used can be measured Data are obtained from large samples	cross-case comparisons and analysis can be conducted Provides understanding and description of people's personal experiences of phenomena Complex questions that can be impossible with quantitative can be examined Issues can be examined in detail and in-depth
Weaknesses	Enforces researcher's	Less easily generalised Knowledge produced might not generalise

	perception to build questions Less helpful in generating theories Limited to rigidly definable variables	to other settings more difficult to test hypotheses Scope is limited due to in-depth, comprehensive approach More easily influenced by the researcher's personal biases and idiosyncrasies. Findings can be more difficult and time consuming to characterize in a visual way

(Sources: Creswell, 2007; Denzin and Lincoln, 2005; Anderson, 2010; Bryman, 1998; Denscombe, 2010)

The choice of mixed method approach was adopted for this research study, having considered the differences, strengths and weaknesses as presented in Table 4.2 as well as the philosophical and realistic reasons with the research objectives along side the wide range of information to be acquired.

The aim of this study is dominantly concerned with in-depth understanding of the lean approach in sustainable construction. In addition the concept under investigation (lean construction, which is one of the ways of achieving sustainable construction) is open to a wide variety of interpretations and is context-dependent. Furthermore, investigating the adoption of lean within construction organisations requires the general perception of construction professionals and research to be taken in a natural setting. Therefore, considering the overall discussion within this section, the combination of quantitative and qualitative approach (i.e. mixed method) is suitable to achieve the aim of this research.

4.4.4 The Rationale for Choosing a Mixed Method Approach

As stated earlier, the use of mixed method approach involves the combination of both quantitative and qualitative methodologies into a single study (Denscombe, 2010). The main area of this study is lean construction. The research method breakdown carried out on lean construction studies reveals that there is a lack of applied lean research in construction. This suggests that more research should be conducted using the mixed method approach (Jacobs, 2011). However, the use of theoretical research cannot be neglected as this has a high percentage of usage as presented in Figure 4.2.

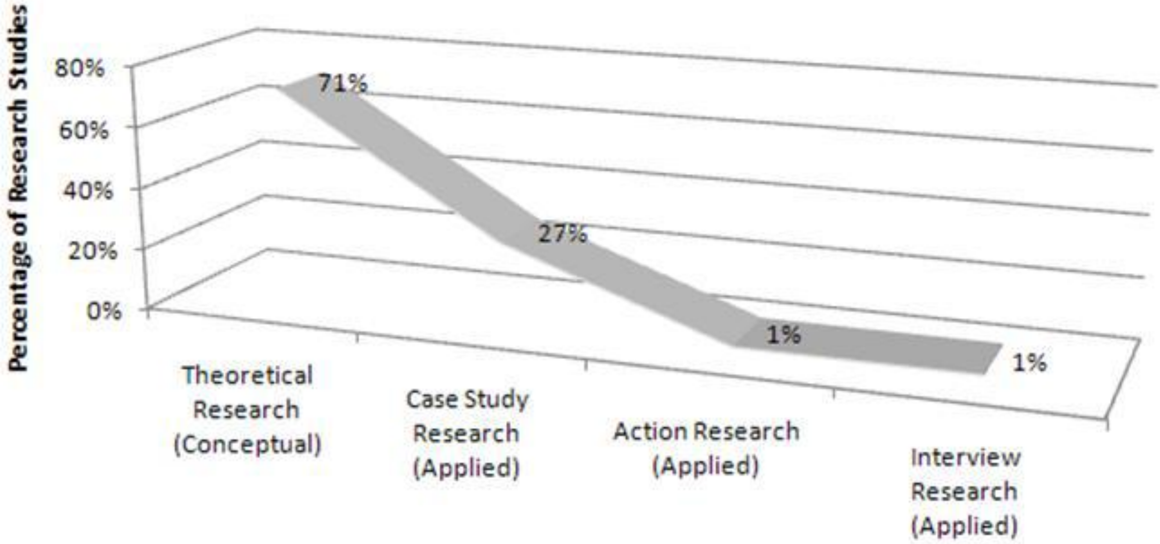

Figure 4.2: Breakdown of Lean Research Studies

(Source Jacobs, 2011)

Jacobs (2011) stated that lean research in construction is representative of a conceptual versus applied research underpinning, the success of lean research in construction is largely dependent on both theory and the practical knowledge.

According to Fellows and Liu (2008) quantitative approaches (of which epistemology is a base) adopt scientific methods and provide 'snapshots' i.e. the data, and results are instantaneous or cross-sectional. Qualitative method on the other hand consists of a set of interpretive material practices that make the world visible i.e. qualitative researchers study things in their natural settings, attempt to make sense of or interpret phenomena with respect to the meanings people bring to them through the use of field notes, interviews, conversations, photographs, recordings. (Denzin and Lincoln, 2005). Although qualitative research is often seen as an inductive approach, the processes of sampling and generalisation from qualitative research involve both induction and deduction (Ritchie and Lewis, 2003).

Furthermore, the combination of different methodologies will generally tend to have a leading strategy for starting out the research, and a follow-up strategy for rounding out and widening the enquiry (Bryman, 2001). High levels of reliability of gathered data, and more in-depth information about the subject matter will be achieved when both qualitative and quantitative method is employed. Thurmond (2001) concluded that the use of both quantitative and qualitative strategies in the same study is a viable option to obtain complementary findings and to strengthen research results.

According to Koskela *et al.* (2002), practical lean construction draws on inspiration from philosophy. Thus, a purely theoretical study of lean construction and design would be of little significance to construction management research which is regarded as a field of application (Jorgensen 2006). Cook and Brown (1999) also argued for studying both theory and practice, and suggested the bridging of epistemologies of organisational knowledge and organisational knowing into action i.e. explicit and tacit knowledge at both individual and group levels. Hence, Jorgensen (2006) concluded that lean philosophy must be understood through the two dimensions: knowledge and practical action, if the bridged epistemology is accepted. Therefore, to achieve deeper understanding of lean construction/design, studying only literature is insufficient and it is similarly insufficient to study only practice. Thus, this calls for a study based on both literature and exploratory research studies.

There are many strategies and sources for data collection such as case studies, questionnaire surveys, interviews, and triangulation which are commonly applied in explorative research (Ritchie and Lewis 2003; Berg 2009; Alvesson and Skoldberg 2009; Neuman 2006; Silverman 2005). These were applied for this research, since these methods were deemed essential to contribute substantially to solving the research problems, and were possible to conduct within the research framework. The discussion of these methods would be seen in Section 4.6.

In relation to the objectives of this study, literature review was critically and extensively carried out in order to understand the concept of both lean and sustainable construction, and to identify the key barriers and success factors for the implementation of lean and sustainability. The review helped in identifying and prioritising the barriers and in identifying gaps in knowledge and formed the basis for the design of the questionnaire survey which is a quantitative approach. The case study was used for further scrutiny as the study progressed. This involved the collation of case studies from successful organisations to establish factors for successful implementation of lean at the strategic level. For the purpose of this study, the case study has been identified as a qualitative strategy owing to the fact that it is a useful research approach for answering "why" and "how" questions and also for understanding a situation (Rowley, 2004). Then, the combination of both the questionnaire survey and the case studies was used for the development of the conceptual framework as shown in Figure 4.3.

4.5 Ethical Consideration

The consideration of ethical issues in field research is an important aspect of every research (De Vaus, 2014). This has raised the awareness of the researcher to give priority to ethical issues from the area (topic selection), data collection and analysis to the presentation of the result. The ethical consideration was necessary in order to promote the research quality and guard against inappropriateness and also to protect the participants and their organisations as mentioned by Creswell (2007). The entire research was undertaken with high respect to the integrity and the confidentiality of the participants. The participants were informed that the information gathered would be treated with high level of confidentiality. This allowed for voluntary participation. An ethical approval was obtained from the University's Ethics Committee prior to contacting the participants. The University has made provision for training researchers on ethical issues and guide to obtaining ethical approval (see Appendix A).

4.6 The Research Framework

The research process used in this study can be depicted using a research framework consisting of four key stages as shown in Figure 4.3. In depth discussions of the research process within each of these stages are presented below.

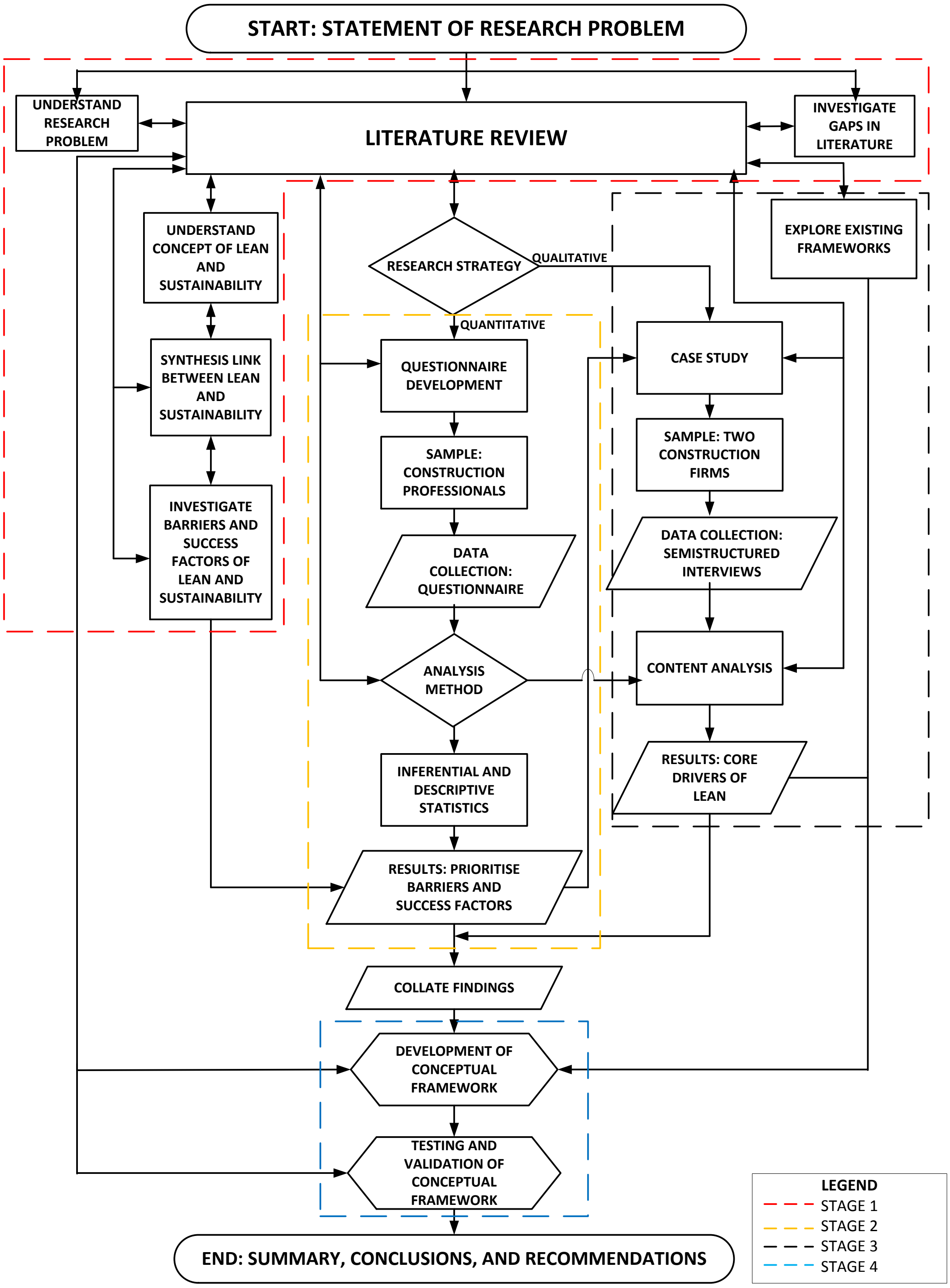

Figure 4.3: The Research Framework

4.6.1 Literature Review

Literature review is a very important aspect of any research. It is a systematic method which allows the identification, evaluation and interpretation of the existing body of knowledge (Fink, 1998). It also helps to establish the context of the topic or problem, identify what has already been done in the research area, and identify the gaps in knowledge as well as identifying the main methodologies and research techniques that have been used in related studies (Randolph, 2009).

For the purpose of this study, the review of literature was extensively and critically undertaken at the initial stage of the study and throughout the study process to build up a solid theoretical base for the research area and a foundation for addressing the problems and achieving the research objectives. The literature review undertaken in this research study encompassed the subject of lean construction, sustainable construction and its applicability within construction organisations. The literature review exercise presented a background study on lean construction reflecting its contributory benefits, barriers and success factors. In addition, the literature review exercise presented the critical analysis of several lean construction techniques and methods. This was necessary in that it allowed the study to select the most appropriate approach for assessing the benefits of the lean approach in sustainable construction within construction firms.

The first part of the literature is centred on the lean approach in sustainable construction and the synergies between lean construction and sustainability. The main priority of lean and how they fit with sustainability improvement particularly lean tools and their sustainability effects and finally how other process improvement methodologies and types of lean organisation based on organisational learning can impact on implementation. The materials discussing the potential for integrating lean and sustainable construction and improvement activities was reviewed. The findings from the literature on the similarities and differences between the two concepts, the benefits of synchronising them and the barriers to integrating or implementing them are presented and analysed in turn. The sources of literature for this study included: reports, journal articles, books, and conference proceedings.

The first stage of the search was to identify peer reviewed papers that contained the word “lean” and one or more of the words “sustainability” or “sustainable construction” in the title or abstract. This formed a body of work from which to draw lists of authors active in the field, journals that contained relevant articles, papers cited in these articles and papers that referred to these articles. Based on this, further searches were made; each authors list of work was reviewed and papers with titles relating to sustainability or lean were scanned for content relating to implementation and lean thinking; searches were run within the contents of each papers identified using the same criteria to check for key authors papers, noted above. The electronic databases used for the initial searching process were ProQuest, EBSCO, Elsevier (Science Direct and SCOPUS), Web of Knowledge, and internet search engines (Google Scholar). Articles that were not peer-reviewed but were referenced by several other papers were also considered for inclusion in the main review. This is because articles relating to the results of integrated implementation of lean and sustainability in a particular company were of interest to this review.

The research area reviewed thoroughly was lean and lean thinking as it relates to construction, and its impact on sustainability. Several themes emerged within the group of papers that were referenced by or referred to the core papers, which were not within the main area of this research but sometimes overlapped it. These separate process improvement methodologies were Total Quality Management, Six Sigma and Lean Six Sigma. A full review of these subjects were not undertaken, but where papers were referred to, they were read many times and if they contained information that pertained or contributed to the emerging themes from the core papers, they were included.

Over the duration of the research, the process was repeated at intervals, with the last search carried out just before submission. The findings of the literature review led to the parameters for the development of the questionnaire survey (see Stage 2 of the research study in the subsequent section.

4.6.2 The Questionnaire Survey

The research process of this stage is shown in Figure 4.4. Discussions on this stage are given in subsequent sections. This stage of the research addressed the third objective of the study. It focuses on the development of the questionnaire survey and the analysis of the results of the survey to prioritise the success factors and barriers identified in the literature review, and to analyse the benefits of the lean approach in sustainable construction.

RESEARCH PROCESS: STAGE 2

↓

Research Question:

1. What are the critical issues associated with the implementation of lean in sustainable construction?
2. Are there synergies and linkage between lean construction and sustainability, what are they?
3. What are the benefits/impact of implementing lean in sustainable construction?
4. What are the barriers and success factors in the implementation of lean construction?
5. What is the level of use of lean tools and techniques/principles for enabling sustainability?

↓

Research Strategy: Quantitative Method

↓

Sample: Construction professionals within construction firms in the UK

↓

Data Collection: Questionnaire Survey

↓

Data Analysis: Inferential and Descriptive Statistics (using SPSS 19.0)

↓

Results: Main Findings of the Research

Figure 4.4: The Research Process- Stage 2 of the Research study

4.6.2.1 Purpose of the Second Stage of the Study

The main purpose of this stage of the study was to identify the area of linkage of lean and sustainability, the benefits of the lean approach in sustainable construction and its associated issues such as barriers and success factors (Objective 3 of the study – see Table 1.1). In addition, this stage of the study was carried out to verify some significant findings of the literature review approach. This is discussed in detail in the following Section.

4.6.2.2 Research Questions and Hypotheses

The literature review findings highlighted the need to investigate issues relating to the level of integration of the lean and sustainability and key factors that promote/inhibit effective implementation of lean. Stage 2 was, therefore, undertaken to examine Research Questions 1- 3 and the hypotheses of the study (see Table 1.1).

The research questions are:

1. What are the critical issues associated with the implementation of lean in sustainable construction?
2. Are there synergies and linkage between lean construction and sustainability, what are they?
3. What are the benefits/impact of implementing lean in sustainable construction?
4. What are the barriers and success factors associated with the implementation of lean construction?
5. What is the level of use of lean tools and techniques/principles for enabling sustainability?

The hypotheses examined are as follows:

1. H1: The level of agreement on the area of linkage between lean and sustainability differs among construction participants.
2. H2: The perception of the success factors in the implementation of lean and sustainability differ according to size of organisation.
3. H3: The perception of the success factors in the implementation of lean and sustainability differ according to organisation's main business activities.
4. H4: The perception of the barriers in the implementation of lean and sustainability differ according to size of organisation.
5. H5: The perception of the barriers in the implementation of lean and sustainability differ according to organisation's main business activities.

4.6.2.3 Research Strategy for the Second Stage of the Study

As shown in the research framework (see Figure 4.3), the second stage of the study adopted a quantitative approach. A survey approach was used to fulfil the objectives of this stage. A survey has been considered as a very popular quantitative method in social science. It involves the collection of information from a chosen sample via their responses to questions (Creswell, 2007). According to Denzin (1978), surveys are suitable to descriptive studies where the interest is to know how many people in a given population possess a particular attribute or opinion. However, survey data can also be used to explore aspects of a situation, or to seek explanation and provide data for testing hypotheses (Oppenheim, 1966). Therefore, a survey is more than the mere compilation of data. The data must be analysed, interpreted, and evaluated. The successful completion of this entire process of data analysis, interpretation and data evaluation therefore depends on the surveyor's (the person involved in the process of survey) skills and the methods adopted.

There are several methods to carry out a survey. Questionnaires are widely used, but other techniques such as in-depth interviews, content analysis, and observation can also be used (de Vaus, 2014). According to Creswell (2007), a survey design provides a quantitative or numeric description of trends, attitudes, or opinions of a population, by studying a sample of that population. Here, Creswell's view was only on sample survey, which is one of the two main methods of surveys. The other method of survey is 'census' (Department of Defence – United States, 1996). This involves looking at the entire population (entire group) coming under the area of the research study. It is, however, obvious that census is not a realistic method for researchers if the population is large and the time allocated for the research study is limited. It can be costly and time consuming, although the accuracy is high if the entire population is selected.

The common types of surveys are mailed, telephone and interview surveys. Out of these, a mailed questionnaire survey was chosen as the mode for the data collection process. According to Oppenheim (1996), mailed questionnaire surveys tend to have a lower response rate, which will distort and hence flaw a sample. Although telephone surveys may be relatively efficient and inexpensive, the more time consuming and correspondingly expensive personal interview allows more details and complex data to be collected (Frankfort-Nachmias and Nachmias, 1996). One of the main reasons for choosing a mailed questionnaire survey was to ensure anonymity of the respondents.

4.6.2.4 Sample Chosen for the Second Stage of the Study

According to Brewerton and Millward (2001), a subset or sample of the population is more suitable for study as it is often not possible to survey an entire population for practical and cost reason.

A sample survey involves examining a portion of the population of the area of research, and inferring information about the population as a whole (Creswell, 2007, Kumar, 2011). Figure 4.5 presents the various types of sampling. These types are broadly categorised under the random/probability sampling, non-random/probability sampling and mixed sampling.

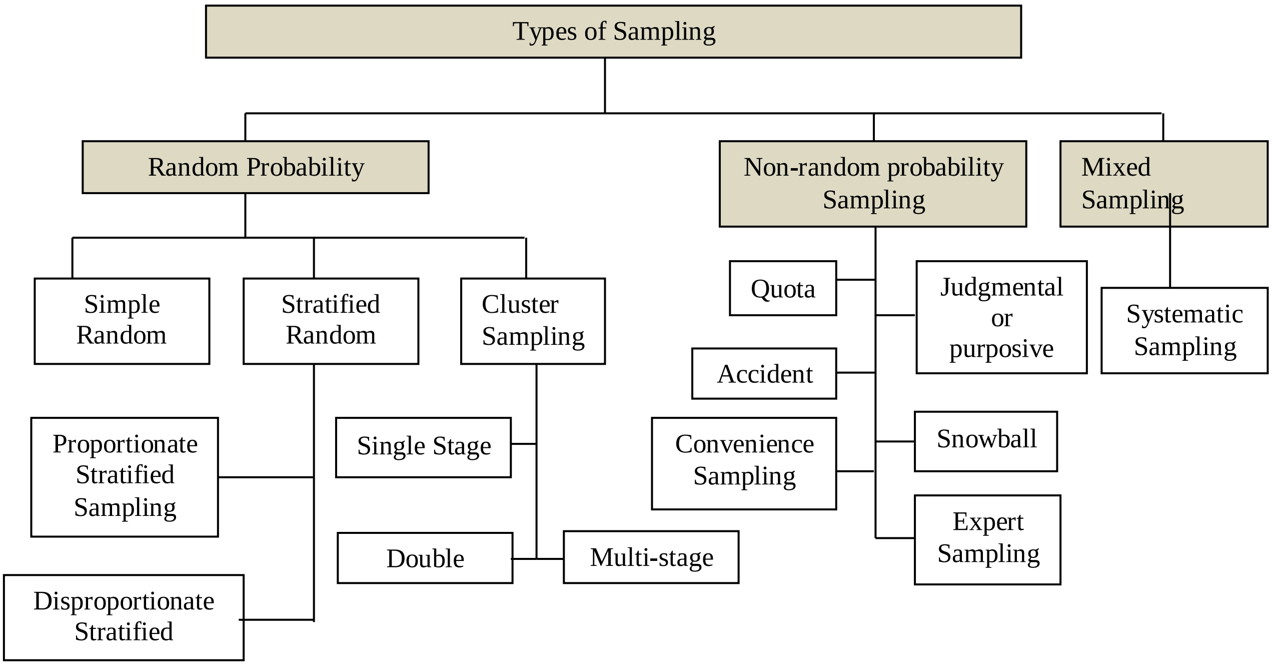

Figure 4.5: Types of Sampling

(Adapted from Creswell, 2009; Mathew and Ross, 2010; Kumar, 2011)

The three most commonly used types of random sampling are the simple random sampling, stratified random sampling and the cluster random sampling (Matthews and Ross, 2010; Kumar, 2011). Simple random sampling is the most commonly used method of selecting a probability sample. Under simple random sampling, each element in the population is given an equal and independent chance of selection (Kumar, 2011). According to Robson (1993), stratified random sampling involves dividing the population into a number of groups of strata, where members of a group share a particular characteristic or characteristics. Stratified random sampling ensures that different groups of a population are adequately represented in the sample, so as to increase the level of accuracy when estimating parameters (Frankfort-Nachmias and Nachmias, 1996). Cluster sampling involves dividing the sampling population into groups based on visible or easily identifiable characteristics, called cluster.

Based on the description of the three random/probability sampling, the simple random sampling was not considered for this study because it assumes that the members of the population are known with equal chance of being selected. The stratified random sampling and the cluster sampling was also exempted as the intention of the research was not to ensure that the numbers of groups selected for the sample reflect the relative numbers in the population as a whole or to divide them into clusters. Although, stratified random sampling is an important strategy in order to have a proportionate sample (Creswell, 2007).

There are other non-random/probability methods of sampling which include the quota sampling, experts sampling, judgemental sampling, accidental and convenience sampling (Robson, 1993, Creswell, 2009; Matthews and Ross, 2010; Kumar, 2011). Matthews and Ross (2010) stated that the approach of quota sampling includes some of the features of a stratified sample. According to Kumar (2011), the main consideration guiding quota sampling is the researcher’s ease of access to the sample population. A researcher may be guided by some visible characteristics, such as gender or race, of the study population that is of interest. Accidental sampling is based upon convenience in accessing the sample population and it is common among market research and newspaper reporters. Data collection stops in accidental sampling when the required numbers of respondents have been achieved (Kumar, 2011).

Judgemental or purposive sampling is more common in qualitative research and generally associated with small in-depth studies. The main consideration in purposive sampling is the ability of the researcher to decide on who can provide the best information to achieve the objectives of the study (Matthews and Ross, 2010; Kumar, 2011). Kumar (2011) stated that purposive sampling is particularly useful to describe a phenomenon, construct a historical reality, or develop something about which only a little is known. Expert sampling is similar to judgement sampling, but the main difference is that respondents must be known experts in the field of interest to the researcher. Snowball sampling can be used when the populations are quite hard to find and there are no lists of such people or cases. A snowball sampling starts with few known people who then help with contacts of other people in relevant case (Matthews and Ross (2010). According to Kumar (2011), a snowball sampling is the process of selecting a sample using networks.

Purposive sampling (rather than random sampling) of UK construction organisations with experience or expressed interest in lean construction/sustainability was adopted, through the database of the UK 100 top construction firms directory. Convenience sampling is the terminology used to describe a sample in which elements have been selected from the target population on the basis of their accessibility or convenience to the researcher (Ross, 1978). It involves drawing samples that are both easily accessible and willing to participate in a study (Teddie and Yu, 2007). Higginbottom (2004) defined convenience sample as consisting of participants who are readily available and easy to contact. Purposive/Convenience sampling was found appropriate for this study since there is no comprehensive, nor any standard, database of UK construction organisation involved in lean construction. Besides, lean construction is evolving. As a result, the number of organisations involved is increasing, but not in a form that the overall number of these organisations involved can be determined easily. Convenience sampling was used as it was not easy to determine the population of the organisations involved in lean construction. Using random sampling would require that the number of organisations involved is reasonably large and that the population is known (Jackson, 2011).

The sample was chosen among the top 100 UK construction companies using the latest databases of the UK Construction Management Firm Directory (2011). Directories were regarded as the most suitable method of choosing the sample for the survey, due to the following reasons:

- Up-to-date nature of the directories
- Information available in the directories was clear and easy to use, in order to choose companies respondents
- Time savings as the respondents' full contact details were available in the directories

In addition to these directories, the researcher was also able to expand the sample through personal contacts (snowball sampling).

The sampling frame included organisations in which lean implementation was very successful and sustainable, only these organisations which had adopted lean were represented. The target sample respondent included contract managers, environmental managers, project managers, sustainability managers, training managers, quality managers, site managers and supervisors at different levels, ranging from the strategic to operational level. The following procedure was adopted in choosing the sample from the directories and through personal contacts:

- Initial telephone calls were made and e-mail sent to request the participation of the target respondents
- It was made clear that the questionnaire should be completed by the person who falls into the category of the target respondent by job role/function

The criterion adopted was that the target respondent must have the knowledge of lean and sustainability. Therefore, the job role of the participants should be one of the afore listed. The chosen respondents were included in the sample only after the researcher had verified (through telephone conversations and e-mail) that their organisations had implemented lean or were going through the lean transformation process and were willing to participate in the survey.

4.6.2.5 Sample Size

The appropriate sample size for a survey is generally not a straightforward decision and can sometimes be very complex. The question is one that usually has no conclusive answer (Bryman and Bell, 2003). Nevertheless, there are different methods that can be used to estimate the sample size, based on the statistical power required to report significance or non-significance accurately. For example Brewerton and Millward (2001) projected the required participants of a survey for various statistical tests to range from 14 to 50 for a large effect size, and to range from 35 to 133 for a medium effect size. Mbugua (2000) presented a rule-of-thumb dictating a minimum of 30 responses being adequate for research based in the construction industry. Alternatively, Easterby-Smith *et al.* (2002), presented a rough formula for calculating sample size (n) in terms of (E) the maximum error required, as shown in Equation 1

$$n = \frac{2500}{E^2} \text{...Equation 1}$$

By using a standard error of, say, not more than 5 per cent the minimum sample size would be 100. If the standard error was to be not more than 10 per cent, the minimum sample size would be 25. The sample size obtained in this survey was 55 respondents, which according to the previous discussion is a reasonable sample size that accounts for a minimum standard error of 6.7 per cent. The standard error is a measure of the expected dispersion of sample estimates around the true population parameter. The standard error is the standard deviation of the sampling distribution of a statistic (Everitt, 2003). The smaller the standard error, the more representative the sample will be of the overall population. The standard error is also inversely proportional to the sample size; the larger the sample size, the smaller the standard error because the statistic will approach the actual value. In relation to this study the standard error is less that 10%.

Response rate is another aspect of sampling in a survey, which is the rate of useful questionnaires returned in the survey. Postal surveys usually have lower response rates than when administered by telephone or in person (Cooper and Emory, 1995). A response rate of 30 per cent or above is often considered satisfactory in a postal survey. However, Akintoye and Fitzgerald (2000) argued that the norm of response rates within the construction indust`ry is 20-30 per cent. Within this survey, 70 questionnaires were sent out, 55 usable fully completed questionnaires were returned thus achieving 79% per cent response rate. This high response rate can be possibly attributed to the interest of the respondents in the topic and the adoption of some of the ‘improving returns' techniques suggested in Cooper and Emory (1995) such as personalised approach, follow-ups, questionnaire length, anonymity, and final report incentive. It is generally difficult to ascertain the reason of non-response of companies; however, two companies revealed such reasons as non-availability of time and non-interest in completing the questionnaire.

4.6.2.6 Data Collection - Questionnaire Design and Survey

A questionnaire was developed to reflect the research questions and key issues identified in Section 1.2. The questionnaire (refer to Appendix1) consisted of three main sections as follows: Section 1 - The general information; Section 2- Lean construction; Section 3 - Lean construction and sustainability close-ended questions, which were multiple-choice in nature, were used for the questionnaire, so as to avoid any complications during the data reduction stage. A Likert scale was used for all the questions. The Questionnaire used a four-point Likert scale of 1-4 where 1= Strongly disagree, 2= Disagree, 3= Agree and 4= Strongly agree. According to Batchelor *et al.*, (1994), attitudinal measures in the form of Likert scale, can generate more valid data than single measures. The four-point scale was seen as the most appropriate to choose options that are far enough apart while at the same time, keeping them close enough to ensure that the researcher does not lose important point. Similarly, a Likert scale of 5 is also acceptable (Garland, 1991). The use of a Likert scale of 6 or more was not considered, as they are perceived by the researcher to cause confusion among respondents. Bernard (2000) stated that there is no best format on the choice of Likert scale; most Likert scale items have an odd number of response choices: three, five, or seven with the idea of including a neutral midpoint; there can also be an even number of response choices which forces respondents to “take a stand” while an odd number of choices allows the respondents to “sit on the fence”.

In order to ensure the adequacy of the issues covered by the questionnaire, a pilot exercise was carried out. The questionnaire was evaluated and validated by the researcher’s supervisors with two other academics and practising professionals. This was done to ensure clarity and unambiguity of the questions. The questions were modified based on the comments given. The pilot exercise carried out also revealed that the questionnaire could be completed in about 15 minutes.

4.6.2.6.1 Scales of Measurement

Measurement is central to any enquiry. Measurement according to Singleton *et al.*, (1988), is the process of assigning numbers or labels to units of analysis in scientific research to represent their conceptual properties. Majority of research studies require some form of measurement. Therefore, it is important to consider critically at the outset the likely quality of the data that the system of measurement to be used will provide in any research involving measurement (Rowlands, 1996).

Oladapo (2005) affirmed that it is essential for a researcher to resolve from the onset of a study the scale of measurement to use based on the nature and type of data to be collected. This is necessary in order to determine the kind of numerical analysis that can be performed on the data generated. The scale of measurement is therefore critical because it relates to the types of statistics that can be used to analyse data (Markham, 2001).

Data has been commonly classified into four types based on scales of measurement, i.e., nominal, ordinal, interval, and ratio scales (Moser and Kalton, 1971, Oppenheim, 1996, Denscombe, 2010; Kumar, 2011). Data are further grouped into continuous and categorical data. Continuous data is described as measurements which can take any value within a certain range, such as weight, height and the opinion scores above. Categorical data, in contrast, can take only one of a few values. The size of a family is an example of categorical data (Hand, 1996).

4.6.2.6.2 Nominal Scales

Nominal measurement entails assigning items to groups or categories. It can be used to classify individuals into two or more groups, the members of which differ with respect to the characteristics being scaled, without there being any implication of gradation or distance between the groups. It is a way of classification rather than an arrangement along a continuum and the question of dimensionally does not arise (Moser and Kalton, 1971). No quantitative information is conveyed and no ordering of the items is implied. Nominal scales are therefore qualitative rather than quantitative. Munro (2005) stated that nominal scale is the lowest level of measurement and since nominal scales merely use numbers as labels, no mathematical relationships are possible at the nominal level. According to Markham (2001), the statistics which can be used with nominal scales are in the non-parametric group, the most likely ones being mode and cross-tabulation with chi-square. The nominal scale was used to measure some of the data required in the general information of section of the questionnaire used for this study for example Question 4 ("professional discipline").

4.6.2.6.3 Ordinal Scales

In ordinal measurement, numbers indicate only the rank order of cases on some variables. Ordinal scale ranks individuals along the continuum of the characteristics being scaled. It carries no implication of the distance between scale positions (Moser and Kalton, 1971). Stockburger (1998) stated that ordinal scales are measurement systems that possess the property of magnitude, but not the property of intervals. The property of rational zero is not important if the property of intervals is not satisfied. The use of the phrases "more than" or "less than" is possible in ordinal scale.

Rank ordering people in a classroom according to height and assigning the shortest person the number "1", the next shortest person the number "2", etc. is an example of an ordinal scale. According to (Markham, 2001), ordinal data can use non-parametric statistics like median and mode, rank order correlation and non-parametric analysis of variance. Modeling techniques can also be used with ordinal data (Markham, 2001). In the general information section of the questionnaire used in this study, the ordinal scale was used to measure responses to most of the questions in the questionnaire used for this study. It measured the strength of opinion of respondents on a Likert-type scale on various aspects of lean and sustainable construction. Respondents were, for example, asked to express their level of agreement to the benefits of synchronising lean and sustainable construction on a scale ranging from "Strongly disagree" to "Strongly agree".

4.6.2.6.4 Interval Scales

The interval scale of measurement has the qualities of the nominal and ordinal scales. It has equal units of measurement, thus making it possible to interpret not only the order of scale scores but also the distances between them (Singleton *et al*, 1988; Moser and Kalton, 1971; Oppenheim, 1996; Kumar, 2011). This is different from the ordinal scale where we can only talk about differences in order, not differences in the degree of order (Markham, 2001). Such parametric statistical techniques as mean and standard deviation, correlation and regression analysis, ANOVA and factor analysis can be used for interval scale data, in addition to a whole range of advanced multivariate and modelling techniques (Markham, 2001).

4.6.2.6.5 Ratio Scales

Ratio scales differ from interval scales only in that they have a rational zero. The highest level of measurement is a ratio scale, which has the properties of an interval scale together with a fixed origin or zero point. Weights, lengths and times are obvious examples (Moser and Kalton, 1971; Markham, 2001). According to Stockburger (1998), ratio scales possess all the three properties: magnitude, intervals, and rational zero. Question 5 ('Number of years of professional experience') is a typical example of a ratio scale, where the number of years were categorised from 1-5 years to over 20 years.

4.6.2.7 Validity and Reliability of Scales

Reliability and validity can be carried out to any aspect of the research process. According to Kumar (2011), the establishment of a logical link between the objectives of a study and the questions used in an instrument, and the use of statistical analysis to demonstrate these links are the two approaches used to establish the validity of an instrument in quantitative research. Rosnow and Rosenthal (1999) stated that all forms of measurement, including surveys, are subject to error which necessitates the assessment of research outcomes for reliability and validity. According to McQueen and Knusson (1999), reliability and validity are two crucial qualities that a survey instrument or measurement scale must possess. The ability of an instrument to yield consistent measurements and produce similar results each time when administered under the same or similar condition or population is referred to as reliability (Oppenheim, 1996; Kumar, 2011). Yin (1994) stated that reliability is the extent to which a test or procedure produces similar results under constant conditions on all occasions. Validity, on the other hand, reflects whether the question, item or score measures what is supposed to measure (Oppenheim, 1996; Rosnow and Rosenthal, 1999). The validity of a measure depends on how we have defined the concept it is designed to measure (De Vaus, 2014).

In quantitative research, there are three types of validity namely; face and content validity, concurrent and predictive validity and the construct validity (Kumar, 2011). Face and content validity is based on the judgment that an instrument measures what is supposed to measure in terms of the logical link between the questions and the objectives of the study. The establishment of this link is called face validity. The assessment of the items of the instrument is called the content validity. Concurrent validity is judged by the degree to which an instrument can forecast an outcome. Content validity is juged by how well an instrument compares with a second assessment concurrently done. Construct validity is a more sophisticated technique for establishing the validity of an instrument. It is based upon statistical procedures. It is determined by ascertaining the contribution of each construct to the total variance observed in a phenomenon (Kumar, 2011).

The methods of determining the reliability of an instrument in quantitative research is often considered under internal or external procedures (Kumar, 2011). According to Amaratunga *et al.* (2002), internal validity refers to whether or not what are identified as the causes actually produce what has been interpreted as the “effect’’ or “responses’’ and checks whether the right cause-and-effect relationships have been established. Thus internal validity is the issue of establishing theoretical territory that goes with the defined construct and ensuring consistency between it and other recognised constructs. External validity, on the other hand, refers to the extent to which any research findings can be generalised beyond the immediate research sample or setting in which the research took place; that is, the extent to which findings drawn from studying one group are applicable to other groups or settings (the applicability of findings beyond the group). External validity could be achieved from theoretical relationships. The goal of reliability is to minimise the errors and biases in a study. The object is to ensure that, if a later investigator followed exactly the same procedures, the same findings and conclusions would result. From the above discussion, it can be seen that the basic difference between reliability and internal validity is that reliability deals with the data collection process to ensure consistency of results, while internal validity focuses more on the way such results support conclusions (Amaratunga *et al*., 2002). It should also be noted that the above deliberation refers to the traditional evaluation criteria of validity and reliability that are governed by the convention of the quantitative research paradigm.

According to Kumar (2011), there are two methods of carrying out an external consistency procedures; these are test/retest and parallel forms of the same test. The test/retest is a commonly used method for establishing the reliability of a research tool. In test/retest, an instrument is administered once, and repeated, under the same or similar conditions. The disadvantage of this method is that responses given in the first round may be recalled by a respondent and this may affect the reliability of the survey. The main advantage of this method is that it permits comparison of the instrument with itself thereby avoiding the sort of problems that could arise with the use of another instrument.

In parallel forms of the same test, two instruments that are intended to measure the same phenomenon are constructed and then administered to two similar populations. The results obtained from both tests are compared. If similar, the instrument is assumed to be reliable. This method does not suffer from the recall problem found in test/retest procedure. Also, there is no requirement of a time lapse between the two tests. However, the need to construct two instruments instead of one and the difficulty in constructing two instruments that are comparable in their measurement of a phenomenon are some of the disadvantages of this method (Kumar, 2011).

Cronbach's alpha is the most widely used measure of reliability (Stangor, 1998). According to Stangor (1998), Cronbach’s alpha measures internal consistency, which refers to the extent to which the scores on the items correlate with each other and thus are all measuring the true score rather than random error. This has to do with whether the respondents respond similarly from question to question (assuming the questions are asking similar things).

Table 4.3 shows that 70 questionnaires were distributed to construction professionals in various construction firms. Fifty five (55) were returned and analysed. This represents a response rate of 79%. According to Idrus and Newman (2002), a response rate of 30% is good enough for research of this nature.

Table 4.3: Survey Return

	Number	Percentage (%)
Total number of questionnaire returned	55	79
Total number of questionnaire unreturned	15	21
Total number of questionnaire distributed	70	100

Frankfort-Nachmias and Nachmias (1996) stated that one of the severe disadvantages of the postal questionnaire survey is the low response. According to them, a typical response rate for a personal interview is about 95% which is higher than a response for a mail survey, which ranges from 20% to 40%. Therefore, the reasons for achieving an adequate response rate for this study could be:

1. Layout of the questionnaire: straightforward and easy to understand.
2. The questionnaire was accomplished with a cover letter which states the importance of taking part in the survey.
3. The questionnaire highlighted the benefits of the study. It was also stated that a copy of the results would be sent to the respondents on demand.

Figure 4.6 presents information on respondents' years of professional work experience. It shows the number of years of experience and the percentage of professional within each category of the years. This is important since most of the answers to be provided in the questionnaire are based on the respondents' experience in the construction firms where they work. The percentage of the respondents that had over ten years of professional experience was 18%, while 35% had over 25 years of experience as shown in Figure 4.6. This reflects a good base of personal experience in the sample. Thus, it is rational to infer that the respondents have a reasonable knowledge of lean construction and that their response can be relied upon to some degree.

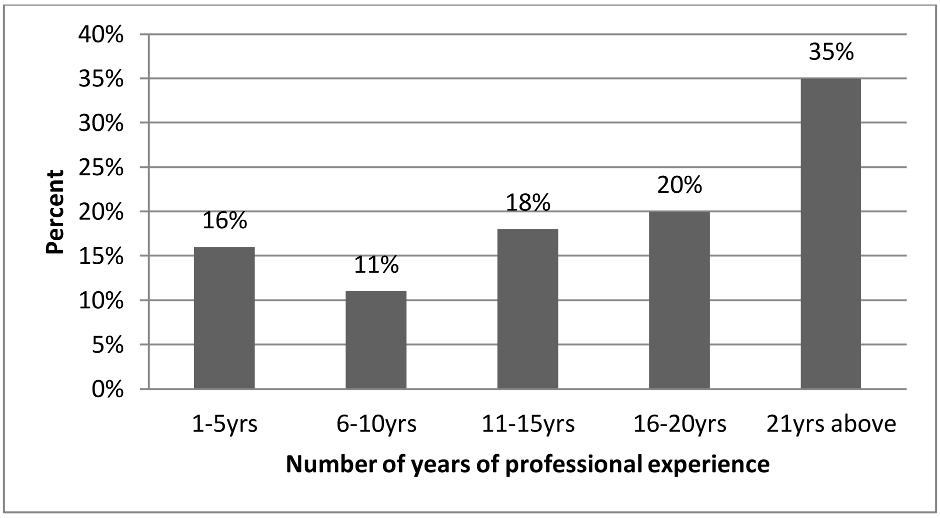

Figure 4.6: Respondents' Number of Years of Professional Experience

Table 4.4 shows the respondents' distribution by profession. It shows that the questionnaires were quite evenly distributed among the professional disciplines in the construction industry.

Table 4.4: Respondent's Professional Discipline

Professional Discipline	Percentage (%)
Architect	22
Quantity Surveyor	20
Engineering	29
Building	29

Table 4.5 shows the respondents' main business activity such as design, construction and both design and construction with each having 36%, 33% and 31% respectively.

Table 4.5: Respondent's Main Business Activity

Business main activity	Percentage (%)
Design	36
Construction	33
Design and Construction	31

Table 4.6 shows the respondents' business size such as small, medium and large scale with each having 22%, 60% and 18% respectively.

Table 4.6: Respondent's Business Size

Business size	Percentage (%)
Small	22
Medium	60
Large	18

4.6.3 Data Analysis – Questionnaire Survey

The data collected from the respondents were analysed with SPSS 19.0 version software using the percentile method, Severity Index Analysis, Kruskal Wallis test and the Cronbach's Alpha (for the measurement of the reliability of the survey). Upon the completion of entering the data into the SPSS software, data was proofread and checked for errors. This was achieved by checking the data at random. Although this was time consuming, it was necessary to ensure the accuracy of the data entry process. Data type identification was also given due consideration. Type of data can be identified in four different ways based on the scales of measurement (The American Psychological Association 1994) i.e. nominal, ordinal, interval and ratio. These data types are further grouped into categorical data and continuous data. Cho (1997) presented nominal and ordinal scales as categorical data; internal and ratio scales as continuous data. Categorical scale data use nonparametric measures, such as logistic regression models and log linear models. Continuous scale data use parametric measures such as t-test, ANOVA, regression (American Psychological Association, 1994).

The gathered data from the questionnaire survey in this study were categorical data, mainly ordinal and nominal data. Identifying the type of data was important as this enables the researcher to apply the appropriate statistics in the data analysis process. Descriptive statistics and inferential statistics were used for the data analysis. Calkins (2005) stated that descriptive statistics generally characterise or describe a set of data elements, by displaying the information graphically or describing its central tendencies and how it is distributed while inferential statistics try to infer information gathered by sampling. The significant level adopted throughout the analysis was 5% (0.05). The description of methods and tests adopted for this study are given below.

4.6.3.1 Severity Index Analysis

According to Kangwa and Olubodun (2003), severity index analysis is essentially a non-parametric technique, which is based on aggregate weighting frequency score of each attribute. The formula for the severity index is given as follows by Elhag and Boussabaine (1999):

$$S.I. = \left\{\sum_{i=1}^{i=n} w_i f_i\right\} \times \frac{100\%}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2}$$

Where: *S.I.* is the severity index; f_i is the frequency of response; w_i is the weight for each rating (i.e. rating in scale/number of points in a scale), and n is the total number of responses. The value (f_i x 100)/n is the valid percentage as computed by SPSS. Severity Index Analysis was chosen because it is known to provide a meaningful interpretation of ranks rather than analyses that use the mean score derived from non-parametric data. It is used for ranking variables (Idrus and Newman, 2002). This method has been used for construction research by many authors including Oladapo (2006) and Kaming *et al.* (1997) to analyse data in a study similar to this.

4.6.3.2 Kruskal-Wallis Test

The Kruskal-Wallis test is a nonparametric statistical test that assesses the differences among three or more independent samples on a single, non-normally distributed continuous variable. It is a one-way analysis of variance by ranks. Ordinal or rank data are suitable for the Krukal-Wallis test. The Kruskal-Wallis test is an extension of the two-group Mann-Whitney U (Wilcoxon rank) test. Thus, the Kruskal-Wallis is a more generalised form of the Mann-Whitney U test and is the nonparametric version of the one-way ANOVA. It tests the null hypothesis that multiple independent samples come from the same population (Kruskal and Wallis, 1952).

The Kruskal Wallis one way ANOVA test for a K-independent sample was used to analyses the statistical differences on how the success factors on the implementation of lean construction and sustainability are perceived by the SMEs, large firms and among the various main business activities which is represented as: design firms, construction firms and both design and construction. It was also used analyses the statistical differences on how the barriers of lean construction and sustainability are perceived between the SMEs and the large firms and among the various main business activities.

4.6.3.3 Mann-Whitney U Test

The Mann-Whitney U Test is equivalent to the Wilcoxon rank sum test and the Kruskal Wallis test for grouping variables (Lane, 1993). It is one of the most powerful of the non-parametric tests for comparing two populations and it can be used to test the null hypothesis that two populations have identical distribution functions. In this study, Mann-Whitney statistics was used to test for differences between the framework validation participants.

4.6.3.4 Cronbach's Alpha

Cronbach's alpha is one of the most popular reliability statistic used for measurement of reliability of scale. Cronbach's alpha (α) is given by the formula

$$\alpha = \frac{k}{k-1}\left(\frac{\sigma_y^2 - \sum \sigma_i^2}{\sigma_y^2}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Equation 3}$$

where k = number of items, σ_y^2= variance of the sum of all items; and σ_i^2=variance of the ith item (Stangor, 1998).

Cronbach's alpha is a coefficient which ranges in value from 0 to 1. There is, however, no consensus as to the value which gives an acceptable level of reliability (Rosnow and Rosenthal, 1999; Hammond, 2001). Rosnow and Rosenthal (1999) stated that the acceptable range depends on the situation in which the instrument is to be used and the purpose or objective of the research. Generally, it is accepted that an increasing sample size leads to a higher reliability estimate (Stangor, 1998; Hammond, 2001). The reliability of the 4-point Likert-type scale, which was the main scale in this study, was subjected to a reliability test using the SPSS statistical software. Cronbach's alpha determines the internal consistency or average correlation of items in a survey instrument to gauge its reliability. It should be noted that Cronbach's alpha is not a statistical test but a coefficient of reliability or consistency (Santos, 1999). Alpha coefficient may be used to describe the reliability or internal consistency of factors extracted from dichotomous (questions with two possible answers) and/or multi-point formatted questionnaires or scales (Santos, 1999). The higher the score, the more reliable the generated scale is. Sekaran (1994) considers a reliability of less than 0.6 as poor, in the range of 0.6-0.7 as acceptable and over 0.8 to be good.

4.6.3.5 Null Hypothesis Testing

Kumar (2011) emphasised that there are many definitions of null hypothesis. Hypothesis is defined by Kerlinger (1986: 17) as ‘a conjectural statement of the relationship between two or more variables’. Black and Champion (1978:126) also defined a hypothesis as ‘a tentative statement about something, the validity of which is usually unknown’. Another definition of hypothesis given by Bailey (1978:35) is ‘a proposition that is stated in a testable form and that predicts a particular relationship between two (or more) variables. Hypothesis serves the function of providing a focus to a research study, clarity to research problem and enhances objectivity in a study (Creswell, 2009; Kumar, 2011). Hypothesis are broadly categorised by Kumar (2011) into research hypotheses and alternate hypotheses. Figure 4.7 presents the various types of null hypotheses under the two broad categories.

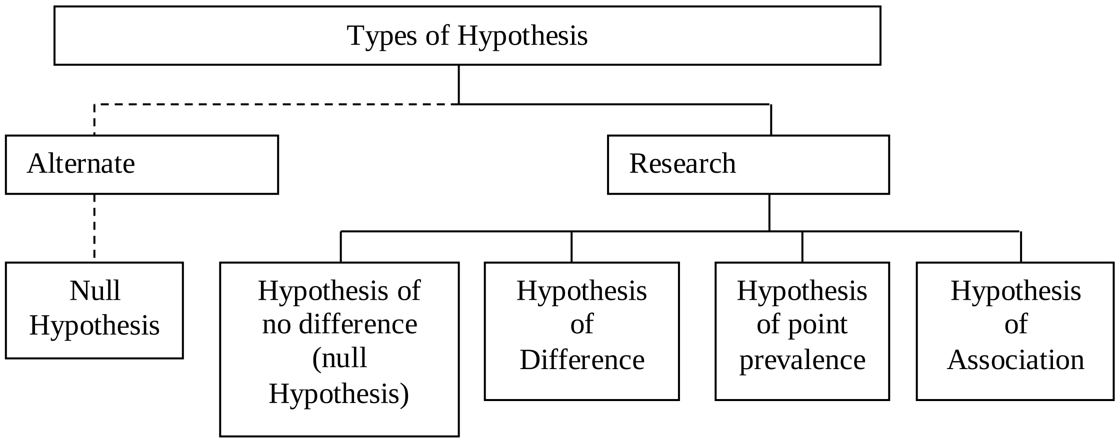

Figure 4.7: Types of Hypothesis

(Source: Kumar, 2011)

Kumar (2011) stated that the main function of formulating an alternate hypothesis is to explicitly specify the relationship that will be considered as true in case the research hypothesis proves to be wrong. This reflects that the alternate hypothesis is the opposite of the research hypothesis.

The null hypothesis or the hypothesis of no difference is usually formulated as an alternate hypothesis. When a hypothesis is constructed stipulating that there is no difference between two situations, groups, outcomes, or the prevalence of a condition or phenomenon, it is referred to as null hypothesis and is usually denoted as Ho. Hypothesis of difference is when a researcher stipulates that there will be difference but does not specify the its magnitude. Hypothesis of point-prevalence is when a researcher has enough knowledge about the study and its likely outcomes to speculate almost the exact prevalence of the situation or the outcome in quantitative units. E.g. the level of infant mortality is 30/1000 and the proportion of female and male smokers is 60 and 30 per cent respectively. Hypothesis of association stipulates the extent of the relationship in terms of the effect of different groups on the dependent variable. E.g. using the aforementioned example of female and male smokers, a hypothesis of association will be stated as 'twice as many female as male smokers'. Null hypothesis testing is an optimal method for demonstrating sufficient evidence for an ordinal claim. Null hypothesis testing is insufficient when size of effect is important, but is ideal for testing ordinal claims relating the order of conditions (Frick, 1996). Null hypothesis statistical testing (NHST) is widely used in research (Nickerson, 2000). Lane (1993) stated that the purpose of null hypothesis is to test the viability of the null hypothesis in light of experimental data. There are two forms when hypotheses are used, null and alternative hypotheses. Null hypothesis makes a prediction that in the general population, no relationship or no significant difference exists between groups on a variable (Creswell, 2009). Thus, the study null hypotheses formed were tested during the data analysis.

4.6.3.6 Kendall Coefficient of Concordance

Kendall's Coefficient of Concordance, W, measures the agreement between several judges who have rank ordered several entities. It represents the ratio of the variability of the total ranks for the ranked entities to the maximum possible variability of the total ranks; a small ratio implies disagreement between judges (Field, 2005).

When measuring the concordance between rank orders within an individual rank structure it is common to rely on the work of Kendall and Smith (1939) and their successors, using a suitable version of the Kendall's coefficient of concordance. Kendall and Smith (1939) provided a descriptive measure of concordance for data comprised of M sets of ranks, where $M > 2$. Similarly, Kendall (1955) presented a Coefficient of Concordance, W, to evaluate the extent of agreement among a set of judges each of whom ranks in entirety a set of objects. The coefficient of concordance, W, is well known and has been widely applied in the literature. For example, it has been widely used to identify significantly associated groups of species in field survey data. The coefficient of concordance, W, is defined as the ratio of sum of squared deviations of rank totals from the average rank total to the maximum possible value of the sum of squared deviations of rank totals from the average rank total (Kendall and Smith, 1939; *cf*. Kendall, 1970): When perfect agreement exists between the values of the ranking variable, W = 1. When maximum disagreement exists, W = 0. Kendall's coefficient of concordance does not take negative values and is thus bounded on the interval $0 \leq W \leq 1$.

The formula for calculating the coefficient of concordance, W, is given by: explained below. Let R be an n x m matrix in which r_{ij} is the rank of the j-th of m objects as judged by the i-th of n judges. Then

$$W = \frac{12S}{m^2 n(n^2-1)} \dots\dots\dots\dots\dots\dots \text{Equation 4}$$

Where S is the sum of the squared deviations from the mean, given as

$$S = \sum \left(r_{.j} - r_{..}/m\right)^2 \dots\dots\dots\dots\dots\dots \text{Equation 5}$$

When the objects to be ranked are the judges, this implies that $n = m$, and the equation becomes:

$$W = \frac{12S}{n^3(n^2-1)} \dots\dots\dots\dots\dots\dots \text{Equation 6}$$

If each pair of object to be ranked appears the same number of times, we have

$$W = \frac{12S}{\lambda^2(n^2-1)} \dots\dots\dots\dots\dots\dots \text{Equation 7}$$

Where λ is the number of times that a given comparison occurs. When each member of a group ranks all of the members except himself, then each pair of members is ranked n-2 times. In this case, $\lambda = n - 2$ and

$$W = \frac{12S}{(n-2)^2 n(n^2-1)} \dots\dots\dots\dots\dots\dots \text{Equation 8}$$

To test the significance of W, Kendall gave the following approximation for large n:

$$\chi^2 = \frac{\lambda(n^2-1)W}{k+1} \dots\dots\dots\dots\dots\dots \text{Equation 9}$$

With $n - 1$ degrees of freedom. There is a close relationship between Spearman's correlation coefficient r_S and Kendall's coefficient of concordance, *W*. W can be calculated directly from the mean ($\bar{r}$) of the pair-wise Spearman correlation r_S using the following relationship (Siegel and Castellan 1988, p. 262; Zar 1999, p. 448):

$$W = \frac{(p-1)\bar{r}+1}{p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 10}$$

where p is the number of variables (or judges) among which Spearman's correlation coefficients are computed. However, in this study, the coefficient of concordance was obtained using SPSS.

4.6.3.7 Pearson's Correlation Analysis

Pearson's correlation is a statistical measure of the strength of a linear relationship between two data. Its calculation and the subsequent significance testing require the interval or ratio level, linear relation, and bivariate normal distribution assumptions to hold. Pearson's correlation coefficient r is used to evaluate sample data as an indication that a linear association exists between two quantitative variables (Matthews and Ross, 2010). It can also be used to test the null hypothesis that there is no association between the variables X and Y. Pearson's r is not represented in any unit of measurement, it ranges between -1 and +1. A correlation value of zero indicates that there is no association between the variables (LeBlanc, 2004). The bivariate correlations procedure computes the pair-wise associations for a set of variables and displays the results in a matrix. Pearson's correlation was used in this study to determine the strength and direction of the association between ordinal variables.

In interpreting the level of correlation among factors or variables, Cohen and Holliday (1982) proposed the following for a large correlation: 0.19 and below is very low; 0.20 to 0.39 is low; 0.40 to 0.69 is modest; 0.70 to 0.89 is high; and 0.90 to 1 is very high.

4.6.3.8 Factor Analysis

Historically, factor analysis has its origin dating back 100 years through the work of Pearson (1901) and Spearman (1904). As noted by Kieffer (1999), cited in Williams *et al*. (2010), Spearman provided the conceptual and theoretical rationale for both exploratory and confirmatory factor analysis through his work on personality theory. The conceptual bases for these methods have been available for many decades and employed with any regularity, even before the wide-spread availability of both the computer and modern statistical software.

Factor analysis is a multivariate statistical approach commonly used in psychology, education, and more recently in the health-related professions. However, it has been used in construction management by many researchers such as Li *et al.* (2005), Ahadzie (2007) and Bassioni (2004). Factor analysis is an important tool that can be used in the development, refinement, and evaluation of tests, scales, and measures that can be used in education and clinical contexts by paramedics. Factor analysis is considered the method of choice for interpreting self-reporting questionnaires which is used for reducing a large number of variables into a smaller set of variables (also referred to as factors). Secondly, it establishes underlying dimensions between measured variables and latent constructs, thereby allowing the formation and refinement of theory. Thirdly, it provides construct validity evidence of self-reporting scales (Williams *et al.,* 2010).

The objectives of exploratory factor analysis according to Pett *et al.,* (2003) and Thompson (2004) are summarised as:

- Reduce the number of variables
- Examine the structure or relationship between variables
- Detect and assess unidimensionality of a theoretical construct
- Evaluate the construct validity of a scale, test, or instrument
- Develop parsimonious (simple) analysis and interpretation
- Address multi-collinearity (two or more variables that are correlated)
- Develop theoretical constructs
- Prove/disprove proposed theories

Factor analysis is widely used with Likert and semantic differential items as an exploratory device. It can be applied to an exploratory study to summarise variables into main representative factors. However, there are some requirements to test data to ensure that factor analysis is an appropriate statistical technique to use (Coakes *et al.,* 2001). The general idea behind factor analysis is that the score on any scale item can be seen of comprising of a number of components, which represent the contributions of fundamental factors to the item; an individual's factor scores are weighted according to the relative importance of various factors in the item and combined together with an error component to form its item score (Moser and Kalton, 1971).

There are three types of factor in factor analysis: a general factor which contributes to all the items on the scale; a group factor contributes to more than one, but not all, items; and a specific factor contributes to just one item. The group and general factors are termed as common factors (Moser and Kalton, 1971). According to Williams *et al*., (2010), there are two major classes of factor analysis: Exploratory Factor Analysis (EFA), and the Confirmatory Factor Analysis (CFA). The EFA is exploratory in nature and the investigator has no expectations of the number or nature of the variables. It allows the researcher to explore the main dimensions to generate a theory, or model from a relatively large set of latent constructs often represented by a set of items (Henson and Roberts, 2006; Thompson, 2004; Pett, 2003) whereas, the researcher uses this approach to test a proposed theory in CFA (CFA is a form of structural equation modelling), or model and in contrast to EFA, has assumptions and expectations based on priori theory regarding the number of factors, and which factor theories or models best fit.

Williams *et al*. (2010) presented the 5-steps exploratory factor analysis protocol for novice researchers with starting reference point in developing clear decision pathways. Figure 4.8 provides the summary of each step.

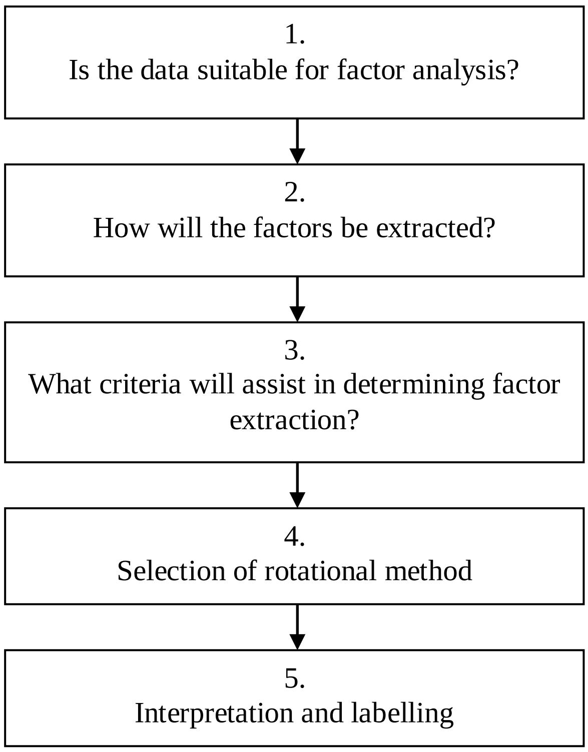

Figure 4.8: The 5-step Exploratory Factor Analysis Protocol

(Source: Williams *et al.*, 2010)

Step 1: Is the data suitable for factor analysis?

The various recommendations made for guiding researcher on the sample size are sample to variable ratio (N:p ratio), factorability of the correlation matrix, Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy/Bartlett's Test of Sphericity. The sample size is a very important aspect to be considered in factor analysis. Henson and Roberts (2006) illustrated that when communalities are high (greater than .60) and each factor is defined by several items, sample sizes can actually be relatively small. Others such as Guadagnoli and Velicer (1988) found that solutions with correlation coefficients >.80 require smaller sample sizes, while Sapnas and Zeller (2002) pointed out that even 50 cases may be adequate for factor analysis. As can be seen, the suggested sample size required to complete a factor analysis of a group of items that participants have responded to, varies greatly.

Sample to Variable Ratio (N:p ratio)

The sample to variable ratio is often denoted as N:p ratio where N refers to the number of participants and p refers to the number of variables. Sample to variable ratio can guide researcher on how many participants are required for each variables (Hogarty *et al.,* 2005).

Factorability of the correlation matrix

A correlation matrix should be used in the EFA process displaying the relationships between individual variables. Henson and Roberts (2006) stated that a correlation matrix is most popular among investigators. Tabachnick and Fidell (2007) recommended inspecting the correlation matrix (often termed Factorability of R) for correlation coefficients over 0.30. Hair *et al.* (1995) categorised these loadings using another rule of thumb as ±0.30=minimal, ±0.40=important, and ±.50=practically significant. Hair *et al*., (1995) stated that if no correlations go beyond 0.30, then the researcher should reconsider whether factor analysis is the appropriate statistical method to be used.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy/Bartlett's Test of Sphericity

Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy test is used to assess the suitability of the respondent data for factor analysis. This should be done prior to the extraction of the factors (Bartlett, 1950). The KMO index ranges from 0 to 1, with 0.50

considered suitable for factor analysis and recommended when the cases to variable ratio are less than 1:5 (Hair *et al.*, 1995; Tabachnick and Fidell, 2007). The Bartlett's Test of Sphericity should be significant ($p<.05$) for factor analysis to be suitable.

Step 2: How will the factors be extracted?

Another important step in factor analysis is how the factors will be extracted from the larger number of factors. There are many ways of extracting factors in factor analysis, these include principal components analysis, principal axis factoring, maximum likelihood, un-weighted least squares, generalised least squares, alpha factoring, and image factoring. The Principal Components Analysis (PCA) and the Principal Axis Factoring (PAF) are the commonly used (Pett, 2003). The decision whether to use PCA and PAF is fiercely debated among analysts. According to Thompson (2004) the practical differences between the two are often insignificant, particularly when variables have high reliability, or where there are 30 or more variables. Thompson (2004) noted that PCA is the default method in many statistical programs, and thus, is most commonly used in EFA. Pett *et al.* (2003) suggested the use PCA when no *a priori* theory or model exists.

Step 3: What criteria will assist in determining factor extraction?

There are many extraction rules and approaches used to determine factor extraction. These include: Kaiser's criteria (which is based on Eigenvalues that are > 1), (Kaiser, 1960), the Scree test (Cattell, 1966), the Cumulative percentage of variance extracted, and parallel analysis (Horn, 1965). The Cumulative percentage of variance (criterion) is another area of disagreement in the factor analysis approach, and this cut across different disciplines. For example, in the natural sciences, psychology, and the humanities, there are no fixed thresholds, even though certain percentages have been suggested (Henson and Roberts, 2006).

According to Hair *et al.* (1995), in the natural sciences, factors should be stopped when at least 95% of the variance is explained. In the humanities, the explained variance is commonly as low as 50-60% (Pett *et al.* 2003, Hair *et al.* 1995). As noted by Gorsuch (1983) Tabachnick and Fidell (2007) and Thompson (2004) interpreting Scree plots requires a researcher's judgment and is therefore very subjective. Thus, disagreement over which factors should be retained is often open for debate (Pett *et al.* 2003). This disagreement and subjectivity is reduced for cases where sample sizes are large, N:p ratios are >3:1, and where communalities values are high (Pett *et al*. 2003, Gorsuch 1983). The “Scree Test” was given its name by Cattell (1996) due to the Scree Test graphical presentation, which has visual similarities to the rock debris (Scree) at the foot of a mountain. The Scree plot can be inspected and interpreted in two steps:

1. By drawing a straight line through the smaller Eigenvalues where a departure from this line occurs. This represents the point where the debris or break occurs. Where the Scree is difficult to interpret, additional manipulation of data and extraction should be carried out.
2. The points above this debris or break (excluding the break itself) indicate the number of factors to be retained.

Step 4: Selection of Rotational Method

Another consideration when deciding the number of factors to analysis is determining whether a variable is related to more than one factor. The concept of Rotation is to maximise high item loadings and minimise low item loadings, in order to produce a more interpretable and simplified solution. The two common rotation techniques are Orthogonal rotation and Oblique rotation. There are several options under both rotation techniques. Orthogonal rotation could be Varimax or Quartimax, while oblique rotation could be Olbimin or Promax. Orthogonal Varimax rotation was first developed by Thompson (2004) and it is the most common rotational technique used in factor analysis which is capable of producing factor structures that are uncorrelated (Costello and Osborne, 2005). In contrast, Oblique rotation produces factors that are correlated. This is often seen as more accurate for research involving human behaviours, or when data does not meet priori assumptions (Costello and Osborne, 2005). Regardless of the rotation technique used, the aim is to provide easier interpretation of results, and produce a solution that is economical (Hair *et al*. 1995, Kieffer 1999). As suggested by Pett, Lackey, and Sullivan (Pett *et al*., 2003) and Kieffer (1999) PAF should be examined, following PCA analysis, for comparison and assessment for best fit. In other words, the rotated solution producing the best fit and factorial suitability, both intuitively and conceptually, should be used. Once this is done, the researcher would examine items that do not load or are unable to be assigned to a factor using the above guides and make a decision whether the items should be retained or discarded. For example, the item might load on several factors, not load on any factors, or simply not conceptually fit any logical factor structure.

Step 5: Interpretation

The final step in factor analysis is interpretation. This is carried out by examining the variables that are attributable to a factor, and giving that factor a name or theme (Williams *et al*., 2010). For example, a factor may have included five variables which all relate to pain perception; therefore the researcher would create a label of "pain perception" for that factor. Traditionally, at least two or three variables must load on the factor so it can be given a meaningful interpretation (Henson and Roberts, 2006; Isaac and Michael 1997). The labelling of factors is a subjective, theoretical, and inductive process (Pett *et al*. 2003). Henson and Roberts (2006) note "the meaningfulness of latent factors is ultimately dependent on researcher definition". The reason for thorough and systematic factor analyses is to identify and isolate items with high loadings in the resultant pattern matrices. In other words, the purpose is to identify those factors which, when grouped together, explain the majority of the responses. If the researcher is content with these factors, these should then be descriptively labelled. The chosen labels or constructs should reflect the theoretical and conceptual intent.

In summary, factor analysis may be used to examine the complex interrelationship between items with the use of correlation matrix which is a systematic grid layout of correlations between all possible pairs of items; from this matrix, factor analysis attempts through one of several possible techniques of 'factor extraction' and of 'factor rotation' to identify the fundamental common factors. Correlation coefficients of each variable should have at least one factor that is above 0.30 (Pallant 2001). All variables had correlation coefficients of more than 0.30. Additionally, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy value was 0.836 (well above 0.60) and the Barlett's test of sphericity value was significant (p=0.0001). Therefore, the use of factor analysis was deemed suitable. Data was analysed using a principal component and varimax rotation for factor extractions. It should be noted that factor analysis as a statistical analysis is not without criticism. Thompson (2004) stated that most of these criticisms are associated with the EFA rather than CFA. These criticisms are largely based on the subjectiveness of the results which are determined by the researcher (Henson and Roberts, 2006).

4.6.4 Derivation of Results – Questionnaire Survey

The final stage of the questionnaire survey was to derive results and conclusions using the aforementioned data analysis process. Conclusions were drawn using the main findings of the data analysis. Generally, this stage of the study contributed to deriving results on the benefit of lean approach in sustainable construction (refer to Chapter 6). The findings of this stage also assisted in the development of the conceptual framework for lean implementation effort which is the main output of the research study.

4.6.5 Reliability Analysis of the Data

Reliability analysis allows for the study of the properties of measurement scales. According to Yin (1994), reliability is the extent to which a test or procedure produces similar results under constant conditions on all occasions Table 4.7 gives the Cronbach's alpha values of the survey carried out in this study. Cronbach (1951) recommended that, if the scale shows poor reliability, then individual items within the scale must be re-examined and modified or completely changed as needed. The reliability test is essential especially when derivative variables are intended to be used for subsequent predictive analyses. Bryman and Cramer (2005) suggest, the nearer the result of alpha value to 1 - preferably 0.8 or above the more internally reliable the scale is. However, Sekaran (1994) considers a reliability of less than 0.6 as poor, in the range of 0.6-0.7 as acceptable and over 0.8 to be good. As shown in Table 4.7, the alpha coefficient of the data of this survey is 0.95. This indicates that the measures of scale used are reliable and the data collected are interrelated, considering 0.7 as the limit value for being acceptable.

Table 4.7: Reliability Statistics

Cronbach's Alpha	No of Items
.951	110

4.6.6 The Case Study Approach

The research process of this stage is presented in Figure 4.9. Discussions on this stage are given in subsequent sections.

RESEARCH PROCESS: STAGE 3

Research Question:

- What are the success factors/challenges encountered during implementation
- What are the drivers of lean construction?
- How can the impact of implementing lean in sustainable construction be assessed

Research Strategy: Qualitative Method (Case Studies)

Sample: Two (2) construction firms that have implemented lean construction

Data Collection: Semi-structured interviews

Data Analysis: Content Analysis

Results: Main Findings of the Research

Figure 4.9: The Research Process- Stage 3 of the Research study

4.6.7 Research Strategy –The Rationale for Choosing a Case Study Approach

The questionnaire survey findings presented the need to investigate issues relating to the implementation of lean such as drivers for lean, success factors, barriers encountered and how the impact of lean in sustainable construction can be assessed. There are several research strategies within the qualitative methodology which can be used in achieving an in-depth research outcome. In the social sciences, phenomenology, ethnography, action research, case study, and grounded theory strategies have been widely debated, for example, in Baldwin *et al.* (2002), Gittins (1997), and Yin (1994). The various strategies available are described below.

4.6.7.1 Case Studies

Livock (2009) stated that the case study method has been employed historically by sociologists from both positivist and interpretivist paradigms as a means of focussing on physical and theoretical slices of social life. The basic idea behind case studies is that a number of cases can be studied in detail for a variety of purposes and research questions but the general objective is to develop as full understanding of the case studied as possible (Punch, 1998). Three different types of case studies were identified by Stake (2000). These are the intrinsic case study, the instrumental case study, and the collective case study. In intensive case study, no attempt is made to generalise beyond the single case but in instrumental case study, the case is examined solely for insight and to revise a generalisation. Collective case study is investigative in nature, and a number of cases are studied in order to investigate some general phenomenon (Stake, 2000). According to Soy (1997), researchers from many disciplines use the case study method to build upon theory, to produce new theory, to dispute or challenge theory, to explain a situation, to provide a basis to apply solutions to situations, to explore, or to describe an object or phenomenon. The advantages of the case study method are its applicability to real-life, contemporary, human situations and its public accessibility through written reports. Case study results relate directly to the common reader's everyday experience and facilitate an understanding of complex real-life situations.

4.6.7.2 Ethnographic Studies •

Ethnography has been described as 'the study of both explicit and tacit cultural knowledge' (Spardley, 1994). In ethnographic research the researcher studies an intact cultural group in a natural setting over a specific period of time. A cultural group can be any group of individuals who share a common social experience, location, or other social characteristic of interest. An illustration of this could range from an ethnographic study of rape victims in crisis shelters, to children in foster care, to a study of a cultural group in Africa. Ethnographic research has been characterised by exploration of phenomena rather than testing hypotheses, tendency to work with unstructured data and analysis of data involving explicit interpretations of meanings of human actions via verbal explanation (Atkinson and Hammersley, 1994).

4.6.7.3 Phenomenological Studies

In a phenomenological study, human experiences are examined through the detailed description of the people being studied. The goal is to understand the 'lived experience' of the individuals being studied. This approach involves researching a small group of people intensively over a long period of time (Byrne, 2001).

4.6.7.4 Grounded Theory

Grounded theory strategies were first reported by, and attributed to, Glaser and Strauss in 1967. Glaser and Strauss (1967) described the method of grounded theory as a means of enabling the systematic discovery of theory from the data of social research. Byrne (2001) states that, the researcher's purpose in using the grounded theory method is to explain a given social situation, by identifying the core and subsidiary processes operating in it. The core process is the guiding principle underlying what is occurring in the situation and dominates the analysis because it links most of the other processes involved in an explanatory network. According to Martin and Turner (1986), grounded theory has been described as 'an inductive theory discovery methodology that allows the researcher to develop a theoretical account of the general features of a topic while simultaneously grounding the account in empirical observations or data'. Martin and Turner (1986) further argued that precise and applicable results can be produced by emphasizing the criticality of context. The methodology of grounded theory is iterative and comparative requiring dynamics between concept and data and constant comparison across types of evidence. This creates an avenue of drawing out the significance levels of analysis and discloses multiple sources of loops of causation and connectivity crucial to explaining patterns in the process of change (Pettigrew, 1989).

4.6.7.5 Action Research

In action research, researcher is an active participant in the research setting and may prompt change; the researcher is present and observes what happens while major parts of the process being researched are occurring (Eden and Huxham, 1996). Myers *et al.* (1999) stated that "to make academic research relevant, researchers should try out their theories with practitioners in real situations and real organisations". According to them, action research combines theory with practice, practitioners with researchers, together in an iterative process, within a cycle of activity that includes problem diagnosis, action intervention and reflective learning. Coughlan and Coghlan (2002) characterised action research by research in action, rather than research about action; particpative, concurrent with action and a sequence of events and an approach to problem solving.

4.6.8 Choice of Strategy

In order to choose an appropriate research strategy for this particular study, the aforementioned approaches were taken into consideration. Based on the aim of this research, the research questions, and the description of each of the identified research strategies; the ethnographic studies, phenomenology studies, grounded theory and the action research were excluded during the selection process of the research strategy. This was because ethnography relates specifically to a group of people who share common culture (McCleverty, 1997); grounded theory is more appropriate for deriving a theory of a process, action or interaction, grounded in the views of participants in a study (Strauss and Corbin, 1990), action research is more suitable for use when understanding and managing the relationship between theory and practice during problem diagnosis (Myers *et al.*, 1999; Ottosson, 2003). The phenomenology would have been another alternative for this study because it pays attention on understanding a phenomenon. The major difference between phenomenology and the case studies is that phenomenology tries to focus on understanding the essence of experiences about a phenomenon, while the case study approach attempts to develop an in-depth analysis of a single case or multiple cases.

The case study technique was adopted to enable close, detailed and continuous observation of a work practice at an appropriate organisational level. This enabled the researcher to capture the response of participants, the manner and extent to which they adopt the concepts of lean, and the circumstances under which they apply it. This was also useful to determine whether the application of the lean approach is, in practice, given the same priority as it is in principle; whether its application yields same sustainable benefits; whether there is consistent managerial support for its actual implementation and application, and whether its use can be sustained in the face of countervailing pressures from the organisation's structures. The case study approach was particularly useful for this research study because it allowed the extension of experience and added strength to what is already known through previous research (Stage 2 of the research- use of questionnaire survey). The lack of generalisability, a common criticism of the case study, sometimes called external validity (Yin, 1994), has been overcome with the use of questionnaire survey at the Stage 2 of the research process.

4.6.9 The Unit of Analysis

According to Collins and Hussey (2003), the unit of analysis is described as the area to which the variables or the phenomenon under study and the research problem refer. The identification of the unit of analysis is an important aspect of the case study, in that it presents the defined limits to the scope of the case study (Remenyi *et al.*, 1998). The analyses in this research were accomplished on construction contracting companies to satisfy the research goals. The factors for successful implementation, barriers and benefits were learned from different firms within construction organisations. In other words, 'construction contracting firms' were the unit of analysis in this study, rather than projects. This research follows the purpose of exploratory research and used a mixed-method approach that utilises quantitative and qualitative types of analyses.

4.6.10 Rationale for Choosing the Sample for the Case Study

A case study is a study in which one case (single case study) or a small number of cases (comparative case study) in their real life context are selected, and scores obtained from these cases are analysed in a qualitative manner (Dul and Hak, 2008). It should be noted here that two main types of case studies are mentioned: "single case study" and the "comparative case study". A single case study is a case study in which data from one instance is enough to achieve the research objective while comparative case study is a case study that requires data from two or more instances to achieve the research objectives.

Yin (2003) also identified four types of case study designs: single embedded, single holistic, multiple embedded and multiple holistic. According to Yin (2003), data collection from a single or multiple cases is a key decision to be made in relation to case study design. Yin (2003) further justified the selection of a single case design when the following five conditions are met: when the case is extreme or unique, when the case represents a critical case to test a well-formulated theory, when the case is representative or typical, when the case is longitudinal or revelatory. More so, the distinction between holistic and embedded case studies was clarified depending on the number of unit of analysis and any sub-units. When the research involves a single unit of analysis the case study design is considered holistic. On the other hand, a case study design is considered embedded when the research involves multiple unit of analysis (Yin, 2003).

Another important factor to consider in the selection of a case study is the sampling issue. The major difference between quantitative and qualitative research approaches is the different reasoning used to select samples (Patton, 1990). Quantitative research tends to favour larger, randomly selected samples while qualitative research mostly concentrates on smaller, purposefully selected samples (Patton, 1990; Miller and Alvarado, 2005).

According to Marshall (1996), there are three broad categories of naturalistic sampling for qualitative research: convenience, judgement and theoretical models.

4.6.10.1 Convenience Sample

This is the least rigorous technique, involving the selection of the most accessible subjects. It is the least costly to the researcher, in terms of time, effort and money, but may result in poor quality data and lacks intellectual credibility (Marshall, 1996). There is an element of convenience sampling in many qualitative studies, but a more thoughtful approach to selection of a sample is usually justified (Marshall, 1996; Matthews and Ross, 2010).

4.6.10.2 Judgement Sample

This is also known as purposive sample and it is the most common sampling technique. The researcher actively selects the most productive sample to answer the research question. This approach is generally associated with collection of qualitative data with focus on the exploration and interpretation of experiences and perceptions (Matthews and Ross, 2010). This can involve developing a framework of the variables that might influence an individual's contribution and will be based on the researcher's practical knowledge of the research area, the available literature and evidence from the study itself (Marshall, 1996). Cases in purposive sampling are selected on the basis of characteristics or experiences that are directly related to the researcher’s area of interest and research questions. This allows for an in-depth study (Marshall, 1996; Matthews and Ross, 2010; Kumar, 2011).

4.6.10.3 Theoretical Sample

Theoretical sampling appears to have originated from the grounded theory which was first developed as a rigorous method of analysing qualitative data in order to produce theory (Coyne, 1997). Marshall (1996) stated samples are usually theory driven to a greater or lesser extent in the process of qualitative design. Theoretical sampling necessitates building interpretative theories from the emerging data and selecting a new sample to examine and elaborate on this theory. It is the principal strategy for the grounded theoretical approach but will be used in some form in most qualitative investigations necessitating interpretation. Glaser (1978: 38) stated that 'when the strategies of theoretical sampling are employed, the researcher can make shifts of plan and emphasis early in the research process so that the data gathered reflects what is occurring in the field rather than speculation about what cannot or should have been observed'. This implies that theoretical sampling entails sampling to test, elaborate and refine a category and further sampling is done to develop the categories and their relationships and interrelationships.

Taking into consideration the practical and philosophical reasons mentioned above and the volume of information to be collected, it was decided to use two (2) case studies which falls into comparative for this research study. Thus, multiple case strategies for collection of data, in order to explore the impact of lean on sustainable construction, were adopted. Two construction firms were chosen for the case study approach; as it helps to establish cross-case conclusions during the data analysis stage. Yin (1994) affirms that a cross-case methodology is generally more robust than a single case study.

A holistic, multiple case study method was selected as the most appropriate for this case study design. This is because the research did not meet up with the above stated conditions necessary for a single case study. For a single case study to be appropriate the case has to be critical or extreme, revelatory, longitudinal or typical (Yin, 2003). In addition, the sampling method adopted was the purposive sampling which conforms to the multiple case design. Case selection in multiple case design has to be done purposefully to predict similar results or contrasting results for predictable reason (Yin, 2003).

A Purposive sampling approach allows the researcher to select cases that demonstrates characteristics in which they are interested (Silverman, 2001). The possibility of having multiple units of analysis within a case ceased with the selection of 'lean' as the case, and 'construction firms' as the unit of analysis. The selection of companies was based on those that have implemented lean. Therefore, the use of a holistic multiple case study approach was justified as the most appropriate for this research. The following sub-sections present the description of the two cases in details.

4.7 Profile of Selected Case Study Companies

This section provides the background details of each of the two case study company selected for this phase of the research.

4.7.1 Case Study 1

The company is a major UK construction contracting organisation. It is one of the largest and most experienced construction contractor organisations. It has employees in excess of 500 and an annual turnover of over £100m. The company enjoys one of the healthiest operating profit margins in the industry. The company's area of expertise ranges from services to construction, civil engineering, property development and facilities management. It has various subsidiaries across the UK with the aim to deliver excellence to customers by meeting and exceeding client's expectations driven by strong leadership and an organisational culture of continual improvement, providing strong growth and enhanced value to stakeholders, and being socially responsible to the community in which it operates. The company's performance measurement system comprises a set of in-house KPIs that cover areas such as human resources, resources management, financial management and customer satisfaction. It uses ISO 14001:2004 Environmental Management Systems for environmental protection. The company is privately owned and has implemented lean construction and adopted a long term strategy with regards to its growth as a company.

4.7.2 Case Study 2

The company is a leading UK contracting organisation that was founded over 50 years ago, and went public in the past 30 years. The company has an annual turnover of over £100m and has several branches in the UK. The company is one of the leading companies that have implemented lean construction, starting its efforts seven years ago. It has the vision of becoming the best contractor within the construction sector with fully trained and equipped workforce; and delivering best value solutions to clients while working in partnership with them based on trust and openness. Also, the company provides continuous improvement by building relationships. The main operations of the company involve building and civil engineering, with heavy involvement in roads and highways. The company also has support services and development divisions with a sound track record of successful delivery of complex building and highway related projects for both the public and private sector. The company uses ISO 9001:2008 Quality Management Systems, ISO 14001:2004 Environmental Management Systems and OHSAS 18001:2007 Occupational Health and Safety Management Systems.

The case study companies' selection was based on the knowledge acquired from literature review and expert opinion. Thorough investigation was made regarding the companies selected and it was found that these companies are one of the leading companies in terms of sustainable lean implementation. In addition, these two selected companies have won industry recognised lean awards and sustainable practices awards and have been known for their lean strategy adoption.

In the process of selection, a few numbers of companies were initially selected and expert opinion about these companies was sought. Based on the advice and the recommendation of the experts, the two case study companies were selected as described above.

4.7.3 Data Collection – Semi Structured Interviews

The interviews were the main method of data collection used in this stage of the research. Interviewing may be defined simply as a conversation with a purpose. Specifically, the purpose is to gather information (Berg, 2009). Several authors have discussed this standard definition of interviewing. Examples are Denzin (1978), Spradley (1979), Patton (2002), Bogdan and Knopp (2002), Leedy and Ormrod (2004), and Babbie (2007). Berg (2009) submits that no consideration of interviewing will be complete without some acknowledgement of the major interview structures. Some sources mentioned only two interview structures namely, formal and informal. Babbie (2007) identified three major categories of interviews: the standardised (formal or structured), unstandardised (unstructured), and semi standardised (semi structured). According to Naoum (1998), an interview can take three forms, unstructured, structured and semi-structured. Telephone interview is another data collection technique. The other method available for data collection is by personal interview. Personal interview is a face-to-face interpersonal role situation in which an interviewer asks respondents questions designed to obtain answer regarding the research (Naoum 1998).

For the purpose of this research, a semi-structured form of interview was adopted. This type of interview is more or less structured where questions may be recorded during the interview. It allows flexibility in wording of questions whereby level of language may be adjusted, interviewer may answer questions and make clarifications, and interviewer may add or delete probes to interview between subsequent subjects (Berg, 2009). The interview session was carried out with the aid of structured opened ended interview questions.

The initial intention was to interview as many professional and staff of various construction organisations, but in order to obtain a cross case synthesis of the issues relating to the implementation of lean in sutainable construction (particularly among contracting firms) the study therefore targets two case study firms with the respondents across all the organisation including strategic level-executives/management, middle management-construction managers enforcing organisational decisions, and bottom level - operational level/supervisors. This was decided to achieve a balanced view for this research by having a broad representation of the organisation. The interview questions addressed the following main areas:

- Background of interviewees
- Interviewee’s perception of lean
- Process of implementing lean
- Barriers of implementaing lean at organisatonal level
- Drivers/success factors and benefits of implementing lean

Additional questions were asked for further clarifications particularly on occasions where responses given were not sufficient or clear enough. This allowed a more indepth discussion about the subject matter (see Appendix 2a for the interview guide).

The importance of piloting the interview guide was not overruled at this stage. Therefore, an initial pilot study was conducted and two pilot interviews carried out. This involved a construction professional with expertise in implementing lean and sustainability and an academic with grounded knowledge in lean and suatianbale construction. Following the pilot interviews, the interview guide was refined based on feedbacks from the interview session. Ambiguous questions were modified and the questions were grouped under themes instead of having long list of questions.

The Ten (10) selected interviewees for each organisation were interviewed. Altogether, 20 people were interviewed face to face from the two case study companies. Each interview lasted between 1-2 hours and were recorded using a digital recorder.

4.8 Data Analysis- Case Study Approach

There are several methods of analysing qualitative data. The data analysis stage normally occurs after the data have been collected. However, the data analysis and interpretation of data in qualitative studies can start during the data collection process. According to Yin (1994), analysing case study data is one of the most difficult tasks and the least developed aspect of qualitative research. The data analysis techniques available include content analysis and cognitive mapping, which are code-based, and the textual data analysis. Moscarola (2002) stated that the purpose of textual data analysis is to analyse the text as a set of words, to make a statistic of their utterance and of their relationship within the text. For the purpose of analysing the data from the case studies, content analysis was used during this stage of the research.

4.8.1 Content Analysis

Content analysis is a research method for making replicable and valid inferences from data to their context, with the purpose of providing knowledge, new insights, a representation of facts and a practical guide to action (Krippendorff, 1980 as cited in Elo and Kyngas, 2007). It is also used for compressing many words of text into fewer content categories based on explicit rules of coding. Content analysis has been viewed as quantitative while other authors believe that it has the elements of both quantitative and qualitative approaches (Neuman, 1994; Berg, 1998). It should be noted that content analysis is usually used to examine contents of communication such as written document and transcripts of interviews (Berg, 1998).

According to Hsieh and Shannon (2005), there are three approaches of content analysis: conventional, directed and summative. These three approaches adhere to the naturalistic paradigm and are used to interpret meaning from the content of the text. In conventional content analysis, coding categories are derived directly from the text data. With a directed approach, analysis starts with a theory or relevant research findings as guidance for initial codes. A summative content analysis involves counting and comparisons, usually of keywords or content, followed by the interpretation of the underlying context. Content analysis has been classified by several authors in different ways for example; Krippendorff (1980) classified content analysis as pragmatic, semantic and sign-vehicle content analysis. Smith and Humphreys (2006) identified two major categories: conceptual analysis and relational analysis. In conceptual analysis a concept is examined for the presence, frequency and centrality. Such concepts can either be words, phrases, or more definitions and this analysis entails quantifying and totalling its presence. Relational analysis tabulates not only the frequency of the concepts in the body of the text, but also the co-occurrence of the concepts, thereby examining how concepts are related to each other.

The choice of content analysis was made mainly because it allows the researcher to test theoretical issues to enhance understanding of the data. Through content analysis, it is possible to distil words into fewer content-related categories. The conceptual analysis was adopted for the data analysis in this study. Coding of data is another important aspect of content analysis. Bernard (2000) stated that code-based analysis is a process for identifying similar concepts from the set of data and categorising them under different names or labels. The two distinctive methods to derive codes are deductive coding and inductive coding. Content analysis is mostly based on deductive coding. Deductive coding is the generation of themes with the support of literature and assigning relevant concepts from a set of data. The advantage of this approach is the ability to connect the finding of the research to the existing body of knowledge (Saunders *et al*., 2007) and the provision of a framework to commence the analysis (Yin, 2003). Inductive coding entails the generation of themes from the data itself, which is heavily rooted in the grounded theory approach.

The interviews were recorded using a digital recorder. The data were then transferred and stored as computer files. The data were coded manually for ease of analysis. The choice of manual coding was made instead of computerised coding because manual coding in content analysis is more reliable, although, it may be time-consuming (Carley, 1990).

4.8.2 Derivation of Results of the Case Study Findings – Cross-Case Synthesis

Apart from the case study interview guide used during the case study data collection, a matrix was developed. This was developed after coding and categorising the interviewees' responses. This allowed for ascertaining the responses of the participants and to depict the main issues, areas and categories captured under each question raised. The main issues or areas were deduced or extracted from the in-depth discussion with the participants of the case studies by means of developed matrix. According to Miles and Huberman (1994), developing a matrix makes data triangulation and adding internal consistency to interviews possible.

The categories of issues and codes developed during the case studies were modified gradually; using the data collected from the semi structured interviews. The findings from the case studies were presented according to the staff categories and the case study company. Table 4.8 presents the codes used for the staff categories of each of the case study company.

Table 4.8: Codes used for Professional/staff Categories

	Codes	Professional/staff category
Case study 1 (CS1)	SM 1	Senior managers
	MM1	Middle managers
	BM1	Supervisors and operational staff
Case study 2 (CS 2)	SM 2	Senior managers
	MM2	Middle managers
	BM2	Supervisors and operational staff

As mentioned above, in the case studies within this study, the interview guide approach was used at both case study companies. Interviews were arranged with individual employees based on their significant role in the management or supervision of processes, projects and people, or in their role of implementing lean construction. The main issues or areas identified during the interview process within the case studies were ticked off in the matrix and the issues were tabulated during the data analysis stage showing the number of interviewees that mentioned any particular issue. An example of the derivation of results from the matrix is given in Table 4.9.

Table 4.9: An example of Derivation of Results

'Question'

Total number of interviewees in the particular staff category in case study 1

Total number of interviewees in case study 1

Staff category code

Total number of interviewees in the two case studies

Barriers to implementing lean construction	CS1				CS2				
	SM1	MM1	BM1	Total	SM2	MM2	BM2	Total	Total for all respondents
	2	**4**	**4**	**10**	**2**	**4**	**4**	**10**	**20**
Lack of top management commitment and support	1	4	4	9	2	4	3	9	18
………………………..	….	…..	….	….	….	….	….	….	…..
Culture and employee attitudinal issues	2	3	4	9	2	3	3	8	17
Financial issues in terms of training cost	2	4	3	9	2	4	2	8	17

Number of interviewees that mentioned the particular issue under the 'question'

Total number of interviewees in case study 1that mentioned the particular issue under the 'question'

Total number of interviewees that mentioned the particular issue under the question for both case studies

4.8.3 Development of the Framework for the Implementation of Lean in Sustainable Construction (Stage 4)

The research process of this stage is divided into the development of the framework, and the refinement and validation of the developed framework.

4.8.3.1 Framework Development

The findings from the previous stages of the research (i.e. literature review, questionnaire survey and the case study) established the need for a framework for assessing lean construction implementation effort and benefits of lean in sustainable construction. The combination of the broad and in-depth understanding of these findings and analyses was used to develop the proposed framework as shown in Chapter 8.

4.8.3.2 The Refinement and Validation of the Developed Framework

The developed framework was refined and validated by experts using semi-structured questions. The experts chosen comprised both academics and practitioners. The number of academics chosen for the study was four (4) and eight (8) practitioners; altogether, 12 participants were chosen. The academics were mainly university lectures/professors. This allowed for a useful feedback in incorporating a sound theoretical base into the initial developed framework.

The experts (academics and practitioners) were chosen based on the following criteria:

- The academics should have an in-depth understanding of the theory of lean and sustainable construction. Thus, the academics must be an expert in the field of lean and sustainable construction in order for their feedback to be useful in the refinement of the developed framework
- The practitioners should be directly involved in the implementation process of lean in their organisation or involved in one or more of the previous approaches of the research study (case study or questionnaire survey). This was to ensure that they have knowledge of lean implementation and also to ensure that they already had an understanding of the research study which gives room for continuity and validity of the framework.

The developed framework was sent out to the interviewees before the interviews. The interviews were conducted using a semi structured 'open' and 'closed' ended questions (see Appendix 3) which covered the following aspects:

- Level of coverage of main issues represented in the framework
- Level of coverage of each section of the framework
- The ease of understanding, logic, or flow of the framework
- Overall usefulness of the framework in terms of applicability
- Comment on areas considered to be deleted/included/improved

4.9 Summary

This chapter presented the research process adopted and the rationale for using both quantitative and qualitative methodologies. The choice of both approaches was justified by the nature of the study investigation and the method deemed fit for the research questions. The qualitative methodology mostly describes phenomena using words while the quantitative methodology measures them and describe results numerically. The case for quantitative analysis has been made in a qualitative methodology with the use of content analysis depending on the type chosen. The strengths and weaknesses of both approaches can strengthen the richness of the findings of a research thus, serving as a platform for triangulation. This is because quantitative methods tend to be broader and more easily generalisable while qualitative can provide a much deeper, richer data set. Having established that, the various methodological options under each methodology were reviewed and the choice of an appropriate method for this study was made for both methodologies. The data analysis methods and the analysis techniques employed were also discussed in detail.

CHAPTER 5: LINKAGE BETWEEN LEAN CONSTRUCTION AND SUSTAINABILITY

5.1 Introduction

The main goal of this chapter is to report the findings of the questionnaire survey carried out as part of the research. The findings are related to the linkages between lean and sustainability. The results of areas of linkage between lean and sustainability, lean tools and techniques for enabling sustainability, benefits of synchronising lean and sustainability, and issues of sustainability and lean within respondents' organisations as well as lean issues in design and construction are presented. The issues included in the survey are based on literature review and the discussions presented are also substantiated with findings from the extant literature. Overall, Chapter 5 fulfils Objective 2 of the research and Research Questions II, III, and IV of the study (see Table 1.1).

5.2 Lean and Sustainability- An Overview

Nahmens and Ikuma (2009) stated that improvement in lean construction principles contribute to sustainable construction practices. Sustainable construction refers to the integration of environmental, social and economic considerations into construction business strategies and practices. It is the application of the principles of sustainable development to the comprehensive construction cycle from the extraction of raw materials, through the planning, design and construction of buildings and infrastructure, until their final deconstruction and management of the resultant waste (Tan *et al.*, 2011).

Forbes *et al*. (2000) stated that the concept of sustainability is very closely linked to lean construction in several respects and that while it is desirable to use lean methods to construct buildings and facilities with little waste and as cost-effectively as possible, it is also highly important to design them such that they will operate in a manner that promotes the sustainability of natural resources. Lean construction maximises value and reduces wastes through the use of supply chain management and just-in-time techniques as well as the open sharing of information between all the parties involved in the production process. One major area of synthesis between sustainable construction and lean is evident in improvement through the reduction of waste (King and Lenox, 2001; Green *et al.,* 1998; Florida, 1996; Larson and Greenwood, 2004; Linton *et al*., 2007).

Another common advantage is that both sustainable construction and lean strategies require similar methodologies of external auditing and ongoing reviews (Parker, 2008). Also, the lean emphasis on rework elimination requires efficient systems to reduce generation of undesired by-products, thus creating an environmental benefit (Womack *et al.,* 1990; Friedman, 2008). While lean practices can lead to environmental benefits, inversely, environmental practices often lead to improved lean practices (Kleindorfer *et al.*, 2005; Hansen *et al.,* 2004). Kibert (2008) identified six principles of sustainable construction: minimise resource consumption; maximise resource use; use renewable or recycled resources; protect the natural environment; create a healthy; nontoxic environment; and purse quality in creating the built environment. Bourdaeu *et al.* (1998) listed some other important sustainable measures such as preserving property value, flexibility, long service life, use of local resources, information dissemination, use of by-products, immaterial services, mobility consideration or supporting local economy in addition to the "common" sustainability criteria.

Cain (2004) proposed that lean construction can be defined by six goals of construction best practice. These are: finished buildings that will deliver maximum functionality, which includes end users; end users benefiting from the lowest optimum cost of ownership; elimination of inefficiency and waste in the use of labour and materials; the involvement of specialist suppliers in design from the outset to achieve integration and buildability; a single point of contract in terms of design and construction for the most effective co-ordination and clarity of responsibility; establishment of current performance and improvement achievements by measurement.

Elimination of non-value adding flow activities and making conversion activities more efficient are the core principles of lean construction (Senaratne and Wijesiri, 2008). With such principles it can be seen that adopting the lean concept within a construction process will directly increase or contribute to the sustainability performance of the project. Found (2009) deduced that taking a lean approach to waste elimination has a considerable potential for environmental and economic sustainability. Found (2009) stated that until recently, lean and the application of lean thinking have concentrated on the economic and some of the social aspects of sustainability. However, the essence of lean is to produce more with less.

According to Larson and Greenwood (2004), the strengths and weaknesses of lean and eco-sustainability initiatives produce an encouraging conclusion: they are potentially perfect complements that, if effectively linked, hold the potential to vault sustainability synergistically forward. Lean reflects and utilises exactly the same core themes as eco-sustainability initiatives. The explicit discussion of this can be seen in Figure 5.1 presented below.

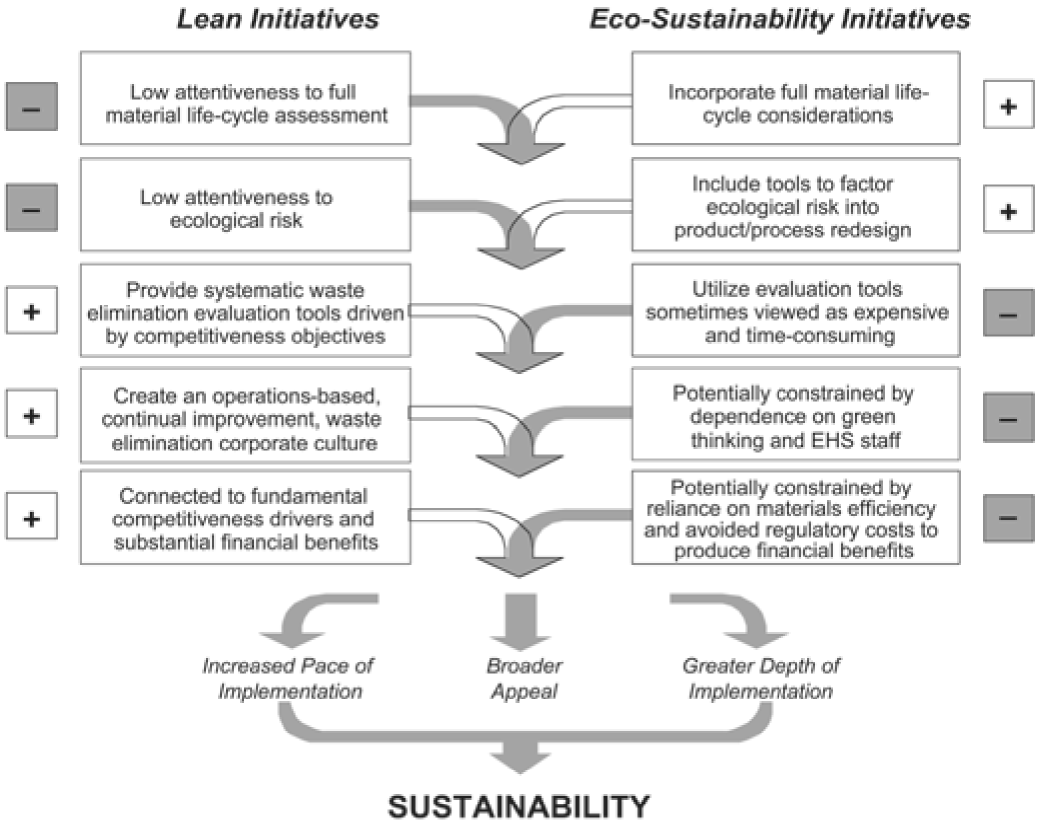

Figure 5.1: Lean and Eco-Sustainability Initiatives

(Source: Larson and Greenwood, 2004)

Lean leads toward sustainability initiatives and lean tools can be applied to any kind of problem, including environmental ones. The lean objective of waste elimination fits sustainability initiatives perfectly. The sustainability initiative is much like lean both in concept and practice; sustainability can be thought of as lean extended to a much broader objective (Langenwalter, 2006). Sustainability shares the same viewpoint as lean, with emphasis on closed-loop cyclical thinking rather than linear, goal-oriented thinking. It actually goes even farther, into whole-system thinking, which causes practitioners to look for long-term unintended consequences of their decisions. Lean and sustainability initiatives are both driven from the top-down within firms (Friedman 2008). Lean construction and sustainability share a common goal on eliminating material waste and promoting health and safety in construction activities (Bae and Kim 2008; Nahmens and Ikuma, 2009).

5.2.1 Sustainability Business Case – Questionnaire Survey Findings

The business case for sustainability was investigated. This was carried out to evaluate organisational understanding of the elements of sustainable construction, how the sustainability concept has been adopted, and to what extent it has been implemented. Table 5.1 presents the understanding of the concept of sustainability. The analysis of the respondents' awareness and understanding of sustainable construction is presented using the descriptive statistics based on the ranking of the severity index. "Sustainability covers the economic, social, and environmental aspects" is the highest ranked (1) of the issues on sustainability business case, while "having an internal written business case for addressing sustainability" is the least issue on sustainability business case. Interestingly, this result conforms to the result of other studies, for example Adetunji (2005), as sustainable construction is generally perceived to cover social, economic and environmental impact.

Table 5.1: Sustainability Issues within Respondents' Organisation

	SPSS Valid Percent					
Sustainability Business case	1	2	3	4	Severity index (%)	Rank
Requires new strategic initiatives	1.8	9.1	67.3	21.8	77.28	3
Awareness has increased	-	16.4	54.5	29.1	78.18	2
Involves the strategic issues of sustainability	-	9.1	83.6	7.3	74.55	4
Has internal written business case for addressing it	12.7	7.3	74.5	5.5	62.71	6
Has increased the efficient and effective operation	-	20.0	49.1	30.9	71.73	5
covers the economic, social &environmental aspects	-	5.5	56.4	38.2	83.25	1

Rating scale: 1-Strongly disagree, 2-Disagree, 3-Agree, 4-Strongly agree

The business case for lean construction implementation was investigated. This was carried out to evaluate the perception of lean construction among the respondents; organisational understanding of the concept of lean construction, and to what extent it has been implemented. As shown in Table 5.2, "awareness of lean construction has increased" is the highest ranked (1) while the least ranked is "lean motivates employees and shapes their behavior".

Table 5.2: Lean Construction Implementation Issues within Respondents' Organisation

SPSS Valid Percent						
LC Implementation Business case	1	2	3	4	Severity index (%)	Rank
Awareness has increased	-	3.6	54.5	41.8	84.5	1
Has improved competitiveness and market share	3.6	16.4	63.6	16.4	73.05	4
Enables sustainability initiatives	3.6	1.8	87.3	7.3	74.58	2
Motivates employees and shapes their behaviour.	3.6	12.7	65.5	18.2	64.58	7
Has complemented marketing effort	9.1	18.2	61.8	10.9	68.63	5
Innovates sustainable competitive advantage	-	12.7	78.2	9.1	73.85	3
Is promoted by integration of supply chain	10.9	18.2	69.1	1.8	65.46	6

Rating scale: 1-Strongly disagree, 2-Disagree, 3-Agree, 4-Strongly agree

The analysis of the link between sustainability and lean was carried out. Table 5.3 and 5.4 presents the analysis of lean in design and construction. Table 5.3 shows that the elimination of waste and non-value adding activities which is ranked (1) is the most important issue addressed by lean construction in design while aiding effective communication among the design team is the least important issue addressed by lean in design. Table 5.4 shows that aiding reduction in on-site transportation which is ranked (1) is the most important issue addressed by lean construction while identification of constraints within construction is the least important issue addressed by lean in construction. However, the least of the severity index score of all the identified issues is almost 65% approximately, which reflects that all the issues are important in construction.

Table 5.3: Lean Construction Issues in Design

SPSS Valid Percent						
Lean construction in Design	1	2	3	4	Severity index (%)	Rank
Leads to better technological efficiency	1.8	9.1	43.6	45.5	83.2	2
Solves potential constructability problems	1.8	10.9	52.7	34.5	79.9	3
Reduces product development time and cost	3.6	10.9	50.9	34.5	79.0	4
Assures supervised quality control procedure	1.8	18.2	56.4	23.6	75.45	5
Aids effective communication among design team	-	7.3	52.7	10.1	70.1	6
Eliminates wastes and non-value adding activities	-	-	52.7	47.3	86.83	1

Rating scale: 1-Strongly disagree, 2-Disagree, 3-Agree, 4-Strongly agree

Table 5.4: Lean Issues in Construction

	SPSS Valid Percent					
Lean in construction	1	2	3	4	Severity index (%)	Rank
Improves safety and environmental issues	-	5.5	56.4	38.2	83.3	3
Improves time, cost and quality	-	3.6	67.3	29.1	79.6	5
Helps to identify constraint within construction	1.8	16.4	65.5	16.4	74.2	6
Focuses on value than cost.	-	9.1	45.5	45.5	84.2	2
Optimises resource delivery schedules	-	12.7	56.4	30.9	79.6	5
Aids reduction in on-site transportation	-	5.5	50.9	43.6	84.5	1
Results in standardisation of work practices	-	1.8	63.6	34.5	83.1	4

Rating scale: 1-Strongly disagree, 2-Disagree, 3-Agree, 4-Strongly agree

Discussion relating to lean in design and construction is given in the next section.

5.2.1.1 Lean in Design and Construction

All the identified issues of lean in design and construction have a severity index above 70% which suggests that all the issues identified are important. The lean construction concept has the potential to better integrate design and construction. The interpretation of the meaning given to design and construction in lean differ (Jørgensen and Emmiitt, 2009). The lean construction production aspect has been initially focused on, with less attention on the lean design issues. Lean design issues have started to receive more attention and integrating a construction design and production processes from a lean perspective is beginning to be addressed. The application of lean in design has been less discussed and investigated with lack of a universal definition. Lean design is referred to as approaches, principles and methods for managing processes of design and/or of product development (Jørgensen and Emmitt, 2009). However, both design and construction under lean should be integrated (Koskela, 2000). Baiden *et al.* (2006) suggested that integration in construction can be described as the introduction of working practices, methods and behaviours that create a culture of efficient and effective collaboration by individuals and organisations. The term "integrated construction project team" was used to characterise "a highly effective and efficient collaborative team responsible for the design and construction of a project" (Baiden *et al.*, 2006).

5.2.2 Analysis of the Link between Sustainability and Lean Construction – Questionnaire Survey Findings

Table 5.5 shows that the "integration of the sustainability and lean concepts improves the construction process" and "the concept of both is very closely linked" are ranked 1 and 2 respectively while the least ranked (6) is that "lean construction is similar to the traditional practices".

Table 5.5: Links between Sustainability and Lean Construction

	SPSS Valid Percent					
Link between Sustainability and LC	1	2	3	4	Severity index (%)	Rank
The concept of both is very closely linked	-	1.8	65.5	32.7	82.73	2
LC is similar to the traditional practices	-	12.7	69.1	18.2	76.38	6
LC leads towards sustainability initiatives	1.8	10.9	56.4	30.9	79.18	4
Both eliminate material waste in construction	-	-	70.9	29.1	82.28	3
LC enhances sustainability	-	12.7	61.8	25.5	78.2	5
Integration of both improves construction process	-	3.6	58.2	38.2	83.65	1

Rating scale: 1-Strongly disagree, 2-Disagree, 3-Agree, 4-Strongly agree

5.2.3 Analysis of Benefits of Synchronising Lean and Sustainability- Questionnaire Survey Finding

The results presented in Table 5.6 show that improved corporate image which is ranked (1) is the most important benefit of synchronising lean and sustainability while increased employee morale and commitment, ranked (12) is the least.

Table 5.6: Ranking of Benefits of Synchronising Lean and Sustainability

	SPSS Valid Percent					
Benefits of Synchronising Lean & Sustainability	1	2	3	4	Importance index (%)	Rank
Improved corporate image	-	3.6	63.6	32.7	82.20	1
Improvement in sustainable innovation	-	7.3	65.5	27.3	80.08	5
Increased sustainable competitive advantage	-	10.9	67.3	21.8	77.73	11
Reduced cost and lead time	-	14.5	50.9	3.5	79.93	7
Improved process flow	-	7.3	65.5	27.3	80.08	5
Increased compliance with customers' expectations	-	14.5	54.5	30.9	79.03	10
Improvement of environmental quality	-	10.9	61.8	27.3	79.10	9
Increased employee morale, and commitment	-	23.6	47.3	29.1	76.38	12
Reduction in material usage					80.00	6
Reduction in energy consumption	-	7.3	63.6	29.1	80.45	4
Reduction in waste	-	5.5	65.5	10.6	81.60	3
Reduction in water usage	-	10.9	61.8	27.3	79.10	9
Increased productivity	-	3.6	65.5	30.9	81.83	2
Improvement in Health and Safety	-	9.1	63.6	27.3	79.55	8

Rating scale: 1-Strongly disagree, 2-Disagree, 3-Agree, 4-Strongly agree

5.2.4 Analysis of Lean Principles and Techniques for Enabling Sustainability-Questionnaire Survey Findings

The results presented in Table 5.7, show the level of use of lean principle/techniques for enabling sustainability in respondents' organisations. The most used lean techniques are Just-in-time, visualisation tool, value analysis, daily huddle meetings and value stream mapping while Six Sigma is the least used techniques.

Table 5.7: Lean Principles and Techniques for Enabling Sustainability

	SPSS Valid Percent					
Lean Principles/Techniques for Enabling Sustainability	1	2	3	4	Severity index (%)	Rank
Value stream mapping	3.6	45.5	49.1	1.8	62.28	5
5S	23.6	43.6	32.7	-	60.40	8
Total preventive maintenance	16.4	34.5	43.6	5.5	59.55	9
Kaizen	12.7	70.9	16.4	-	50.93	14
Pull approach	40.0	29.1	30.9	-	47.73	13
Last planner	21.8	32.7	40.0	5.5	57.30	10
Six sigma	61.8	23.6	14.5	-	38.13	16
Visualisation tool	10.9	21.8	56.4	10.9	66.82	2
Daily huddle meetings	7.3	38.2	50.9	3.6	62.71	4
Kanban	34.5	43.6	18.2	3.6	47.68	15
Fail safe for quality	9.1	41.8	45.5	3.6	60.91	7
First run studies	5.5	60.0	34.5	-	57.26	11
Just-In-Time	-	25.5	74.5	-	68.63	1
Value Analysis	12.7	23.6	54.5	9.1	64.96	3
Total Quality Management	10.9	34.5	50.9	3.6	61.76	6
Concurrent Engineering	-	43.6	52.7	3.6	54.03	12

4= high use, 3= medium use, 2= low use and 1= don't use.

5.2.5 Analysis of Lean Tools and Techniques/Principles - Case Study Findings

It was apparent from the questionnaire survey findings that there is low use of the lean principles and techniques. This could be attributed to the slow rate of adoption of the concept of lean. However, the reason for this in not clear and it should be noted that the responses obtained are views of each respondent representing their respective organisation which means there might be differing views among respondents within the same organisation. This prompted the need to investigate whether the situation is the same when carried out among different personnel within the same organisation. This was fulfilled through a case study approach. The results presented in Table 5.8, show the lean tools and techniques/principle used in the two case study companies. 5S, value stream mapping, just in time, visualisation tool, last planner, value analysis, pull approach and continuous improvement are the commonly adopted lean tools and techniques/principles. Almost all the respondents across the two organisations mentioned all the listed tools as shown in Table 5.8 (above 80%). As mentioned by one of the interviewee "*our companies use 5S to clean and make more efficient areas within our works, removing unwanted parts, tools and general debris and setting a new standard for cleanliness and tidiness. It is mostly useful in organising our construction site, thereby resulting to environmental improvement and health and safety improvement*" – BM2

Table 4.9 is inserted in this chapter to serve as a quick reference to how the case study results are presented.

Table 4.9: An example of Derivation of Results

Barriers to implementing lean construction	CS1				CS2				
	SM1	MM1	BM1	Total	SM2	MM2	BM2	Total	Total for all respondents
	2	**4**	**4**	**10**	**2**	**4**	**4**	**10**	**20**
Lack of top management commitment and support	1	4	4	9	2	4	3	9	18
………………………..	….	…..	….	….	….	….	….	….	…..
Culture and employee attitudinal issues	2	3	4	9	2	3	3	8	17
Financial issues in terms of training cost	2	4	3	9	2	4	2	8	17

Table 5.8: Lean Tools and Techniques – Case Study Findings

Lean tools and techniques/principles	Case study 1				Case study 2				
	SM1	MM1	BM1	Total	SM2	MM2	BM2	Total	Total for all respondents
5S	2	3	4	9	2	3	3	8	17
Value stream mapping	2	4	2	8	2	4	3	9	17
Continuous improvement (kaizen)	2	3	4	9	2	4	3	9	18
Pull approach	2	4	3	9	2	4	3	9	18
Last planner	2	3	4	9	1	3	4	8	17
Daily huddle meetings	1	3	4	8	2	4	4	10	18
Fail safe for quality	2	3	2	7	2	3	3	8	15
Just in time	2	3	4	9	2	4	4	10	19
Value analysis	2	4	2	8	2	4	3	9	17
Concurrent engineering	1	2	2	5	1	3	2	6	11
Total quality management	2	3	2	7	1	4	3	8	15
First run studies	2	2	1	5	2	3	2	7	12
Visualisation tool	2	3	4	9	2	4	4	10	19
Total preventive maintenance	1	3	2	6	2	3	2	7	13
Six sigma	1	2	2	5	1	1	2	4	9
Kanban	2	3	3	8	2	2	3	7	15

SM - Senior manager, MM - Middle manager, BM - Bottom manager. Also see Table 4.9 to identify the way results are presented in this Table.

Taking the findings presented in Table 5.7 and Table 5.8 into consideration, it appears that some of the lean tools are popular and commonly used. Respondents from both the questionnaire survey and the case study presented almost the same tools and techniques. The most ranked lean tools and techniques based on the questionnaire survey result are Just-in-time, visualisation tool, value analysis, daily huddle meetings and value stream mapping. The analysis of the case study result presented 5S, value stream mapping, Just-in-time, visualisation tool, last planner, value analysis, pull approach and continuous improvement as the commonly adopted lean tools and techniques/principles. The case study result presented a high percentage of use of these tools with the inclusion of 5S which was not part of the highly used based on the survey result. As pointed out by Hirano (1995), 5S is the starting point in the development of improvement activities to ensure organisational survival. It is very necessary in the day-to-day activities of an organisation in order to maintain orderliness and smooth and efficient flow of activities. Six sigma appears to be the tool with the lowest usage from both the questionnaire and case study result.

5.2.6 Analysis of the Area of Link between Lean Construction and Sustainability – Questionnaire Survey Findings

The results presented in Table 5.9 show that value maximisation, waste reduction, Health and Safety and environmental management are the most important areas of link between lean construction and sustainability while cost reduction (ranked 11) is the least important. However, all the identified areas of links are considered important as the least severity index percent is 80%.

Table 5.9: Area of Link between Lean Construction and Sustainability

	SPSS Valid Percent					
Area of link between LC and Sustainability	1	2	3	4	Importance index (%)	Rank
Waste reduction	-	-	45.5	54.5	88.63	1
Environmental management	-	-	45.5	54.5	88.63	1
Health and Safety improvement	-	5.5	40.0	54.5	87.25	3
Value maximisation	-	1.8	43.6	54.5	88.10	2
Cost Reduction	3.7	5.6	57.4	33.3	80.08	11
Energy minimisation	-	5.7	58.5	35.8	82.53	9
Quality improvement	-	3.7	48.1	48.1	86.03	6
Continuous improvement	-	10.9	49.1	40.0	82.28	10
Resource management	-	1.8	58.2	4.0	84.55	7
Design optimisation	-	3.6	47.3	49.1	86.38	5
Performance maximisation	-	-	52.7	47.3	86.83	4
Elimination of unnecessary process	1.8	3.6	56.4	38.2	82.75	8

Rating scale: 1-Strongly disagree, 2-Disagree, 3-Agree, 4-Strongly agree

Discussions related to the most important area of link between lean construction and sustainability (see Table 5.9) are given in the subsequent sections. Continuous improvement, cost savings, efficiency/performance improvement, optimisation, resource management are discussed under the area of drivers (refer to section 6.4).

5.2.6.1 Environmental Management

The severity index percentage that ranked environmental management as one of the most important areas of link between lean and sustainability was 88.63% (see Table 5.9). Environmentally sustainable practices are a natural extension of lean operational philosophy and techniques. Special emphasis has been placed on the attempts for reducing waste generation and improving techniques in minimisation of the harmful effects of construction activities on the environment since the construction industry has a great impact on the environment (Tan *et .al*., 2011). Environmental burdens caused by construction can be minimised and construction technology can be used to remedy the environment (Huovila and Koskela, 1998). Klotz *et al* (2007) stated that "sustainable" buildings have the potential to reduce the environmental and economic footprint of the built environment by minimising energy use, reducing resource consumption and waste, and providing healthy and productive environments for occupants. This is essential because construction, buildings and infrastructure are the main consumers of resources: materials and energy. In the European Union, buildings require more than 40 % of the total energy consumption and the construction sector is estimated to generate approximately 40 % of the man-made waste (Sjöström, 1998).

Environmental issues are gaining prominence in the UK construction industry. The link between environmental and economic performance has been widely debated in the literature. One view is that improved environmental performance mainly causes extra costs for the firm and thus reduces profitability. However, the opposite has been argued for: improved environmental performance would induce cost savings and increase sales and thus improve economic performance. Theoretical and empirical research has provided arguments for both positions and has not been conclusive so far (Schaltegger and Synnestvedt, 2002). CIRIA (2001) stated that the construction industry is coming under increasing pressure to make its activities more environmentally acceptable. Good practice on site to preserve our environment is now usually a high priority for clients, their professional advisors, contractors and regulators. According to Griffith and Watson (2004), effective environmental management focuses on ensuring that the site works are planned, organised and carried out with full awareness and understanding of the environmental effects that the works create. Griffith and Watson (2004) also stated that construction waste is variable by type and quantity, yet can be categorised into three broad groups of those which have (1) potential and value for reuse-such as concrete, mansory, bricks, blocks, asphalt, solid and aggregates; (2) potential and value for recycling- such as timber, glass, paper, plastics, oils and metals; and (3) no potential and value for reuse and recycling- such as paints, plastics, oils and asbestos. Griffith *et al.* (2000) developed a framework for project environmental management which reflects the consideration of environmental effects at the regulatory, company and project organisation levels throughout the construction project.

5.2.6.2 Waste Minimisation

The severity index percentage for waste reduction as one of the most important areas of link between lean and sustainability was 88.63% (see Table 5.9). Waste, according to Koskela (1992), is defined as any inefficiency that results into the use of equipment, materials, labour and capital in larger quantities than those considered as necessary in the production of a building. According to Rushbrook and Finnecy (1988), proper management of waste has several aspects: political, social, environmental, economic and technical. The objectives of waste management policy differ slightly from country to country; the methods used to achieve them must be adapted to the prevailing circumstances in each. Waste has been considered to be a major problem in the construction industry with a significant impact on the construction industry and the economy of a state as a whole. With the implementation of lean construction techniques contracting construction organisations have begun to seek ways of increasing their competitive advantage by removing all kinds of waste inherent in the construction process (Polat and Ballard, 2004).

Pheng and Tan, (1998) defined waste in construction as the difference between the value of those materials delivered and accepted on site and those used properly as specified and accurately measured in the work, after the deducting cost saving of substituted materials and those transferred elsewhere. Construction waste is however, classified into eight types according to Lee *et al.* (1999). These are: delay times, quality costs, lack of safety, rework, unnecessary transportation trips, long distances, improper choice or management of methods or equipment, and poor constructability.

According to Womack and Jones (1996), eight basic types of waste are classified as follows:

- Defect that must be corrected
- Over production (producing more or doing more that is needed)
- Excess inventory
- Unnecessary processing steps
- Transportation of materials with no purpose
- Motion of employee with no purpose

- Waiting by employees to for process equipment to finish its work or for an upstream activity to complete
- Goods and services that do not meet customer needs.

These wastes add no value to the customers, and hence need to be avoided. Waste is considered a major problem in the construction industry. Special emphasis has been placed on the attempts for reducing waste generation and improving techniques in minimisation of the harmful effects of construction activities on the environment since construction industry has a great impact on the environment (Tan *et al.*, 2011).

5.2.6.3 Health and Safety Improvement

The severity score of health and safety as one of the most important areas of link between lean and sustainability was 87.25% (see Table 5.9). Huovila and Koskela (1998) discussed the potential and profitability of lean principles to promote sustainable construction and a requirement framework was presented. The implementation of lean production concepts in construction appears to be a major factor in the attempt to eliminate accidents. The use of lean production concepts has been identified as a strategy for designing, controlling and improving engineering and construction processes to ensure predictable material and work flow on site; improving safety management and planning processes themselves to systematically consider hazards and their countermeasures; improving safety related behaviors- instituting procedures that aim at minimising unsafe acts (Koskela, 1993).

Safety is an important part of every production process. It relies on every action, material and person used, and therefore it should not be an afterthought or neglected (Nahmens and Ikuma, 2009). Poor safety should be eliminated in process and production plans in order to achieve desired goals of productivity, reduced costs, increased value and improved worker health. Lack of integration of safety into process and production plans can result in worker compensation costs, lost time, lost productivity, and higher employee turnover (MHRA, 2007).

One of the major problems in construction is lack of safety, as evident from the high accident rates. Employees in the industrialised housing industry sustain higher rates of reported injuries than their counterparts in the on-site construction industry (Nahmens and Ikuma, 2009). According to HSE (2013), the construction industry remained a high risk industry in the UK. Although it accounts for only about 5% of the employees in Britain it accounts for 27% of fatal injuries to employees and 10% of reported major injuries.

According to Rozenfeld *et al.,* (2009), factors such as frequent work team rotations, exposure to weather conditions, high proportions of unskilled and temporary workers on construction project, and the dynamic features of construction make managing construction site safety more difficult than managing safety in manufacturing plants. Rozenfeld *et al.* (2009) developed a structured method for hazard analysis and assessment for construction activities, called ‘‘Construction Job Safety Analysis” to address the difficulty encountered on construction sites as the physical environment is constantly changing, workers move through the site in the course of their work, and they are often endangered by activities performed by other teams. This method was developed within the framework of research toward a lean approach to safety management in construction, which required the ability to predict fluctuating safety risk levels in order to support safety conscious planning and pulling of safety management efforts to the places and times where they are most effective.

5.2.6.4 Value Maximisation

The severity index percentage of value maximisation as one of the most important areas of link between lean and sustainability was 88.10% (see Table 5.9). The implementation of lean within construction is a value-seeking process that maximises value and continually redefines perfection. Value as specified in lean thinking relates to materials, parts or products – something materialistic which is possible to understand and to specify (Koskela 2004). Value is also seen as an output of the collective efforts of the parties contributing to the design and construction process; central to all productivity; and providing a comprehensive framework in which to work. Value is the end-goal of all construction projects and therefore the discussion and agreement of value parameters is fundamental to the achievement of improved productivity and customer or user satisfaction (Emmitt *et al.,* 2005). Value maximisation in relation to the stakeholder theory is not a vision, strategy or a purpose but the scorecard for the organisation. It tells the participants in an organisation how they will assess their success in achieving a vision or in implementing a strategy (Jensen, 2001).

5.3 Test of Hypothesis

Based on the analysis presented in Table 5.9, the research hypothesis H1: “There is agreement on the area of linkage between lean and sustainability among the respondents” was examined (refer to Table 1.1). This can be examined using the test of null hypothesis.

Null hypothesis Ho – “There is no agreement on the area of linkage between lean and sustainability among the respondents”.

In Table 5.10, the significance value of Kendall’s coefficient of concordance is 0.000 (i.e. < 0.05). This result makes it possible to reject the null hypotheses at 5% significant level. Therefore, the alternative hypothesis “There is agreement on the area of linkage between lean and sustainability among the respondents” was accepted.

Table 5.10: Kendall’s Coefficient of Concordance Test of Agreement

No of cases	W	X^2	Df	Significance
28	.413	1249.362	108	.000

5.4 Data Synthesis and Discussion

The least severity index percent for all the benefits of lean construction and sustainability was 76% (See Table 5.6) which shows that, generally, all the benefits of synchronising lean construction and sustainable construction can be realised. Also, the level of experience of respondents has no significant influence on their perception of the benefits of synchronising lean construction and sustainable construction.

The most used lean techniques are just-in-time, visualisation tool, value analysis, daily huddle meetings, “5S” and value stream mapping while Six Sigma is the least used technique for enabling sustainability. “5S” and value stream mapping are commonly noted for environmental improvement. “5S” helps companies to look at their workplace in a new dimension. Previous studies show that environmental benefits, such as reducing waste of out dated components, reducing vehicle emissions, and reusable packaging are attributed to Just-in-time (Ross and Associates, 2004). Similarly, just-in-time has been identified as a major component of the lean construction concept with the overall objective of ensuring that the correct quantities of materials are delivered to the exact location as and when needed (Eriksson, 2010).

The most important areas of linkage between lean and sustainability are waste reduction, health and safety improvement, environmental management and value maximisation while cost reduction is the least ranked area. From the analysis, it could be seen that waste reduction has the strongest area of linkage between lean and sustainability. This is probably because construction wastes are non-value adding and they constitute serious threats to sustainability and value maximisation. Cost reduction was the least ranked linkage probably because of the associated implementation cost in lean or the cost of operating in a sustainable manner. However, the respondents regarded all the identified areas of link as important, since the least severity index percent was 80%. This suggests that there are synergies and linkages between lean construction and sustainability. Successful integration and implementation of lean and sustainability will foster the delivery of maximum benefits from both concepts, particularly in their areas of linkage.

5.5 Summary

From the gathered data and analysis of the questionnaire survey findings of this study, the most important area of link between lean and sustainability are the waste reduction, value maximisation, health and safety and environmental management. Lean and sustainability are seen to be linked as both are interested in waste, and this is supported by authors such as Bergmiller and McCright (2009), Edwards and Jonkman (2001), Larson and Greenwood (2004), Rothenburg *et al.*, (2001); Sarkis (1995), and Weinrach, (2002). The concepts of lean and sustainability promote the reduction of waste but with a different understanding of waste in construction. Both concepts are very closely linked and the integration of both improves the construction process. Lean in design eliminates wastes and non-value adding activities and also aids reduction in on-site transportation during construction.

CHAPTER 6: DRIVERS AND SUCCESS FACTORS IN THE IMPLEMENTATION OF LEAN

6.1 Introduction

The main goal of this chapter is to report on some findings of the case studies carried out as part of the research. The findings are related to the drivers, benefits, and success factors in the implementation of lean construction. The results of the interviews carried out in the two case studies are presented in the form of a cross- case synthesis in order to ascertain the similarities and differences in the responses of the two cases. The discussions presented in the chapter are also substantiated with findings from the extant literature. Overall, Chapter 6 fulfils objective 4, part of Objective 3 and the Research Questions V and VI of the study (see Table 1.1).

6.2 Success Factors in the Implementation of Lean – An Overview

Organisations fail to successfully implement lean because of lack of broad-based acceptance of the critical success factors to the implementation of lean. Embedding improvement techniques into the culture of a business requires the integration of the improvement process into the organisational system as a whole. However, it is imperative for an organisation to understand its business drivers for lean implementation. The drivers for introducing business process improvement methodologies such as lean within public services include the demand for increased efficiency and the need for service expansion with limited resources (Radnor and Walley, 2008).

Crute *et al.* (2003) identified five factors significant for a lean implementation from a case study carried out in the aerospace industry. These factors include change strategy targeted and holistic, senior management commitment, product focus, company culture and timing for performance improvements. The critical success factors of Banuelas and Antony (2002) as cited in Naslund (2008) are as follows:

(1) Business plan and vision;

(2) Top management support;

(3) Project management (including project champion, teamwork and composition);

(4) Change management and organisational culture;

(5) Effective communication, education and training, knowledge transfer, knowledge management (including skills and expertise);

(6) Organisational structure; and

(7) Monitoring and evaluation of performance, performance measurements

Lakshman (2006) suggested that the leadership of an organisation must exhibit certain behaviours for sustaining lean principles. Communicating, structuring through both enhancing control and exploration of teamwork, designing and conducting systematic experimentation in quality and implementing participation systems are described within the model developed by Lakshman (2006). These behaviours have been rephrased as monitoring and evaluation, engaging employees and celebrating and recognising success.

6.2.1 Analysis of the Success Factors of LC and Sustainability-Questionnaire Survey Findings

The respondents were asked to indicate their level of agreement with the identified success factors to lean and sustainability based on their experience in their organisation (refer to Appendix 2a). The results are presented in Table 6.1.

Table 6.1: Success Factors of Lean and Sustainability

	SPSS Valid Percent					
Success factors of LC and Sustainability	1	2	3	4	Severity index (%)	Rank
Management commitment	-	12.7	50.9	36.4	80.93	7
Good working environment	-	5.5	58.2	36.4	82.88	5
Customer focus and integration	-	14.5	54.5	30.9	79.03	11
System and process change management	-	5.5	67.3	27.3	80.53	8
Regular training of workforce	-	5.5	49.1	45.5	85.08	2
Effective planning	-	-	52.7	47.3	86.83	1
Integration of team and end to end supply chain	-	7.3	67.3	25.5	79.63	10
Adoption of a continuous improvement culture	-	-	60.0	40.0	85.00	3
Benchmarking of suppliers against each other	-	5.5	63.6	30.9	81.35	6
Communication and coordination between parties	-	-	60.0	40.0	85.00	3
Review of performance/progress towards targets	-	-	67.3	32.7	83.18	4
Wide adoption of lean and sustainability concepts	-	9.1	63.6	27.3	79.55	9
Understanding of lean benefits on sustainability	-	-	67.3	32.7	83.18	4

Rating scale: 1 - Strongly disagree, 2 – Disagree, 3 – Agree, 4 - Strongly agree

The results presented in Table 6.1 show that effective planning (ranked 1) is the most significant success factor to implementing lean and sustainability. It appears that all the identified success factors extracted from literature are seen to be important in the implementation process. The least significant of all the identified success factors was 79% which indicates a very high percentage.

6.2.2 Analysis of the Success Factors of Lean and Sustainability Based on the Main Business Activity and Size of Organisation- Questionnaire Survey Findings

Table 6.2 presents the differences on how the success factors on the implementation of lean construction and sustainability are perceived by the SMEs and the large firms and among the various main business activities which is represented as: design firms, construction firms and both design and construction. Effective planning is the most significant success factor of both the SMEs and the large firms while customer focus is the least for the SMEs and management commitment, good working environment, and system and process change management are the least for the large firms. Adoption of a continuous improvement culture together with communication and coordination between parties are the most significant success factors identified by the design firm while system and process change management is the least. Effective planning is the most severe factor for the construction firm while understanding of lean benefits on sustainability is the least. Lastly, the most significant factor for design and construction firms is the understanding of lean benefits on sustainability while the least is customer focus and integration. The correlation of the success factors could be found in Appendix 1c. The correlation shows a very strong relationship between the success factors at the 0.01 level. Some of the strongest relationships exist between management commitment and good working environment, review of performance/progress towards target and benchmarking of supplier against each other.

Table 6.2: Ranking of Success Factors of Lean and Sustainability

Success Factors	Design firms		Construction firms		Design and Construction Firms		Large firms		SME		All Respondents	
	SI	Rank	SI	Rank	SI	Rank	SI	Rank	SI	Rank	SI	Rank
Management commitment	86.25	4	75.69	9	79.41	6	82.50	3	76.67	8	80.93	7
Good working environment	87.50	3	79.16	5	80.88	5	82.50	3	81.12	5	82.88	5
Customer focus and integration	86.25	4	77.77	6	72.07	9	82.50	3	73.88	10	79.03	11
System and process change management	81.25	6	77.77	6	82.35	4	82.50	3	78.33	7	80.53	8
Regular training of workforce	90.00	2	80.72	3	83.82	2	85.00	2	84.99	3	85.08	2
Effective planning	87.50	3	87.50	1	83.75	3	87.50	1	86.66	1	86.83	1
Integration of team and end to end supply chain	83.75	5	76.38	8	77.94	7	85.00	2	78.33	7	79.63	9
Adoption of a continuous improvement culture	91.25	1	86.25	2	73.53	8	85.00	2	85.00	2	85.00	3
Benchmarking of suppliers against each other	86.25	4	76.38	8	80.88	5	85.00	2	78.89	6	81.35	6
Communication and coordination between parties	91.25	1	80.55	4	82.35	4	85.00	2	85.00	2	85.00	3
Review of performance/progress towards targets	86.25	4	80.55	4	82.35	4	85.00	2	82.78	4	83.18	4
Wide adoption of lean and sustainability concepts	83.75	5	77.77	6	82.35	4	85.00	2	75.55	9	79.55	10
Understanding of lean benefits on sustainability	86.25	4	76.39	7	86.76	1	85.00	2	82.78	4	83.18	4

Rating scale: 1-Strongly disagree 2-Disagree 3-Agree 4-Strongly agree

Based on the results presented in Table 6.2 the research hypothesis H2: ‘The perception of success factors for the implementation of lean and sustainability do not differ according to size of organisation’ was examined (refer to Table 1.1).

6.2.2.1 Success Factors to Implementing Lean and Sustainability vs. Size of Organisation

There is need to establish whether the perception of the respondents on the success factors to implementing lean and sustainability differ according to size of their organisations. This can be examined using the test of null hypothesis.

Null hypothesis Ho – There is no significant difference in the perception of the success factors to the implementation of lean and sustainability between organisational sizes.

The null hypothesis was tested using the Kruskal-Wallis test of grouping variable. Table 6.3 illustrates the size of organisation based on the number of employees. The Kruskal-Wallis test for grouping variables between the SMEs and large firms as presented in Tables 6.3 shows that all *P* values are greater than 0.05 which indicates that there is no statistically significant difference between the SMEs and large firms at 0.05 significant level. Therefore, at 5% level of significance, the null hypothesis is accepted, which means that ‘the success factors to the implementation of lean and sustainability do not differ according to size of the organisation of the respondents.

6.2.2.2 Success Factors to Implementing Lean and Sustainability vs. Organisation’s Main Business Activities

There is a need to establish whether there is difference in the perception of the respondents on the success factors in the implementation of lean and sustainability according to their main business activities (see Table 1.1). This can be examined using the test of null hypothesis.

The research hypothesis H3: “The perception of the success factors in the implementation of lean and sustainability differs according to organisation’s main business activities” was examined (refer to Table 1.1). This can be examined using the test of null hypothesis.

Null hypothesis *Ho* – *"There is no significant difference in the perception of the success factors in the implementation of lean and sustainability according to organisation's main business activities."*

The null hypothesis was tested using the Kruskal-Wallis test. Table 6.4 illustrates the organisation's main business activities as the design firms, construction firms, and design and construction firms. All the P values are greater than 0.05 which indicates that there is no statistically significant difference between the design firms, construction firms and the design and construction firm at 0.05 significance level (except for customer focus and integration, adoption of continuous improvement culture, and communication and coordination between parties). Therefore, at 5% level of significance, the null hypothesis is accepted, which means that 'the success factors in the implementation of lean and sustainability do not differ according to organisation's main business activities.

Table 6.3: Kruskal-Wallis Test of Size of Organisation on the Success Factors of Lean and Sustainability in Priority Ranking

	SF 1	SF 2	SF 3	SF 4	SF 5	SF 6	SF 7	SF 8	SF 9	SF 10	SF 11	SF 12	SF 13
Chi-square	.069	.416	.402	1.815	3.149	.197	12.604	.019	4.741	.298	.561	6.259	.561
Df	2	2	2	2	2	2	2	2	2	2	2	2	2
Asymp.Sig.	.966	.812	.818	.403	.207	.906	.002	.991	.093	.862	.755	.044	.755

a. Kruskal Wallis Test
b. Grouping variable: Size of Organisation
LEGEND

SF 1 Management commitment

SF 2 Good working environment

SF 3 Customer focus and integration

SF 4 System and process change management

SF 5 Regular training of workforce

SF 6 Effective planning

SF 7 Integration of team and end to end supply chain

SF 8 Adoption of continuous improvement culture

SF 9 Benchmarking of suppliers against each other

SF 10 Communication and coordination between parties

SF 11 Review of performance/progress towards targets

SF 12 Wide adoption of lean and sustainability concepts

SF 13 Understanding of lean benefits on sustainability

Table 6.4: Kruskal Wallis Test of various Business Main Activities on the Barriers of Lean and Sustainability in Priority Ranking

	SF 1	SF 2	SF 3	SF 4	SF 5	SF 6	SF 7	SF 8	SF 9	SF 10	SF 11	SF 12	SF 13
Chi-square	2.819	3.290	6.911	.960	3.395	.360	2.833	8.221	4.382	8.221	2.313	2.432	2.181
Df	2	2	2	2	2	2	2	2	2	2	2	2	2
Asymp.Sig.	.244	.193	.032	.619	.183	.835	.243	.016	.112	.016	.315	.296	.336

a. Kruskal Wallis Test
b. Grouping variable: Business Main Activity
LEGEND

SF 1 Management commitment

SF 2 Good working environment

SF 3 Customer focus and integration

SF 4 System and process change management

SF 5 Regular training of workforce

SF 6 Effective planning

SF 7 Integration of team and end to end supply chain

SF 8 Adoption of continuous improvement culture

SF 9 Benchmarking of suppliers against each other

SF 10 Communication and coordination between parties

SF 11 Review of performance/progress towards targets

SF 12 Wide adoption of lean and sustainability concepts

SF 13 Understanding of lean benefits on sustainability

6.2.3 Factor Analysis of Dependent Variables

Factor analysis was deemed necessary to be used in this study, due to the relatively large number of dependent variables (i.e. thirteen success factors). Factor analysis is useful for finding clusters of related variables and thus perfect for reducing a large number of variables into a more easily understood framework (Norussis, 2000). Tables 6.5 to 6.9 and Figure 6.1 provide the details of the results. The value of the test statistics for spherity was large (Bartlett test of spherity – 669.163) and the associated significance was (p=0.000), suggesting that the population correlation matrix is not an identity matrix. In an identity matrix, all the elements of the diagonals are one and all off-diagonals are zero (Field, 2000). The value for the KMO statistic is 0.836, which is satisfactory according to Norusis (2000).

The data was subjected to principal component analysis and varimax rotation. Prior to principal component analysis, the communalities involved were first established (see Table 6.5). Communality explains the total amount an original variable shares with all other variables included in the analysis and it is very useful in deciding which variables to finally extract in the varimax rotation and in determining the adequacy of the sample size (Field, 2005). After extraction of all variables, the average communality value was above 0.6 which suggests that the sample size is adequate. A correlation matrix of 13 variables from the research survey data was calculated and presented in Table 6.9. The correlation matrix shows that the success criteria identified share some common fundamental relationships and that clusters do exist.

Table 6.5: Communalities

	Initial	Extraction
Management commitment	1.000	.841
Good working environment	1.000	.793
Customer focus and integration	1.000	.495
System and process change management	1.000	.676
Regular training of workforce	1.000	.796
Effective planning	1.000	.561
Integration of team and end to end supply chain	1.000	.717
Adoption of a continuous improvement culture	1.000	.600
Benchmarking of suppliers against each other	1.000	.878
Communication and coordination between parties	1.000	.776
Review of performance/progress towards targets	1.000	.861
Wide adoption of lean and sustainability concepts	1.000	.820
Understanding of lean benefits on sustainability	1.000	.755

Extraction Method: Principal Component Analysis.

Table 6.6: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.836
Bartlett's Test of Sphericity	Approx. Chi-Square	669.163
	Df	78
	Sig.	.000

Table 6.7: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.068	62.064	62.064	8.068	62.064	62.064	5.349	41.147	41.147
2	1.499	11.529	73.593	1.499	11.529	73.593	4.218	32.446	73.593
3	.805	6.195	79.788						
4	.557	4.284	84.072						
5	.460	3.541	87.613						
6	.431	3.312	90.925						
7	.348	2.677	93.602						
8	.218	1.677	95.279						
9	.198	1.525	96.804						
10	.162	1.247	98.051						
11	.126	.969	99.020						
12	.090	.689	99.709						
13	.038	.291	100.000						

Extraction Method: Principal Component Analysis.

The total variances explained by each component extracted in Table 6.7 are: component 1 (62.06%) and component 2 (11.53%). Thus, the final statistics of the principal component analysis and the components extracted accounted for 73.59

Table 6.8: Correlation Matrix

Correlation Matrix

		Management commitment	Good working environment	Customer focus and integration	System and process change management	Regular training of workforce	Effective planning	Integration of team and end to end supply chain	Adoption of a continuous improvement culture	Benchmarking of suppliers against each other	Communication and coordination between parties	Review of performance/progress towards targets	Wide adoption of lean and sustainability concepts	Understanding of lean benefits on sustainability
Correlation	Management commitment	1.000	.824	.374	.321	.737	.599	.642	.495	.438	.608	.631	.414	.631
	Good working environment	.824	1.000	.500	.320	.715	.511	.644	.470	.391	.666	.576	.385	.576
	Customer focus and integration	.374	.500	1.000	.475	.301	.264	.531	.533	.545	.590	.477	.646	.536
	System and process change management	.321	.320	.475	1.000	.361	.367	.432	.505	.751	.575	.738	.647	.592
	Regular training of workforce	.737	.715	.301	.361	1.000	.653	.681	.452	.473	.641	.577	.428	.577
	Effective planning	.599	.511	.264	.367	.653	1.000	.555	.416	.492	.416	.581	.461	.581
	Integration of team and end to end supply chain	.642	.644	.531	.432	.681	.555	1.000	.547	.702	.684	.695	.710	.695
	Adoption of a continuous improvement culture	.495	.470	.533	.505	.452	.416	.547	1.000	.638	.773	.696	.581	.617
	Benchmarking of suppliers against each other	.438	.391	.545	.751	.473	.492	.702	.638	1.000	.774	.880	.836	.738
	Communication and coordination between parties	.608	.666	.590	.575	.641	.416	.684	.773	.774	1.000	.775	.710	.696
	Review of performance/progress towards targets	.631	.576	.477	.738	.577	.581	.695	.696	.880	.775	1.000	.790	.835
	Wide adoption of lean and sustainability concepts	.414	.385	.646	.647	.428	.461	.710	.581	.836	.710	.790	1.000	.723
	Understanding of lean benefits on sustainability	.631	.576	.536	.592	.577	.581	.695	.617	.738	.696	.835	.723	1.000

Table 6.9: Rotated Component Matrix[a] of success factors

	Component	
	1	2
Management commitment		.886
Good working environment		.857
Customer focus and integration	.665	
System and process change management	.814	
Regular training of workforce		.857
Effective planning		.689
Integration of team and end to end supply chain		.634
Adoption of a continuous improvement culture	.679	
Benchmarking of suppliers against each other	.899	
Communication and coordination between parties	.715	
Review of performance/progress towards targets	.801	
Wide adoption of lean and sustainability concepts	.872	
Understanding of lean benefits on sustainability	.695	

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalisation.

a. Rotation converged in 3 iterations.

The rotated component matrix of the principal component matrix was presented (see Table 6.9. The eigenvalue and factor loading were set at conventional high values of 1.0 and 0.5 respectively (see Ahadzie, 2007). As shown in Table 6.9, two components with an eigenvalue greater than 1.0 were extracted using the factor loading of 0.50 as the cut-off point. The scree plot (Figure 6.1) also presents the two components. The components can be thought of representing measuring scales for lean and sustainability implementation success factors.

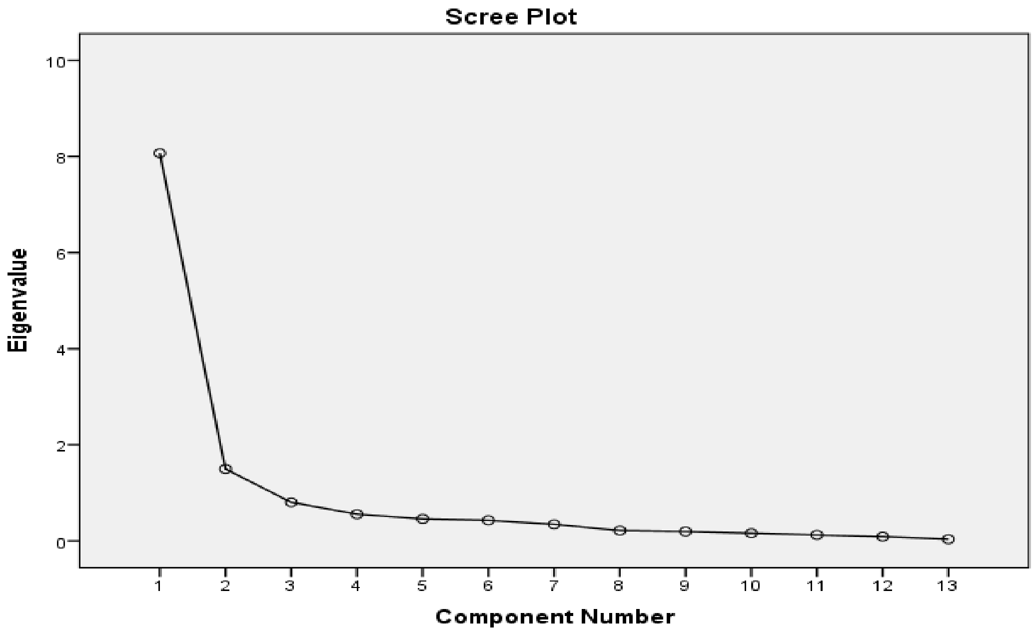

Figure 6.1: Scree Plot

Based on the examination of the fundamental relationships among the variables under each component, the following interpretation has been presented; component 1 is termed management and resource factor and component 2 is termed organisational culture factor.

6.3 Success Factors in the Implementation of Lean Construction- Case Study Findings

The results of the questionnaire survey presented substantial variation in the different groups of respondents on the issues relating to the success factors of implementing lean (refer to Section 6.2.2). It, therefore, prompted the need to investigate the success factors of implementing lean construction among different respondents within the same organisation. Also, the interpretation of the success factors through the use of the factor analysis was based on a close examination of variables under the 2 components derived. It was therefore, necessary to determine whether the response of respondents within the same organisation will have an impact on the result of the survey presented (see Section 6.2.1). This was fulfilled through a case study approach. All the 20 interviewees across the two case studies were asked questions on the success factors to their lean implementation (refer to Appendix 2a). The interviewees identified and explained several success factors. These success factors were then summed up in order of frequency of citation. Table 6.10 presents the analysis of these mentioned success factors.

Table 6.10: Success Factors to Lean Implementation-Case Study Findings

Success Factors	Case study 1				Case study 2				
	SM1	MM1	BM1	Total	SM2	MM2	BM2	Total	Total for all respondents
Management commitment	2	4	4	10	2	4	3	9	19
Good working environment	1	1	3	5	1	2	2	5	10
Customer focus and integration	2	3	4	9	2	3	3	8	17
System and process change management	2	2	3	7	2	4	2	8	15
Regular training of workforce	2	3	3	8	1	4	3	8	16
Effective planning	1	4	3	7	2	3	4	9	16
Integration of team and end to end supply chain	1	3	2	6	1	3	3	7	13
Adoption of a continuous improvement culture	2	4	3	9	2	3	4	9	18
Benchmarking of suppliers against each other	2	2	1	5	1	2	1	4	9
Communication and coordination between parties	2	2	4	8	2	4	3	9	17
Review of performance/progress towards targets	2	3	3	8	2	4	2	8	16
Wide adoption of lean and sustainability concepts	2	1	3	6	1	4	3	8	14
Understanding of lean benefits on sustainability	2	2	3	7	2	3	2	7	14
Teamwork and composition	2	1	2	5	1	2	3	6	11
Business plan and vision	2	2	3	7	2	4	2	8	15
Monitoring, evaluation and reporting of performance	2	4	2	8	2	3	4	9	17

SM - Senior manager, MM - Middle manager, BM - Bottom manager. Also see Table 4.9 to identify the way results are presented in this Table.

Discussions related to these aforementioned factors (see Table 6.10) are given in the subsequent sections. An important finding from the case studies was that these success factors were further categorised into: leadership and management factors, organisational cultural factors, skills and expertise and the resource factors. This was based on the findings from the literature review and the results of the analysis carried out on the survey data. Table 6.11 shows the classification of the success factor in the implementation of lean construction.

Table 6.11: Success Factors in the Implementation of Lean Construction at the Organisational Level

Leadership and management factors
1. Management commitment and support
2. Customer focus and integration
3. Effective planning
4. System and process change management
5. Communication and coordination between parties
6. Review of performance/progress towards targets
7. Business plan and vision
8. Monitoring, evaluation and reporting of performance
Organisational cultural factors
9. Integration of team and end to end supply chain
10. Adoption of a continuous improvement culture
11. Benchmarking of suppliers against each other
12. Wide adoption of lean and sustainability concepts
Resource, skills and expertise factors
13. Regular training of workforce
14. Understanding of lean benefits on sustainability
15. Good working environment
16. Teamwork and composition

The success factors for implementing lean construction will be discussed under these three broad headings.

6.3.1 Leadership and Management Factors

Based on the analysis in Table 6.10, management commitment and support was identified as a success factor in the implementation of lean by nineteen out of the twenty interviewees (95%). Management commitment and support was seen as very crucial to the implementation of lean in both cases. Kim and park (2006) stated that top management support is essential to reinforce lean implementation as professionals involved in the construction sector may face many difficulties in adopting the lean concept without top management support.

Seventeen out of the twenty (85%) interviewees identified customer focus and integration as a success factor for implementing lean; sixteen (80%) identified effective planning; fifteen (75%) identified system and process change management; seventeen (85%) identified communication and coordination between parties; sixteen (80%) identified review of performance/progress towards targets; seventeen (85%) identified monitoring, evaluation and reporting of performance; while fifteen (75%) identified business plan and vision as success factors for implementing lean in their organisation. This reflects the aspect of vision generation by the organisation. There has to be a vision of a fully integrated lean organisation from the outset, a realistic timescale for making changes and embedding lean, help for staff to understand how lean may impact upon the organisation, and evaluating the degree to which a process and customer view already exist within the organisation.

The integration of the objectives of the organisation with the improvement activities aid in prioritising improvements and make them an important part of the organisation's core activity for all staff to see (Barros Neto, 2002). Three critical factors have been identified regarding lean strategy to leanness; these are strategy, structure and strength. Strategy reflects the kind of company the organisation aims to be; structure relates to how the business internal and external relations are organised; and then strength reflects the organisational abilities and capabilities (Anvari, *et al.*, 2011). These three factors should be considered as well as defining a lean strategy i.e. understanding and analysing the fundamental areas of improvement that will allow the organisation to reach its goal. The lean strategic priorities have to be linked to daily improvement activities for a successful lean strategy implementation. Therefore, there is a need for establishment and execution of a deployment process and identification of financial and social impact. The organisation's current state, strategic objective, appropriate measurements and targets to improve must also be defined (Anvari and Moghimi, 2012).

Management commitment, specifically the top management, is crucial to successful implementation of lean. Full support of the top management shapes progress but lack of commitment of the top level staff may lead to partial engagement in the change process, lack of attendance at events, and a visible reluctance to implement the workforce's ideas (Womack and Jones, 1996; Boyer and Sovilla, 2003). The responsibility of the top management goes beyond demonstrating commitment and leadership, it must also work to create interest in the implementation and communicate the change to everyone within the organisation (Boyer and Sovilla, 2003). Achanga (2007) stated that management support is vital to lean readiness because a supportive management initiative may lead to successful lean implementation. According to de Miranda Filho *et al*. (2006), the perceived root cause of the difficulties in implementing lean practices in construction firms is lack of understanding by top managers of construction firms that, in any context, the development of a successful production system is the result of not one but many internal adjustments in the context of a production strategy. Kim and Park (2006) stated that top management support is essential to reinforce lean implementation on a construction project as professionals involved in the construction sector may face many difficulties in adapting the lean concept without top management support.

Transforming into a lean organisation requires three types of leaders, according to Womack and Jones (1996):

- One who is committed to the business in a long run and can be the anchor who will provide stability and continuity- an experienced worker with longer history in the company
- One with deep knowledge of lean techniques – lean specialist
- One who can be the champion or leader and fight against the organisational barriers which arise as a result of the dramatic change in the organisational operation

A common understanding and language of change and improvement is needed to be established by the organisation as effective communication is essential for successful implementation of lean. This was revealed in the result of the survey carried out by Kim and Park (2006) on construction firms in USA where lean was successfully implemented in firms that had good communication and mutual coordination. Diligent sharing of information by the senior managers and involvement of the low level employee to do same has been seen as a pillar of any lean system (Green, 2002).

6.3.2 Organisational Culture

Thirteen out of the 20 interviewed (65%) identified integration of team and end to end supply chain as a success factor in implementing lean in their organisations. Nine out of the 20 interviewed (45%) identified benchmarking of suppliers against each other, fourteen (70%) identified wide adoption of lean and sustainability concepts while eighteen (90%) identified adoption of a continuous improvement culture as very crucial to implementing lean in their organisation.

In comparing the responses of the various staff categories across the two cases, there is not much difference between the two cases. Six interviewees from Case Study 1 and seven interviewees from Case Study 2 identified integration of team and end to end supply chain as a success factor in implementing lean out of thirteen interviewees (see Table 6.10). Likewise, the same number of interviewees (nine) from each of the case studies identified adoption of a continuous improvement culture as very crucial to implementing lean in their organisation, making a total of eighteen (see Table 6.10).

The main factor in the successful application of lean is the development of a culture of continuous improvement in which staff are willing to accept initiatives and develop a sense of ownership. Staff become motivated when engaged in the process thereby generating a culture of continuous improvement (Radnor *et al.*, 2006). It has been affirmed by Gilbert (2004) that high performing companies are those with a culture of sustainable and proactive improvement.

According to Senge *et al.,* (2002), profound organisational change is the combination of inner shifts in people's values, aspirations and behaviours with outer shift in process, strategies, practices and systems. It has been noted by Anvari *et al.,* (2011) that it is not enough to change strategies, structure, and systems, unless there is change in the thinking that produced those strategies structures and systems. The attainment of a successful lean implementation requires cultural change and continuous improvement.

6.3.3 Resources, Skills and Expertise Factors

Fourteen out of the 20 interviewed (70%) identified understanding of lean benefits on sustainability, eleven (55%) identified teamwork and composition, ten (50%) identified good working environment, while sixteen (80%) out of the twenty interviewed across the two cases identified regular training of the workforce as success factors in the implementation of lean in their organisation. As mentioned in Section 6.3.2, not many differences exist between the two cases when comparing the responses of the various staff categories across the two cases (see Table 6.10).

Successful lean implementation requires resources which could be in the form of staff time and monetary value such as cost of employing a management consultant to assist with the lean process. It should be noted that availability of finance alone is not enough for a successful lean implementation project as it has to be combined with the management support (Achanga, 2007). Workforce training is also of high importance to the implementation of lean. There is need for staff to be trained on lean principles as educated workforce and other factors such as the management support and financial availability can reflect how ready a company is for lean uptake. Coffey (2000) stated that lean construction implementation depend on the potential and abilities of employees to successfully perform many of its functions and achieve its potential.

6.4 Drivers of Implementing Lean Construction – Case Study Findings

In this section, the key drivers behind the lean practices within the two case studies were explored, in order to establish the drivers for lean construction. Waste elimination, process control, flexibility, optimisation, people utilisation, continuous and efficiency improvement and value to customer were identified as some of the drivers of lean. However, lean construction has also been adopted by the construction industry as a means of supply chain improvement (Jorgensen and Emmitt, 2009). The adoption of innovative management practices, such as supply chain management and lean thinking, from a manufacturing context to the construction industry is not without challenges (Hook and Stehn, 2008). Table 6.12 presents the findings of the drivers from the case study.

Table 6.12: Drivers of Implementing Lean

Drivers	Case study 1				Case study 2				
	SM1	MM1	BM1	Total	SM2	MM2	BM2	Total	Total for all respondents
Waste elimination	2	4	4	10	2	4	4	10	20
Meeting customer expectation and requirement	2	4	3	9	2	4	4	10	19
Continuous improvement	2	3	4	9	2	4	3	9	18
Efficiency improvement	2	2	3	7	2	3	3	8	15
Process control	2	3	2	7	1	4	3	8	15
Flexibility	1	4	3	7	2	3	1	6	13
People and resource utilisation	2	4	2	8	2	3	3	8	16
Optimisation	2	4	1	7	2	2	4	8	15
Increasing competitive advantage	2	4	2	8	2	4	3	9	17
Business pressure	1	3	2	6	1	4	2	7	13
Government policy and regulation	2	3	2	7	1	4	3	8	15
Cost savings	2	2	4	8	2	4	3	9	17

SM - Senior manager, MM - Middle manager, BM - Bottom manager. Also see Table 4.9 to identify the way results are presented in this Table.

Based on the case studies and the review of the literature, a number of internal and external drivers of lean in organisations were identified. Most of these drivers fall under the internal reasons that may influence the adoption of lean in organisations. The external drivers are regarded as those drivers external to the organisation that may influence the adoption of lean in organisations. Analysis of the case studies highlighted a number of external drivers for lean that are promoting the adoption of lean in organisations. The external drivers include competitive advantage, government policy and regulation and business pressure in terms of competition between organisations.

6.4.1 Competitive Advantage

Seventeen out of the 20 interviewed (85%) identified competitive advantage as key driver in implementing lean in their organisation. According to them, their organisations seek a more suitable approach in order for them to be more profitable than their competitors. Moreso, one of the interviewee revealed:

'Our organisation aims to deliver great value as our competitors at a lower price' - SM2

There is a growing requirement for companies to continuously improve their operations to stay competitive. There are many pressures that threaten construction industry performance, such as global competition, environmental protection, and advances in construction and information technology. The degree of competition is a key environmental variable (Kim and Lim, 1988). Many studies have reported the empirical evidence of lean in respect of improving the company's competitiveness (Oliver *et al.* 1996; Billesbach, 1994; Taleghani, 2010). Henrich *et al.* (2006) stated that the implementation of lean in construction requires the organisation to become a learning company in order to sustain competitive advantage.

6.4.2 Continuous Improvement

Sixteen out of the 20 interviewed (80%) identified continuous improvement as one of the drivers in implementing lean in their organisation. Continuous improvement is defined as 'a culture of sustained improvement targeting the elimination of waste in all systems and processes of an organisation. It involves everyone working together to make improvements without necessarily making huge capital investments' (Bhuiyan and Baghel, 2005: 761). However, these improvements will not occur without managers understanding the advantages of such changes and demonstrating their willingness to commit to them.

Continuous improvement is conceptualised as innovation (Alves *et al*. 2009). The continuous improvement and 'Kaikaku' perspectives create a relationship between lean and benchmarking, in which benchmarking can be used as a tool for introducing and/or undertaking lean construction (Ramirez *et al.* 2004; Serpell and Alarcon 1996). However, benchmarking is not a straightforward task for construction (Mohamed 1996). Benchmarking is a way to achieve innovation and "breakthrough" (Alves *et al*., 2009) and leading construction organisations use benchmarking to constantly improve their performance (Pickrell *et al*. 1997). Benchmarking is seen as an important continuous improvement tool, enabling companies to enhance their performance by identifying, adapting, and implementing best practice in a participating group of companies (Ramirez *et al*,. 2004). It is a tool for business strategy development (McCabe, 2001) where the aim is to change business processes for the better (Pickrell *et al.*, 1997). It involves change in relation to culture, process, improvement of performance and productivity (Alarcon *et al.*, 1998).

The application of continuous improvement philosophy within the implementation of lean construction is essential. Rother (2010) argues that this might not be enough because an additional overall direction is required i.e. applying Lean thinking to construction needs long-term thinking (Mossman 2009). Long-term visions or directions will help to navigate through different actions to finally achieve the aim (Rother, 2010).

6.4.3 Business Pressure

Eleven out of the 20 interviewed (55%) mentioned business pressure as another driver for implementing lean in their organisation. Katayama and Bennett (1996) identified competitive pressure as the driver for a lean production response through cost reductions, facilitating price competition to expand market share. In response to competitive pressures, these organisations have implemented lean as revealed by the respondents. This is not surprising as it has been suggested by Vokurka and Fliedner, (1998) that world-class firms should strive to achieve agility in response to competitive pressures. Sharifi and Zhang (1999, 2001) also identified intensified competitive pressure as a driver of agility.

6.4.4 Meeting Customer Expectation and Requirement

Nineteen out of the 20 interviewees (95%) across the two case studies reported that their visibility to the customer was a driving force for their organisation to implement lean (see Table 6.12). It is obvious that meeting customer expectation and requirement is common to both case studies. One of the interviewees in the case study stated that the core driver of implementing lean in their organisation is to meet up with customer expectation and requirement.

"Our lean journey began as a response to our client requirement who requested for lean concept adoption on his project'- SM2

The changing market and shift in customer preferences in terms of value specifically quality, has promoted the adoption of lean construction. This led to an aggressive and unprecedented focus on quality while maintaining competitive price. Increasing customer expectations in the form of strong taste for quality help intensify the attention devoted to product quality initiatives.

The construction industry is changing (Ashworth, 2010; Kelly *et al.,* 2008), driven by the power of clients. Large regular-procuring clients of the construction industry are increasingly seeking innovative approaches to the way in which their projects are planned, designed and delivered to facilitate their business strategies. They are looking for a structured method to manage their project processes within the context of their organisational business strategies, and to work closely with the supply chain to maximise value and achieve continuous improvement in construction performance (Kelly *et al.,* 2008).

6.4.5 Cost Savings

Seventeen out of the 20 interviewed (85%) identified cost savings as driver for implementing lean in their organisation (see Table 6.12). Lean is driven by cost reduction (Friedman, 2008) and many organisations have implemented lean to generate cost reduction on their day to day operations. Jeff (2010) stated that there has been a notable increase in the popularity of lean construction in the general construction industry especially in the past years as a result of at least two main drivers. First, plant managers seeking to reduce their total cost of ownership and mitigate the effects of unforeseen risks consider lean construction as a new execution platform. Second, energy-oriented construction firms looking for ways to be more competitive in the wake of the 2008 U.S. economic crisis are attracted to lean construction as a new model for conducting business. The application of lean thinking concepts has produced success stories in several construction segments, most notably in health care construction (Jeff, 2010).

6.4.6 Government Policy and Regulation

Fifteen out of the 20 interviewed (75%) identified government policy and regulation as a driver in implementing lean in their organisation. Government regulation and ISO standards (9000 and 1400) are becoming integral in a company's reputation and corporate image (Cole, 2008). There is a requirement by the UK government for the construction sector to aim for lean construction. This awareness has been raised following the Egan Report (DETR, 1998).

6.4.7 Efficiency Improvement

Fifteen out of the 20 interviewed (75%) identified efficiency improvement as another driver in implementing lean in their organisation (see Table 6.12). Efficiency is described as a measure of utilisation of resources (Sumanth, 1994). These resources according to the response of the interviewees, are in terms of human power (labour) and materials used during construction projects. Neely *et al.* (1995) also described efficiency as a measure of how economically the firm's resources are utilised when providing the given level of customer satisfaction.

6.4.8 Process Control

As shown in Table 6.12, 15 out of the 20 interviewed (75%) identified process control as another driver in implementing lean in their organisation. Alarcon *et al*. (2005) stated that the outcomes of lean are processes which are highly efficient and effective, i. e. performance improvement. A lean organisation is mindful of process thinking, the need to eliminate waste and uses customised lean techniques and methods which are adapted to suit the organisational requirements (Nesensohn and Bryde, 2012).

6.4.9 Flexibility

Thirteen out of the 20 interviewed (65%) identified flexibility as one of the drivers of implementing lean in their organisation (see Table 6.12). The interviewees explained flexibility in terms of their organisational structures. Flexibility has a main structure characteristic in lean companies. This has been mentioned by many authors (Holbeche, 1998; Faron, 2012). Many organisational structures (functional, divisional, matrix structure, and team-based structure) in use are described in terms of their flexibility. The functional structure is still being used by many companies despite the fact that it is the least flexible type. Lean goes together with flexible organisational structures (Faron, 2012).

6.4.10 People and Resource Utilisation

Sixteen out of the 20 interviewed (80%) identified people and resource utilisation as driver in implementing lean in their organisation. According to them, lean techniques help in coordinating people and resources (materials). As noted by one of the interviewees:

'People are not necessarily busy because our work is performed based on and dependent upon customer's demand'

"Better utilisation of resources is interesting in lean context since waste can be eliminated"- SM2

6.4.11 Optimisation

Fifteen out of the 20 interviewed (75%) identified optimisation of work processes as one of the drivers of implementing lean in their organisations. The need to take full advantage of work processes necessitated the adoption of lean as mentioned by the interviewees. This was important in order for their organisation to improve their work processes.

6.5 Benefits of Implementing Lean Construction – Case Study Finding

A detailed examination of the questionnaire survey result reveals that all the identified benefits of lean and sustainability fall under the economic, social and environmental benefits. A further investigation of these benefits was then necessary to classify them. This was carried out through the use of the case study approach. All the twenty interviewees across the two case studies were asked question on the benefits of implementing lean and to classify them (refer to Appendix 2a). The identified benefits of implementing lean were classified into environmental, social and economic benefits. Table 6.13 presents the analysis of the environmental benefits of lean.

Table 6.13: Environmental Benefits of Implementing Lean

Environmental benefits of implementing lean	Case study 1				Case study 2				
	SM1	MM1	BM1	Total	SM2	MM2	BM2	Total	Total for all respondents
Improved process flow	1	2	3	7	2	2	2	6	13
Improvement of environmental quality	2	4	2	8	2	3	2	7	15
Reduction in material usage	2	2	4	8	1	3	3	7	15
Reduction in energy consumption	2	2	2	6	2	3	2	7	13
Reduction in waste	2	4	3	9	2	4	3	9	18
Reduction in water usage	1	3	3	7	2	3	3	8	15
Improvement in health and safety	2	4	4	10	2	3	4	9	19

SM - Senior manager, MM - Middle manager, BM - Bottom manager. Also see Table 4.9 to identify the way results are presented in this Table.

Across the two case studies, almost all the interviewees (95%) identified improvement in health and safety as one of the major benefits of implementing lean.

The analysis of the economic benefits of lean across the two case studies is presented in Table 6.14. Increased productivity, reduced costs and lead time, reduction in over ordering of materials and reduced on-site transportation are the most significant economic benefits of implementing lean.

Table 6.14: Economic Benefits of Implementing Lean Construction

Economic benefit of implementing lean	**Case study 1**				**Case study 2**				
	SM1	MM1	BM1	Total	SM2	MM2	BM2	Total	Total for all respondents
Reduced costs and lead time	2	4	3	9	2	3	3	8	17
Improvement in quality	2	4	2	8	2	3	2	7	15
Increased productivity	2	3	4	9	2	4	3	9	18
Higher return on investment	1	3	3	8	1	4	2	7	15
Construction project value enhancement	2	3	2	7	2	3	3	8	15
Reduction in over ordering of materials and reduced on-site transportation	2	3	3	8	2	4	3	9	17
More robust process- less variability and improved predictability leading to less deliveries to site	1	2	3	6	2	2	3	7	13
Improved integration of trades enabling optimisation of the way resources are deployed	2	4	3	9	2	3	2	7	16

SM - Senior manager, MM - Middle manager, BM - Bottom manager. Also see Table 4.9 to identify the way results are presented in this Table.

The analysis of the social benefits of lean across the two case studies is presented in Table 6.15. Improved corporate image, increased organisational supply chain communication and integration, increased levels of organisational commitment, and enhanced organisation reputation are the most significant social benefits of implementing lean.

Table 6.15: Social Benefits of Implementing Lean

Social benefits of implementing lean	Case study 1				Case study 2				
	SM1	MM1	BM1	Total	SM2	MM2	BM2	Total	Total for all respondents
Improved corporate image	2	4	4	10	2	4	3	9	19
Improvement in sustainable innovation	1	2	3	6	1	3	3	7	13
Increased levels of organisational commitment	2	3	4	9	2	3	3	8	17
Employee autonomy	2	2	3	7	2	4	2	8	15
Information transparency	2	3	3	8	1	4	3	8	16
Performance improvement	1	4	3	7	2	3	4	9	16
Cultural fit	1	3	2	6	1	3	3	7	13
Increased organisational supply chain communication and integration	2	4	3	9	2	3	4	9	18
Long term implementation of lean effort	2	2	2	6	1	3	2	6	12
Enhanced organisation reputation	2	2	4	8	2	4	3	9	17
Increased sustainable competitive advantage	2	3	3	8	2	4	2	8	16
Increased employee morale, and commitment	2	1	3	6	1	4	3	8	14
Client satisfaction	2	2	3	7	2	3	2	7	14
Standardisation of work practices	2	2	3	7	2	4	2	8	15
Enhanced organisational knowledge management	2	2	3	7	2	4	2	8	15
Increased compliance with customers' expectation	2	4	2	8	2	3	4	9	17

SM - Senior manager, MM - Middle manager, BM - Bottom manager. Also see Table 4.9 to identify the way results are presented in this Table.

6.6 Summary

This chapter presents the drivers, success factors and the benefits of implementing lean. The success factors in implementing lean and sustainability were also analysed and subjected to factor analysis. All the identified benefits from implementing lean construction were classified into economic, social, and environmental benefits. The success factors in implementing lean were discussed under three broad headings: leadership and management, resources and organisational culture. Management commitment is seen a major factor in the successful implementation of lean based on the questionnaire survey findings and the case study findings. The impact of lean is significant to companies in the areas of economic, social, and environmental benefits as companies are under increasing pressure to deliver profit improvement and to operate their businesses in a responsible manner bearing in mind their activities' impact on society and the environment. Also, the drivers for implementing lean were discussed and classified into internal and external drivers.

CHAPTER 7: BARRIERS IN THE IMPLEMENTATION OF LEAN

7.1 Introduction

Chapter 7 presents some of the findings of the questionnaire survey and the case studies. The findings are related to the barriers of implementing lean and sustainability. The common barriers to implementing lean and sustainability are presented through the use of the questionnaire survey. The barriers to implementing lean were further investigated through the use of case study approach. The reason for this is to compare the views of respondents in the same organisation as to what is perceived as the barriers in implementing lean. The findings are also augmented with some of the findings of the literature review. Overall, Chapter 7 addresses the remaining part of Objective 3 and Research Question V of the study (see Table 1.1).

7.2 Implementation Barriers- An Introduction

Mohd-Zainal (2011) stated that many companies worldwide have tried to implement lean but a majority of them only achieved modest levels of success as the adoption of lean has presented more failure than success among many industries. According to Hines *et al.* (2004), the common factors for lean failures include, among other things, poor leadership, poor communication, lack of concrete processes or mechanisms, lack of clear targets or direction, lack of conducive environment, staff resistance to change, and lack of learning that leads to poor understanding of lean. One explanation for the difficulties companies encounter in sustaining lean may be attributed to a lack of focus on the developmental progression of lean capabilities amongst the members of the organisation. By focusing on developing lean capabilities, members of the organisation should then become progressively better at doing lean while at the same time, creating a learning environment that supports a lean culture (Jorgensen *et al.*, 2007).

7.2.1 Barriers to Lean Construction and Sustainability- Questionnaire Survey Findings

The respondents were asked to indicate their level of agreement with the identified barriers to lean and sustainability based on their experience in their organisations (refer to Appendix 1a). The results are presented in Table 7.1.

Table 7.1: Barriers to Lean Construction and Sustainability

	SPSS Valid Percent					
Barriers to LC and Sustainability	1	2	3	4	Severity index (%)	Rank
Lack of management commitment	5.5	9.1	50.9	34.5	78.61	6
Long implementation period	-	32.7	65.5	1.8	67.28	11
Lack of proper training	-	5.5	76.4	18.2	78.25	7
Lack of adequate skills and knowledge	-	5.5	76.4	18.2	78.25	7
Lack of application of the fundamental techniques	-	5.5	74.5	18.2	76.83	8
Gaps in standards and approaches	-	-	83.6	16.4	79.10	5
Fragmented nature of industry	-	9.1	58.2	32.7	80.90	4
Cultural barriers	-	7.3	54.5	38.2	82.73	2
Lack of implementation understanding & concepts	-	-	72.7	27.3	81.53	3
Resistance to change	1.8	-	52.7	45.5	85.48	1
Government bureaucracy and instability	-	18.2	72.7	9.1	72.63	10
Long lists of supply chain and lack of trust	-	9.1	76.4	14.5	76.35	9

Rating scale: 1-Strongly disagree, 2-Disagree, 3-Agree, 4-Strongly agree

The results presented in Table 7.1 show that the most significant barrier in the implementation of lean and sustainability is resistance to change. However, the results indicate that long implementation period is the least significant barrier in the implementation of lean and sustainability (refer to Table 7.1). Resistance to change, cultural barriers and the lack of implementation understanding are the top highest ranked barriers. These results conform to the findings in the study carried out by Sarhan and Fox (2013), where culture and human attitudinal issues, lack of adequate lean awareness/understanding and lack of management commitment were considered as the significant barriers to successful implementation.

7.2.2 Analysis of the Differences of the Barriers of Lean Construction and Sustainability Based on the Main Business Activity and Size of Organisation- Questionnaire Survey Findings

Table 7.2 presents the differences on how the barriers of lean construction and sustainability are perceived between the SMEs and the large firms and among the various main business activities which is represented as design firms, construction firms and both design and construction.

Table 7.2: Ranking of some Barriers of Lean and Sustainability

Barriers	Design firms		Construction firms		Design and Construction Firms		Large firm		SME		All Respondents	
	SI	Rank	SI	Rank	SI	Rank	SI	Rank	SI	Rank	SI	Rank
Lack of management commitment	85.00	2	70.82	6	79.41	4	82.50	4	77.77	7	78.61	6
Long implementation period	68.75	8	63.89	8	72.06	7	75.00	6	63.89	11	67.28	11
Lack of proper training	80.00	5	73.61	5	80.88	2	75.00	6	78.80	4	78.25	7
Lack of adequate skills and knowledge	80.00	5	73.61	5	80.88	2	77.50	5	78.32	5	78.25	7
Lack of application of the fundamental techniques	78.75	6	77.78	3	79.41	4	75.00	6	77.78	6	76.83	8
Gaps in standards and approaches	82.50	4	77.78	3	67.64	9	85.00	3	77.78	6	79.10	5
Fragmented nature of industry	87.50	1	77.78	3	76.48	5	87.50	1	76.67	8	80.90	4
Cultural barriers	87.50	1	77.77	4	65.23	10	65.00	7	79.99	3	82.73	2
Lack of implementation understanding and concepts	85.00	2	79.16	2	79.57	3	77.50	5	82.78	2	81.53	3
Resistance to change	83.75	3	87.50	1	85.30	1	85.56	2	85.00	1	85.48	1
Government bureaucracy and instability	76.25	7	69.43	7	72.05	8	77.50	5	66.12	10	72.63	10
Long lists of supply chain and lack of trust	82.50	4	70.82	6	75.00	6	85.00	3	71.67	9	76.35	9

Rating scale: 1-Strongly disagree, 2-Disagree, 3-Agree, 4-Strongly agree

“Resistance to change’ is the most significant barrier while “long implementation period” is the least barrier among the SMEs. The most significant barrier among the large firms is the “fragmented nature of the industry” while cultural barriers are the least. The most significant barrier for the design firms are “fragmented nature of the industry” and “cultural barriers” which are both ranked 1 while the least is “long implementation period”. “Resistance to change” is the most significant barrier for the construction firms while “long implementation period” is the least. Lastly, the most significant barrier for both design and construction is “resistance to change” while “cultural barrier” is the least barrier. It is obvious that “resistance to change” impacts on SMEs, construction firms and both design and construction firms. The correlation of the above barriers could be found in Appendix 1b. The correlation table shows that the strongest relationship exists between “lack of adequate skills and knowledge”, and “lack of proper training”, with highest significance at the 0.01 level.

Based on the results presented in Table 7.2, the research hypothesis H4: “The perception of the barriers to the implementation of lean and sustainability differs according to size of organisation” was examined (refer to Table 1.1).

7.2.2.1 Barriers to Implementing Lean and Sustainability vs. Size of Organisation

There is a need to establish whether there is difference in the perception of the respondents on the barriers to implementing lean and sustainability according to size of their organisation. This can be examined using the test of null hypothesis.

Null hypothesis Ho – “size has no significant influence on an organisations’ perception of the barriers of lean and sustainability”

The null hypothesis was tested using the Kruskal-Wallis test. Table 7.3 illustrates the size of organisation based on the number of employees. All the *P* values are greater than 0.05 which indicates that there is no statistically significant difference between the SMEs and large firms at 0.05 significance level (except for “long implementation period” and “long lists of supply chain and lack of trust”). Therefore, at 5% level of significance, the null hypothesis is accepted, which means that ‘the barriers to the implementation of lean and sustainability do not differ according to size of the organisation of the respondents.

7.2.2.2 Barriers to Implementing Lean and Sustainability vs. Business Main Activities

There is a need to establish whether there is difference in the perception of the respondents on the barriers to implementing lean and sustainability according to their main business activities (see Table 1.1).

The research hypothesis H5: “The perception of the barriers to the implementation of lean and sustainability differs according to organisation’s main business activities” was examined (refer to Table 1.1). This can be examined using the test of null hypothesis.

Null hypothesis Ho – “There is no significant difference in the perception of the barriers to the implementation of lean and sustainability according to organisation’s main business activities.”

The null hypothesis was tested using the Kruskal-Wallis test. Table 7.4 illustrates the organisation’s main business activities as the design firms, construction firms, design and construction firms. All the *P* values are greater than 0.05 which indicates that there is no statistically significant difference between the SMEs and large firms at 0.05 significance level (except for “long lists of supply chain and lack of trust”). Therefore, at 5% level of significance, the null hypothesis is accepted, which means that ‘the barriers to the implementation of lean and sustainability do not differ according to organisation’s main business activities.

Table 7.3: Kruskal Wallis Test of Size of Organisation on the Barriers of Lean and Sustainability in Priority Ranking

	Barrier 1	Barrier 2	Barrier 3	Barrier 4	Barrier 5	Barrier 6	Barrier 7	Barrier 8	Barrier 9	Barrier 10	Barrier 11	Barrier 12
Chi-square	.407	6.288	2.408	.998	2.987	5.261	2.234	2.457	9.645	3.933	1.882	7.394
Df	2	2	2	2	2	2	2	2	2	2	2	2
Asymp.Sig.	.816	.043	.300	.607	.225	.072	.327	.293	.008	.140	.390	.025

a. Kruskal Wallis Test

b. Grouping Variable: Size of Organisation

LEGEND

Barrier 1	Lack of management commitment
Barrier 2	Long implementation period
Barrier 3	Lack of proper training
Barrier 4	Lack of adequate skills and knowledge
Barrier 5	Lack of application of the fundamental techniques
Barrier 6	Gaps in standards and approaches
Barrier 7	Fragmented nature of the industry
Barrier 8	Cultural barriers
Barrier 9	Lack of implementation understanding & concepts
Barrier 10	Resistance to change
Barrier 11	Government bureaucracy and instability
Barrier 12	Long lists of supply chain and lack of trust

Table 7.4: Kruskal Wallis Test of Organisation's Main Business Activities on the Barriers of Lean and Sustainability in Priority Ranking

	Barrier 1	Barrier 2	Barrier 3	Barrier 4	Barrier 5	Barrier 6	Barrier 7	Barrier 8	Barrier 9	Barrier 10	Barrier 11	Barrier 12
Chi-square	3.022	1.534	3.668	3.668	.065	4.364	5.778	4.241	2.724	.312	3.021	8.869
Df	2	2	2	2	2	2	2	2	2	2	2	2
Asymp.Sig.	.221	.464	.160	.160	.968	.113	.056	.120	.256	.855	.221	.012

a. Kruskal Wallis Test

b. Grouping variable: Business Main Activities

LEGEND

Barrier 1 Lack of management commitment

Barrier 2 Long implementation period

Barrier 3 Lack of proper training

Barrier 4 Lack of adequate skills and knowledge

Barrier 5 Lack of application of the fundamental techniques

Barrier 6 Gaps in standards and approaches

Barrier 7 Fragmented nature of the industry

Barrier 8 Cultural barriers

Barrier 9 Lack of implementation understanding & concepts

Barrier 10 Resistance to change

Barrier 11 Government bureaucracy and instability

Barrier 12 Long lists of supply chain and lack of trust

7.3 Organisational Barriers to Implementing Lean Construction – Case Study Findings

The results of the questionnaire survey presented substantial variations in the different groups of respondents on issues relating to the barriers of implementing lean (refer to Section 7.2.2). It therefore, prompted the need to investigate the barriers of implementing lean construction among different respondents within the same organisation. This was carried out to determine if there will be differing views among respondents in the same organisation. This was fulfilled through a case study approach. All the case study participants interviewed were asked question on the barriers encountered during implementation (refer to Appendix 2a). The participants identified and explained several barriers as presented in Table 7.5.

Table 7.5: Organisational Barriers to Implementing Lean Construction

Barriers	Case study 1				Case study 2				
	SM1	MM1	BM1	Total	SM2	MM2	BM2	Total	Total for all respondents
Lack of top management commitment and support	1	4	4	9	2	4	3	9	18
Poor communication	1	3	3	7	1	4	3	8	15
Culture and employee attitudinal issues	2	3	4	9	2	3	3	8	17
Financial issues in terms of training cost	2	4	3	9	2	4	2	8	17
Lack of adequate lean awareness/understanding	2	3	3	8	1	4	3	8	16
Lack of adequate skills and knowledge	1	4	3	7	2	3	4	9	16
Inadequate training/lack of proper training	1	3	3	7	1	4	3	8	15
Long implementation period	2	2	2	6	2	3	1	7	13
Poor team work skills	2	2	2	6	1	3	2	6	12
Lack of customer focus and process based performance management system	2	2	4	8	2	4	3	9	17
Lack of implementation understanding and concepts	2	3	3	8	2	4	2	8	16
Resistance to change	2	3	3	8	1	4	4	9	17
Gaps in standards and approaches	2	2	3	7	2	3	2	7	14
Long lists of supply chain and lack of trust	2	1	4	7	1	3	4	8	15
Government bureaucracy and instability	2	2	2	6	2	1	2	5	11
Fragmented nature of the industry	2	4	2	8	2	3	4	9	17

SM - Senior manager, MM - Middle manager, BM - Bottom manager. Also see Table 4.9 to identify the way results are presented in this Table.

Discussions related to these aforementioned barriers (see Table 7.5) are given in the subsequent sections. An important finding from the case studies was that these barriers could be further categorised into: process, people, cost, management, technology and other related barriers based on findings from the literature. Table 6.6 presents the classification of these barriers. Barriers to the implementation of lean construction has been classified by many authors these include Olatunji (2008), Alinaitwe, (2009), Bashir *et al.,* (2010), Sarhan and Fox (2013).

Table 7.6: Classification of Barriers to Implementing Lean Construction at Organisational Level

People related barriers
1. Culture and employee attitudinal issues
2. Poor team work skills
3. Resistance to change
Management related barriers
4. Lack of management commitment and support
5. Poor communication
6. Lack of customer focus and process based performance management system
7. Long lists of supply chain and lack of trust
Technology related barriers
8. Lack of adequate skills and knowledge
9. Lack of application of fundamentals techniques
Resource related barriers
10. Inadequate training/Lack of proper training
11. Financial issues in terms of training cost
Process related barriers
12. Lack of adequate lean awareness and understanding
13. Lack of implementation understanding and concepts
14. Gaps in standards and approaches
15. Long implementation period
Other barriers
16. Government bureaucracy and instability
17. Fragmented nature of the industry

As listed in Table 7.6, the other barriers are those that cannot be attributed to the people, process, cost, management and the technology barriers. These barriers also have an impact on the implementation of lean construction and therefore, could be regarded as external barriers.

7.3.1 Lack of Top Management Commitment and Support

Eighteen out of the 20 interviewees, who were asked about their implementation barriers, identified lack of top management commitment and support as a major challenge in their lean implementation journey. Previous studies found lack of top management, leadership and commitment as a key barrier to the implementation of lean construction (Abdullah *et al*. 2009; Alinaitwe, 2009). Similarly, several management related issues have been identified by many studies and these include poor planning, lack of delegation to enhance work flow, poor understanding of customer needs, lack of a participative management style for the workforce, logistics problems, absence of look-ahead planning and poor coordination (Olatunji, 2008; Alinaitwe, 2009; Tourki, 2010). Management support is essential to the implementation of lean and sustainability. In achieving successful implementation of both concepts, the management of every organisation has a crucial role to play. Two of the respondents made the following comments:

> *'at the initial stage getting the management buy in was really difficult'- SM1*
> *'..getting the full support of the management was really a challenging task as they expect tangible benefits, however, this issue was managed'-MM2*

7.3.2 Poor Communication and Poor Team Work Skills

Fifteen out of the 20 interviewees identified poor communication as one of the barriers to implementing lean. This was further divided into poor communication among employees and poor communication between the senior management and the general workforce. Only 12 of the interviewees mentioned poor team work as one of the barriers of implementing lean. Employees are to be involved in the implementation process as the importance of involving the general workforce is often neglected by senior management. Poor communication can result in no change within the organisation as knowledge would have remained within the circle of the senior managers (Achanga, 2007). It is important to establish effective communication among the parties by means of partnering and integrated team working route (Thomas and Thomas, 2005). Effective communication channels, such as through work teams, have the possibility of increasing adaptability to corporate culture change and enhancing knowledge sharing and cooperation within the work group for performance improvement (Coyle-Shapiro, 1995; Burnes *et al.*, 2003).

7.3.3 Culture and Employee's Attitudinal Issue and Resistance to Change

Seventeen out of the 20 interviewees across the two cases identified culture and employees attitudinal issue as one of the barriers encountered during the implementation of lean in their organisation. The effect of an organisation culture has a long way to go in the implementation of lean as noted by one of the interviewees.

> *'I think a change in employees' mind-set can make them think differently and contribute to the organisation's improvement initiatives such as lean'-SM2*

To move towards sustainability, companies need employee involvement in changing corporate culture (Hanna *et al.,* 2000). The success of the adoption of environmentally responsible practices is dependent on employee involvement in cultural change because organisations are viewed as complex systems of individuals and coalitions, each having its own beliefs and culture. It is imperative to change beliefs and values assigned to the environment by all employees in an organisation. To do this, they will need to understand the need for change and to be in a position to create appropriate responses. A clear understanding of the future direction of business goals make employees commit to their organisations (Walker *et al.,* 2007). Organisational culture is a main element for promoting an innovative environment. The organisation's culture represents the process of the way things are done. Corporate culture is the core factor, but it must also fit with the structure of organisation, the management of employees, leadership style, and knowledge strategy systems (Forcadell and Guadillas, 2002). Tidd *et al.* (2001) held that since many process innovations represent major changes in "the way we do things around here", the question of managing cultural change and overcoming resistance to innovation needs to be addressed.

There is a human element in the culture of an organisation that cannot be left out and is the determinant in effective business performance and management of change. Moffet *et al*. (2002) observed that to change an organisation's culture, peoples' values, norms and attitudes must be amended so that they make the right contribution to the collective culture of the organisation. Another aspect that must be understood is that each organisation requires a different set of cultural values. If an organisation is dealing with ambiguous situations that require a variety of insights, then there is a higher need for flexibility

7.3.4 Financial Issues in Terms of Training Cost

Financial issues in terms of training cost were raised by 17 out of the 20 interviewees. Resources in financial terms are required for employee training programmes and external consultants. Another form of financial issue in terms of training cost is the financial incapacity of organisations which has been considered as one of the major barriers to the adoption and implementation of lean (Achanga, 2007).

7.3.5 Lack of Adequate Lean Awareness and Understanding, and Lack of Implementation Understanding and Concepts

Lack of adequate lean awareness and understanding was identified by 16 out of the 20 interviewees. Likewise, 16 out of the 20 interviewees identified lack of implementation understanding and concepts as one of the barriers to implementing lean. Most of the employees find it difficult to understand the lean concept across the two cases. It was probably due to the low level of awareness of the concept within the construction industry and the difficulties in understanding what is meant by lean and the lack of an agreed definition of lean (Green, 1999; Mossman, 2009; Jorgensen and Emmitt, 2008).

7.3.6 Lack of Adequate Skills and Knowledge, and Lack of Application of Fundamental Techniques

Sixteen of the interviewees identified lack of adequate skills and knowledge as one of the barriers to implementing lean. The successful implementation of the lean and sustainability concepts by an organisation depends on the level of commitment, knowledge and skill. However organisations do face significant barriers in taking the first steps towards adopting lean. Examples include understanding the underlying concepts of lean (Green, 1999). The introduction of lean thinking principles to the construction industry has been adopted from the manufacturing sector. Therefore, many lean construction principles and techniques are adapted from the manufacturing sector. There is a debate on the extent to which these tools and techniques can be applicable to construction (Green, 1999; Howell and Ballard, 1998). There is need for some of these techniques and principles to be amended (Eriksson, 2009). The use of inappropriate tools and techniques has been identified as a barrier to successful implementation of lean by many researchers in the area of lean (Bashir *et al.*, 2010; Johansen *et al.*, 2002).

It is imperative to have a full understanding of the lean manufacturing concepts in order to clearly understand the concept of LC. The two most important barriers identified are lack of knowledge and lack of expertise which reflects the inadequacy of training and education in relevant techniques. A central tenet of lean is that improvements are based on the ideas and knowledge of employees (Found and Harvey, 2006; Van Dun *et al.,* 2008).

7.3.7 Inadequate Training or Lack of Proper Training

Across the two cases, 15 interviewees identified inadequate training as one of the barriers encountered. One of the interviewees in case study 1 (SM1) noted that there is no in-house lean expert, only those that were trained by the consultants carry on with the training to get it across to the other members of the organisation. Training and communication play a crucial role in increasing employee awareness, knowledge and understanding of the adoption of environmental management systems (Zutshi and Sohal, 2004). Required training is necessary for proper implementation of lean across an organisation.

> *'… lean consultants trained us and worked with us on one of our projects, and that was all, but we call them in if need be….' SM1*

Training or team training is not successful unless reinforced by regular follow ups of an on-going systematic change in how work is conducted (Wiklund and Wiklund, 2002).
A lack of quality training causes insufficient implementation of quality methods and quality learning (Sandvik and Karrlson, 1997). Education, training and participation are factors critical in the implementation of a quality improvement process (James, 1996). Effective implementation of an improvement programme is about organisational learning and without organisational learning there can be no continuous improvement (Wiklund and Wiklund, 2002). Organisational learning is also critical in the implementation of lean; otherwise organisations focus on personal mastery rather than "team learning" and a systems view (Senge, 1990).

7.3.8 Lack of Customer-Focused and Process-based Performance Measurement Systems

Seventeen out of the 20 interviewees identified the lack of customer-focused and process-based performance measurement systems as one of the barriers of implementing lean. Performance measurement have mostly been considered in terms of quality, time, and cost and extended to health and safety within the construction industry; but limited attention has been paid to customer satisfaction (Forbes *et al*., 2002). The three triangles for measuring project performance especially the time and costs are not sufficient enough for continuous improvement. This is because they are not efficient in identifying the root cause of quality and productivity losses (Alarcon and Serpell, 1996)

7.3.9 Long Implementation Period

Thirteen out of the 20 interviewees identified the long implementation period as one of the barriers to implementing lean. Many organisations have been put off considering the implementation period of the concepts of lean and sustainability. Meanwhile, the integration of sustainability into strategic planning will also require businesses to develop a more long-term focus which helps them to examine threats and opportunities, see relationships in the external environment, and make sense of current trends (Hitchcock and Willard, 2009). Managers need to take a long term view and consider issues from a broad perspective. Lack of a long time perspective has been identified as one of barriers to implementing sustainability; the benefits that can be derived from implementing sustainability are generally realised in the long term. These benefits may not be easily seen and therefore organisations may not be interested in investing in sustainability (Sourani and Sohail, 2011). Lean implementation should not be considered as a quick process but should be viewed as a journey for continuous improvement. It requires training and the adoption of a culture of continuous improvement and developing the system to support lean implementation as well as long term thinking (Mossman, 2009; Rother, 2010).

7.3.10 Gaps in Standards and Approaches

Fourteen out of the 20 interviewees identified gaps in standard and approaches as one of the barriers to implementing lean. One of the major threats to the implementation of lean is the fact that there are no standard approaches to how a company should implement lean; this has presented a lot of challenges for organisations who intend to implement lean (Bernson, 2004). Bernson (2004) presented the challenges of a standard approach to lean as selecting the appropriate level of detail, lack of customisation at the local level, and top down implementation model.

7.3.11 Long Lists of Supply Chain and Lack of Trust

Fifteen out of the 20 interviewees identified long lists of supply chain and lack of trust as one of the barriers to implementing lean. Supply Chain Management (SCM) has been defined by Tommelein *et al*. (2003) as the practice of a group of companies and individuals working collaboratively in a network of interrelated processes structured to best satisfy customer needs while rewarding all members of the chain. SCM is characterised by achieving increased competitive advantage in the construction market. Supply chain participants such as owners, contractors, suppliers are still in search of a better understanding of supply chain, its dynamics and how they can increase their competitive advantage by applying it (Arbulu and Ballad, 2004). SCM is closely related to lean supply (Lamming, 1996).

The basic concept of SCM includes tools like Just-In-Time delivery and logistics management. The current concept of SCM is very broad but still largely dominated by logistics. The development of a lean supply chain is probably one of the most difficult, but more financially rewarding, aspects of implementing lean. Organisations need to extend the improvement efforts to the suppliers. "*Supply Chain Management is the collaborative effort of multiple channel members to design, implement, and manage seamless value-added processes to meet the real needs of the end customer. The development and integration of people and technological resources as well as the coordinated management of materials, information, and financial flows trigger successful supply chain integration*" (Fawcett and Magnam, 2001).

Collaboration and trust are important in SCM. One of the biggest obstacles obstructing collaboration as identified in other studies is the lack of trust over complete information sharing between supply chain partners (Hamilton, 1994; Stein, 1998). There are other barriers to supply chain management and these arise due to lack of technical expertise and the lack of integration capabilities of current technology across the supply chain (Schenck, 1998). The study carried out by Mollenkopf *et al.*, (2010) revealed the barriers, drivers, converging, and contradictory points across the three supply chain strategies namely green, lean, and global supply chain. Sharing of information among partners of a supply chain will not only reduce the operation costs of each of the partners, but the efficiency of this ‘trust’ based business transaction will give rise to a sense of ‘customer satisfaction’ along the value chain.

7.3.12 Fragmented Nature of the Construction Industry

Seventeen out of the twenty interviewees identified the fragmented nature of the construction industry as one of the barriers to implementing lean. The fragmented nature of the construction industry is recognised as restricting change within the industry (Myers, 2005). The UK construction industry has been characterised by a complex and fragmented structure and this is conceptualised as a barrier to effective implementation of any process improvement within the construction sector. The traditional construction process is characterised by its fragmented nature with loosely coupled actors who only take part in some of the phases of the process (Johansen *et al.*, 2002). The effect of the fragmented nature of the construction industry has been identified by many studies (Bashir *et al*., 2010; Mossman, 2009).

7.4 Summary

This chapter has presented the analysis of the barriers to the implementation of lean and sustainable construction. It also presents the organisational barriers to implementing lean. These analyses were conducted using the severity index, ranking statistical methods and content analysis of the interviews conducted.

As discussed earlier, the support of top management and leadership, culture and employees’ attitudinal issues, and resistance to change are very important to the implementation of lean in any organisation. The results of the questionnaire survey and the case study indicate that resistance to change and culture; employees’ attitudinal issue; lack of management support; lack of customer-focused and process-based performance measurement systems; lack of adequate lean awareness and understanding; and lack of implementation understanding and concepts are some of the most severe barriers to the implementation of lean. Based on the results presented in Table 7.2 and the test of null hypothesis, it was found that ‘the barriers to the implementation of lean and sustainable construction do not differ according to size of organisation’. The barriers to implementing lean based on the case studies findings were further grouped into: process, people, cost, management, technology and other related barriers, based on categorisation from existing literature.

CHAPTER 8: DEVELOPMENT AND EVALUATION OF LEAN IMPLEMENTATION ASSESSMENT FRAMEWORK

8.1 Introduction

This chapter presents the proposed framework for assessing lean construction implementation efforts within construction organisations. This accomplishes the overall aim of this research. The findings and conclusions from each objective presented in previous chapters (chapter 2, 3, 5-7) serve as basis for the development of the framework component areas and also for justification of the need for the proposed framework. This chapter also discusses the development and validation of the Lean Implementation Assessment Framework (LIMA). This chapter achieves Objectives 6 and 7 of the study.

8.2 Lean Implementation Assessment Analysis

The importance of managing tangible and intangible benefits of adopting an innovative strategy or practice such as lean in the current business environment is evidently increasing. The ability of a company to determine and measure its intangible and tangible benefits arising from lean uptake has become far more decisive.

The drive for developing an impact assessment framework for lean construction implementation is to enable construction organisations to assess the impact of implementing the concept of lean and focus on areas for improvement. Construction organisations should be able to evaluate their lean implementation efforts in terms of where they are, where they are going and where they would like to be. A thorough examination of such questions will enable an organisation to know whether the implementation of lean construction would be worthwhile.

The review of several frameworks developed in the area of lean necessitates the need for a more comprehensive framework. Most of the existing frameworks focused mainly on process design, the implementation of lean on projects and very few emphasised improving organisational learning capacity to embrace lean at the strategic level (Jorgensen *et al.*, 2007; Huovila *et al.*, 1997; Hines *et al.* 2004). The LIMA framework is therefore, proposed as a self-assessment framework. It focuses on the strategy positioning and implementation and the way both tangible and intangible benefits of the lean approach can be measured throughout the organisation.

The lean implementation assessment consists of all the perceived components of lean implementation and the expected return thereafter i.e. the drivers of lean, barriers, success factors and the benefits that can be derived from its implementation. It is expected that a company considers the positive and negative effects of implementing lean on the overall business performance. Prior to successful lean implementation and eventual derivation of any benefits, some challenges are likely to occur. Such challenges are presented as barriers in the framework. This research has therefore investigated the influence of all the identified components of the framework in detail. Figures 8.1 and 8.2 present the critical evaluation of the structure of lean construction implementation and lean construction implementation road map respectively.

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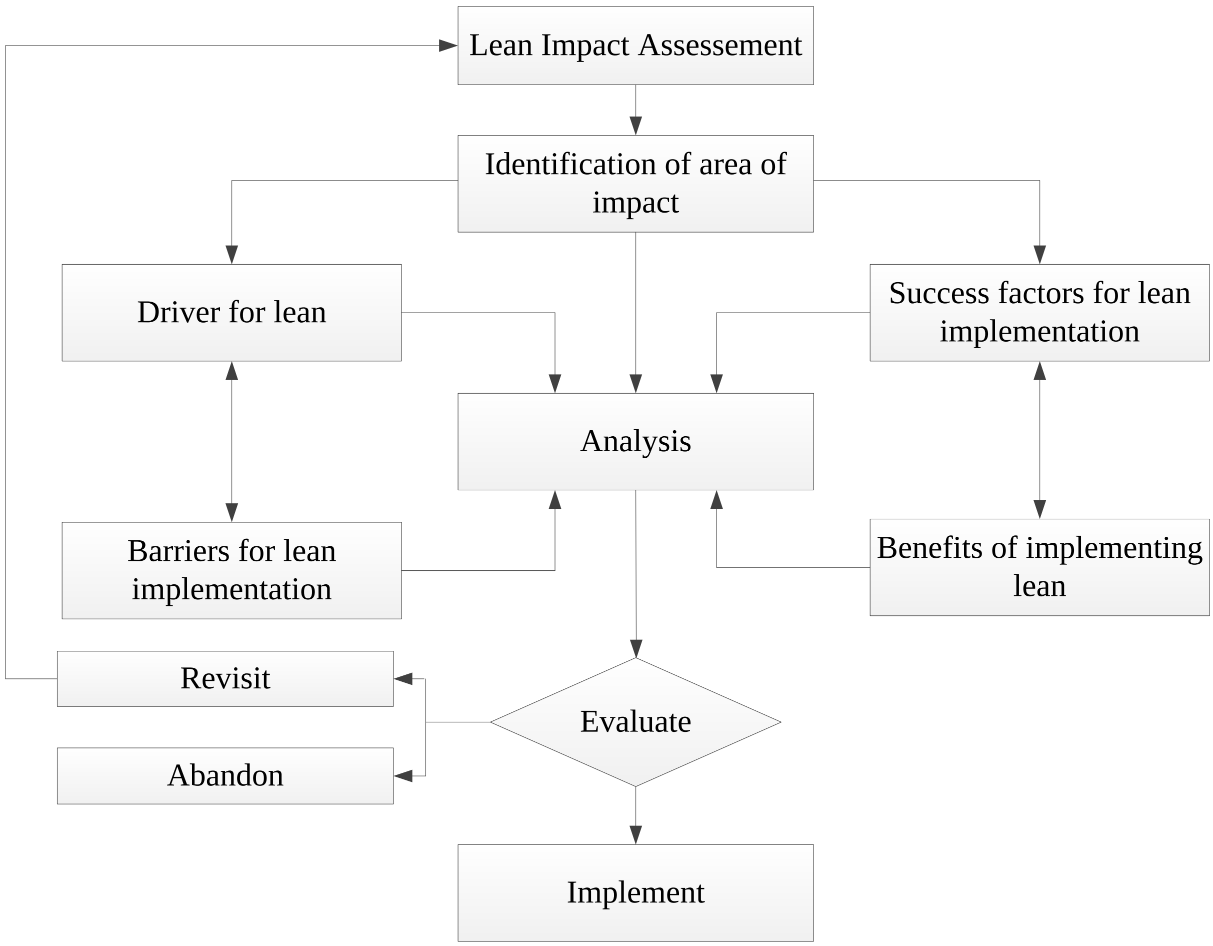

Figure 8.1: Critical evaluation of the structure of lean construction Implementation

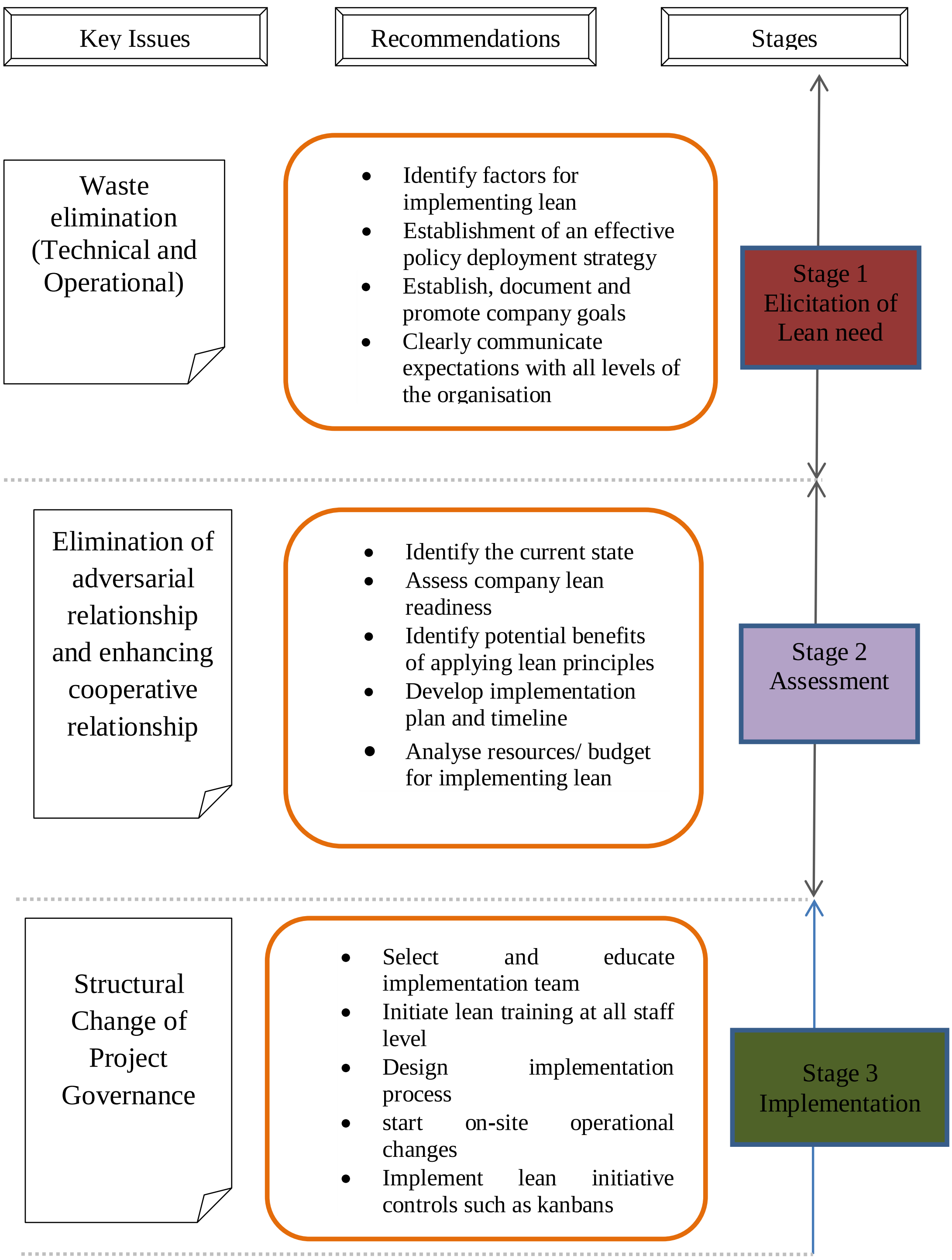

Figure 8.2: Lean Construction Implementation- Road Map

8.3 The Proposed Lean Implementation Assessmnt (LIMA) Framework

Based on the insights that have been identified through the cross-case comparison discussed in previous sections, and the findings of the questionnaire survey, the framework for assessing lean implementation efforts in construction organisations has been developed. The proposed framework is mainly focused on the implementation of the lean approach in sustainable construction. Its purpose is to allow contracting construction organisations to evaluate and analyse their lean implementation efforts and assess the benefits of lean in sustainable construction within their organisations. The lean implementation assessment framework is a reflective guide that promotes the awareness of implementation issues as well as the benefits of implementing lean. Therefore it is a means and not an end in itself.

The framework is adapted from the EFQM model (refer to Section 3.6.4 for detailed discussion) by using the nine criteria of the EFQM as given by (EFQM, 2013).
The significant issues considered in the LIMA framework as shown in Figure 8.3 are as follows:

- Policy and strategy deployment
- Leadership and direction
- People management
- Resources
- Processes
- Drivers for lean
- Success factors
- Barriers
- Business results (benefits) and organizational learning

8.3.1 Combining the Criteria of the EFQM

The criteria of the EFQM (see Section 3.6.4) are considered to be the performance factor in the framework developed. Therefore, the framework performance factors of Section 1 (policy and strategy development) have included leadership and direction, people management, process management and the drivers for lean. Section 2 (assessment criteria) included the resources and the main implementation issues to be considered i.e. barriers and success factors. In the same manner, Section 3 (implementation and application) merged ‘employee satisfaction’, ‘customer satisfaction’ and ‘impact on society' performance factors of the framework into a single performance factor of ‘business benefits’. To have a better classification among the performance factors, and in line with the adapted EFQM model, the implementation and application section is also split into the development of training programmes and application of tools and techniques.

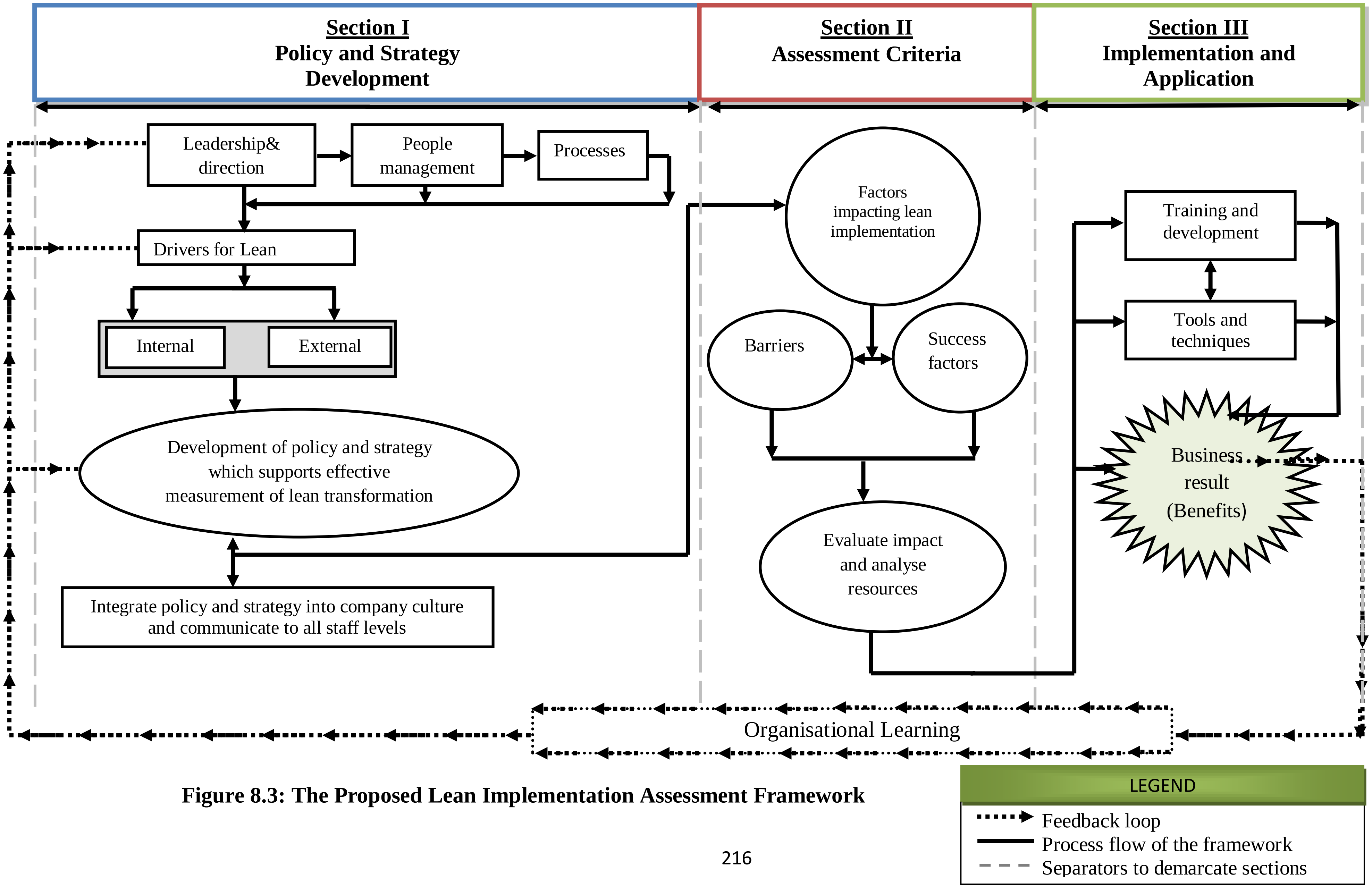

Figure 8.3: The Proposed Lean Implementation Assessment Framework

8.4 Introduction to the LIMA Framework

LIMA framework is a roadmap depicting the processes and guidelines to assess the lean implementation effort. It begins with the development of policy and strategy positioning to set up implementation goals (Section 1). Section 2 provides the lean implementation issues which the company has to assess themselves on. It then thereafter sets out Section 3: application and implementation phase which outlines the measure to track the benefits of lean approach in sustainable construction. The benefits are divided into environmental benefit, economic benefits, and the social benefits.

<table>
<tr><th colspan="2">SECTION 1: POLICY AND STRATEGY DEPLOYMENT</th></tr>
<tr><td>Setting the right policy and strategy</td><td>Leadership is central to lean implementation success. In the lean environment, leadership is about creating the strategy, the values, the sense of purpose and the goals of the organisation, then living them so that all employees are motivated by them and come to share them (Wickens, 1993). The lean implementation strategy of a company forms a critical route for determining how long lean implementation may take. Setting the right policy is very essential and this must be suited to the culture of the organisation as policy should be linked to organisation strategy.
A good policy must be:
• Well written, easily understood and clear
• has a definite purpose for its creation
• be flexible and can adapt to change
• developed through the involvement of employees and interested stakeholders
• communicated to all relevant people
Likewise, organisational strategy should be developed for agreed tactics. Communication strategy /plan, awareness raising and training plan must be developed alongside strategies and processes to ensure future compliance and improvement.</td></tr>
<tr><td>Drivers of lean</td><td>The identification of the drivers of lean is an important aspect to be considered prior to implementing lean in an organisation. Drivers in the context of this study refer to the reasons why organisations adopt lean. Diverse drivers have been attributed to</td></tr>
</table>

	the implementation of lean; these are customer requirements, increasing competitive advantage, business pressure, government policy and regulation, cost savings, operational efficiency, waste elimination, continuous and efficiency improvement. These drivers can be of internal or external drivers or the combination of both depending on the organisation. Lean implementation is a strategic driver that requires the support and commitment of the management. The identification of lean drivers in an organisation will help the organisation to sustain a lean focus.
People and process management	Successful lean implementation can be achieved when people and processes are well managed. A process is seen as a series of operations linked together to provide a result that has increased value (Jablanski, 1992). Process management is a set of concepts and practices aimed at better stewardship of business processes (Guha *et al.*, 1997).

SECTION 2: ASSESSMENT CRITERIA	
Identifying factors impacting on lean implementation	The assessment stage is the second stage of the LIMA framework which serves as a guide for companies anticipating on embarking on a lean journey. It provides the main issues in the implementation of lean construction. The main idea is that a company should be able to carry out a reflective assessment of their current state and make decision on whether the implementation of lean construction is worthwhile. The following are suggested steps in the reflective assessment: • Identify the current state • Assess company lean readiness • Identify potential barriers and success factor for lean implementation • Develop implementation plan and timeline • Analyse resources or budget for implementing lean

Success factors	Top management commitment is necessary to integrate lean into core business processes and decision making. Organisations should organise a lean transition team and formulate a vision and guiding principles while undertaking current lean impact assessment. Lean implementation areas and priority can be decided based on business strategies. The following are some of the identified success factors impacting on lean implementation: Leadership and management commitment, organisational culture, good working environment, customer focus and integration, system and process change management, effective planning, regular training of work force, integration of team and end to end supply chain, adoption of continuous improvement culture, benchmarking of suppliers against each other, communication and coordination between parties, wide adoption of lean and sustainability concepts, understanding of lean benefits on sustainability and performance review or progress towards targets. These success factors are classified as leadership and management factor, organisational cultural factor and resource and expertise factors.
Barriers	Employee educational level is essential to a company in the path of lean journey or a company wishing to implement lean construction, as lack of adequate skills and knowledge is presented as barrier to lean implementation. Cost of training staff is considered as a barrier to the implementation of lean. Ongoing training should be provided to ensure that vision and principle are embedded into practice. It is easier to train a highly educated workforce the principles of lean than the low level employees. It is essential for an organisation to have an adequate understanding of the concept and overcome cultural barriers. Resistance to change, long lists of supply chain and lack of trust, lack of fundamental techniques and the fragmented nature of industry are also some of the barriers to be considered when implementing lean construction.

Analyse company's lean readiness/resources	Considering all the factors explained above, the company's lean readiness can then be evaluated. If the barriers of implementing lean can be met or has been met by a company, then the company can go ahead and implement lean or evaluate its lean implementation effort.

SECTION 3: IMPLEMENTATION AND APPLICATION	
Implement training and development programme	The result of the assessment in the previous section would result in either remedial action or improvement action to be taken. The first step is to analyse the assessment and initiate a lean training at all staff levels, select and educate implementation team, or design implementation process as the case maybe and then start on-site operational changes, implement lean initiative controls such as 'kanbans', introduce structured problem solving tools and apply lean tools and techniques. There should be a continuous training programme to drive cultural and behavioural change and innovation.
Lean tools and techniques	Successful lean implementation also requires the integration of practices and methods. The effectiveness of the lean operating system emerges from the integrated nature of its practices and methods i.e. the tools, techniques and methods need to be implemented and tied together into a complete system as they cannot work without each other (Drew *et al.*, 2004). There are many lean tools and techniques that can be applied by organisations, these tools include value stream mapping. It should be noted that the application of only lean tools and techniques will not ensure lean success as there are a number of other issues such as people and process that could impact on the successful implementation of lean in UK construction organisations. The people and process issues appear to be a major determinant of lean success, the tools and techniques are only a small part of the whole intervention (Sinnicks, 2005).
Benefits of implementing lean	Many benefits could be derived from this section (3). The implementation of lean can yield both tangible and intangible

	benefits. Tangible benefits are those benefits that can be identified easily and are quantifiable. They are measurable outcomes from the application of lean principle, tools and techniques; hence, they can be assigned financial figures. Examples of these include increase in productivity, return on investment and reduction in lead times. The intangible benefits are those benefits such as process improvement and a motivated workforce emanating from the good lean organisational culture. These benefits of implementing lean in sustainable construction are also classified under economic, social, and the environmental benefits.

A list of self assessment questions are presented below, for companies to identify gaps in their lean implementation efforts, assess the benefits of lean in sustainable construction , and focus attention on areas for improvements.

SECTION 1: STRATEGY POSITIONING AND IMPLEMENTATION					
General approach	1	2	3	4	5
Our organisation's lean construction strategy and sustainable construction initiative address the social, economic and environmental impacts of our operations and supply chain					
Our organisation has a policy for tracking lean benefits and management					
Our organisation's holistic approach is reducing non-value-generating activities in the workplace and construction process					
Our organisation has an effective policy deployment strategy, continuously measures the effectiveness of lean transformation and ensures that the company's measure is aligned with lean thinking					
Leadership and top management support					
Our top management is in support of the organisation's lean implementation					
Our senior management is fully in support of implementing lean approach in our sustainability policy					
Our senior management is fully committed to the integration of lean and sustainability at the core of our decision making processes and project delivery					
Our employees are aware of our lean policy and some have specific roles and responsibility					
Our organisation leaders develop and communicate mission, vision, and values					
People management					
A healthy and safe working environment exist in our organisation					
People resources and capabilities are planned , managed and improved in our organisation					

Our organisation and people usually have a dialogue					
People are empowered and involved in the implementation process of lean					
Our organisation work systems and processes motivate employees					
Processes					
Processes are systematically identified and designed on our organisation					
Our organisation processes are controlled, improved and managed					
Our organisation process design is based on customer and stakeholder needs and requirements					
Business case					
Our organisation has an internal written business case and clearly defined limits for responsibility, capability and capacity for addressing lean issues					
Vision and operating principles					
Our organisation has a vision and mission statements, which set the organisation's direction in relation to lean construction					
Our organisation has a definition of lean construction for internal and external use					
Our organisation has an agreed set of operating principles/codes of conduct to support and facilitate the achievement of its long –term vision of lean					
Our organisation considers respect for people, processes and procedures efficiency as a core element of lean construction					
Organisational structures, culture and appropriate management					
Our organisation has undertaken a cultural analysis including operational practices, organisational structure and governance					
Our organisation has taken necessary action to ensure that its internal culture, structure and governance are supportive of its lean vision, policy and principles					
Our organisation adopts a continuous improvement culture					
Our organisation provides an environment of team ethos and blame-free atmosphere in its mission statement					
Change management					
Our organisation has a change management system for helping stakeholders to accept and embrace change					
Our organisation has a functioning team with the overall responsibility for change management (change agents)					
Our organisation has an effective change management process to ensure that its vision and policy are effectively communicated and organisational change is supportive of a move toward lean					
Organisational learning and training					
Our organisation leadership initiates lean education for all staff through training and communication					
Our organisation regularly undertakes a training needs analysis of its staff and other necessary business stakeholders from time to time and launches training programmes as appropriate to drive cultural change					
Our organisation makes use of training consultants for staff development and regular training of workforce					
Legal and regulatory review and management					
Our organisation has a system in place for managing and updating future legal, regulatory and contractual agreement					
Our organisation has a planned structure for assessing level of compliance and people responsible for compliance management					
Our organisation uses a system perspective in the management of business					

and pays attention to end customer issues					
Internal control and external influence					
Our organisation has internal control mechanisms for measuring and refining the effectiveness of vision, operating principles, strategy, objectives, targets and overall lean strategy					
Our organisation has a mechanism for identifying opportunities for collaboration with external bodies and organisations to create a more positive enabling environment					
Our organisation has been known for implementing lean and has won an industry recognised lean award or been noted for its lean strategy adoption in the last five years					
Operation assessment					
Our organisation promotes team integration and end to end supply chain					
Our organisation has a mechanism for wider integration of lean and sustainability concepts					
Our organisation applies lean principles and tools to business operations					
Our organisation extends the deployment of lean principles to all projects					
Monitoring and reporting					
Our organisation has attempted to assess its lean implementation effort					
Our organisation collects both quantitative and qualitative data to measure the benefits of lean on its business					
Our organisation produces assessment reports of its lean implementation journey					
Our organisation reviews performance and progress towards targets					
SECTION 2: BENEFITS OF LEAN APPROACH IN SUSTAINABLE CONSTRUCTION					
Our organisation's implementation of lean approach has resulted in the following benefits					
PART 1: ENVIRONMENTAL BENEFITS					
Improved process flow					
Improvement of environmental quality					
Reduction in material usage					
Reduction in energy consumption					
Reduction in waste					
Reduction in water usage					
Improvement in health and safety					
Compliance with sustainable construction legislation					
Design optimisation					
Continuous improvement					
Reduction in environmental pollution					
PART 2: ECONOMIC BENEFITS					
Reduced cost and lead time					
Improvement in quality					
Improved integration of trades enabling optimisation of the way resources are Deployed					
More robust processes- less variability and improved predictability leading to less deliveries to site					
Reduction in over-ordering of materials and reduced on-site transportation					
Increased productivity					
Construction project value enhancement					
Higher return on assets					

PART 3: SOCIAL BENEFITS					
Improved corporate image					
Improvement in sustainable innovation					
Increased levels of organisational commitment					
Employee autonomy					
Information transparency					
Performance improvement					
Cultural fit					
Increased organisational supply chain communication and integration					
Long term sustainability of lean efforts					
Enhanced organisation reputation					
Increased sustainable competitive advantage					
Increased employee morale, and commitment					
Client satisfaction					
Standardisation of work practices					
Enhanced organisational knowledge management					
Increased compliance with customers' expectations					

Rating scale: 1-No indication of positive initiative or outcome in this area, 2- Very little indication of positive initiative or outcome in this area, 3- Some indication of positive initiative but progress is transient, 4- Strong indication of positive initiative, 5- Very strong positive initiative and the result in this area

The interpretation of results is based on the overall mean score of each of the sections of the assessment.

POOR (mean score 1.0-2.0): Your organisation urgently needs to improve these aspects;
AVERAGE (mean score 2.0-3.0): Your organisation needs to address these issues:
GOOD (mean score 3.0-4.0): Your organisation has moderate capability and maturity and scope for improvements; and
VERY GOOD (mean score 4.0-5.0): Your organisation has high capability and maturity

Interpretation of results for Section 2 is given below:
POOR (mean score 1.0-2.0): Your organisation derives little or no benefits and urgently needs to tackle some aspects
AVERAGE (mean score 2.0-3.0): Your organisation derives low benefits and needs to address some issues
GOOD (mean score 3.0-4.0): Your organisation derives moderate benefits and there is scope for improvement
VERY GOOD (mean score 4.0-5.0): Your organisation derives high benefits from lean approach

8.5 Composition of the LIMA Framework

The LIMA framework consists of three main sections (See Figure 8.3). The first section is the ‘policy and strategy deployment’. It sets out the expected actions to achieve successful implementation targets and objectives, and accounts for action by reporting. This is then followed by the ‘assessment stage’ which presents the main issues that impact on lean construction implementation, thus allowing organisation’s awareness, and guiding in deciding whether it is worthwhile to implement lean construction. Finally, the third section is the implementation and application stage. The main focus of this stage is the implementation of lean and application of lean tools and techniques for derivation of maximum benefits. Below is the description of the three sections and their related sub sections:

8.5.1 Policy and strategy deployment (Section 1)

Policy and strategy formulation is regarded as a process which involves decisions to shape the path an organisation takes to meet its objectives (Forster and Browne, 1996). According to Zayko (2006), policy or strategy deployment is an effective management process for organisations which links improvement practices to the organisation’s business strategy on an annual basis with monthly reviews. This helps to clarify the scope and pace of improvement, as well as expected targets, to help balance and connect activities across the spectrum of the organisation.

Generally, there is no agreed and acceptable definition of strategy; a fundamental distinction can be made between the process, content and context of a strategy. These three interacting dimensions define the ‘how, who, when, what and where’ of strategy (De Wit and Meyer, 2004). It is very important for an organisation to assess the suitability of its strategies for implementation with regards to the environment. Heracleous (2000) presented the environment as one of the key elements which affect an organisation in taking action for both the development, and implementation of strategies. Also, there has to be strategy formulation before deployment but there is a tendency for the formulation and the implementation to be done separately.

Strategies are employed to ensure that the organisational purpose is realised. Therefore, the implementation of a new strategy within an organisation could lead to changes to the organisational structure for the strategy to be successful. A failure to rigorously define and deploy policy at the onset has been the root cause of every failed initiative (Jones, 2003). According to Heracleous (2000), an organisational structure can dictate the types of strategies it can support. Organisational culture is also one of the factors to consider. Resource allocation is a crucial part of strategy implementation, availability of resources in terms of staff, skills, finance, knowledge and time is essential when implementing lean. Resources represent the strengths that companies can use to assist with the conception and implementation of strategies. Hence, appropriate allocation of resources is important to the survival and success of an organisation (Barney, 1991).

Strategy implementation is the critical link between formulation of strategies and superior organisational performance (Noble and Mokwa, 1999). Communication, management support and good information system are the key factors affecting the success of strategy implementation (Al-Ghamid, 1998). A leadership style which learns from feedback, clear strategy and clear priorities, an effective top team having a general management orientation, open vertical communication, effective coordination, and down-the-line leadership are required for a successful implementation of a strategy (Beer and Eisennstat, 2000).

The importance of linking lean to business strategy has been emphasised. The introduction of lean techniques to every business activity has been suggested to be at the core of the organisation's strategy. Lean provides the opportunity and the resolve to generate and sustain profitable growth (Womack and Jones, 2003). The result of the survey carried out within this study revealed that 53% of the respondents held that lean construction is linked to their business strategy while 47% held that lean construction is not linked to their business strategy.

8.5.1.1 Leadership and Direction

Leadership and top management support and commitment are crucial to the implementation of lean in any organisation. Companies should utilise strong leadership capability to exhibit successful implementation. It is very important to stress the distinction between leadership and management as mentioned by Kotter (1990). Leaders foster change and create an environment where change is the norm, whereas managers stabilise the organisation and assure that the changes are well implemented. Almeida and Salazar (2011) argued that successful implementation is not definite even though the implementation process needs the support of top management (in terms of both financial and human resources). Therefore the implementation of lean should first focus on activities which are important and visible (Womack and Jones 2003). This will motivate people and lead to high levels of engagement within the organisation's staff, which is a key requirement for the success of Lean (Coffey, 2000). Management and leaders behaviour are necessary to achieve excellence and different approaches may be needed at different times, depending upon the specific stage of the lean transformation process. Leaders should create a crisis in order to force the organisation to adopt lean thinking and that should be part of the strategy (Womack and Jones, 2003).

The overall leadership issues regarding business case for a lean implementation include the definition of the business objective, documentation of the expected benefits, overcoming resistance to change, establishment of the future benefits of lean implementation, creation of a vision of how the lean implementation will improve the performance of the organisation and maintaining focus and participation of all team members and leadership engagement (Donovan, 2005).

8.5.1.2 Drivers of Lean and Change Management

The drivers of lean need to be identified at the initial stage. This then leads to pressure to change to lean. The reasons could be internal or external pressures driving the change. For a successful change to occur, the organisation and the people who work in that organisation must be ready for the transformation. A robust change management strategy is needed for successful lean implementation (Parks, 2002). Changes required in lean organisation include changes in process, changes in function, coordination and control, changes in values and human behaviour and changes in power within the organisation (Stewart, 2001; Motwani, 2003). Failure to assess organisational and individual changes may result in significant lost of time, energy and hard work.

Within the context of this research, the case study analysis revealed that the drivers for lean implementation can be classified as internal and external drivers. The internal drivers are those internal reasons why organisations adopt lean while the external drivers are those external reasons why organisations adopt lean.

8.5.1.3 Readiness for Change and People Management

Many studies have considered people management as crucial to ensure successful implementation (Candido and Morris, 2001). Howardell (2004) stated that a lean organisation requires a lean people, i.e. lean people make a lean organisation, and these people have to become lean before the organisation can get lean. Therefore, the mindset and behaviour of people within a lean organisation are fundamental for success. Lack of effective management of people within an organisation may cause disruption to the implementation process (Smeds, 1994). Lean is much more than a combination of tools, methods and principles. Lean readiness and people management can be addressed by identifying and understanding the need for change, having clear and consistent leadership and direction, and creating a strong change agent team. It is important that those who lead the change projects should have the skills, competencies and aptitude to implement lean.

The implementation of change must be aligned with the operational issues, so that people in the organisation can understand how they will be affected and what must be done to address the challenges in the organisation (Oakland and Tanner, 2007). Management should make sure that there is a strategy of change whereby the organisation understands and adapt the changes and communicates how the goals will be achieved. To become lean requires cultural change, radical change in structure, strategy and technical aspect of an organisation (Smeds, 1994).

8.5.1.4 Processes

Process change mainly begins with strategic initiatives which are often included in the corporate strategic plan by the senior management team (Kotter, 1995). Processes that require almost no inventory should be designed. A lean process can be regarded as a perfect process: perfectly satisfying the customer's desire for value with zero waste (Womack, 2005). Lean represents a unique culture that grows and improves with time. For the transformation towards a lean system, people should have a better understanding of lean and also need to be aware of the change management principles. For successful organisational change towards lean organisation, the critical factors are strong leadership, capable team, and effective communication.

The process improvement is usually prior to implementation plan and it is also a continuous process to carry out in order to review and make improvements where necessary. This allows for reflection of the current state (what do we do now?) and how can it be improved, and the future state -what do we want it to look like? (Morrey *et al.*, 2013).

8.5.2 Assessment Criteria (Section 2)

The second section of the LIMA framework is the 'assessment stage'. This provides a guide in assessing and identifying current capabilities within an organisation and helps prioritise improvement activities, which must be done to achieve implementation goals and targets.

8.5.2.1 Resources and Factors Impacting on Lean Implementation

Top management's job is to lead a policy deployment process, to prioritise the resources to implement the value stream plans, and to align the plans with the overall needs of the organisation. There is a need for organisations to evaluate and manage the barriers and success factors to implementing lean. It is also essential for organisation to analyse resources effectively in order to carry out effective business performance as stated in its mission and strategic planning. The implementation of lean in organisations, like any other productivity improvement initiative, is believed to face enormous difficulties. These barriers and success factors need to be assessed and evaluated.

8.5.2.2 Barriers

Organisational culture and employee attitude can facilitate or inhibit the implementation of lean. Open communication and information sharing can promote a common culture and innovative behaviour in the organisation (Guha *et al.,* 1997). Top management commitment and support is an important prerequisite for implementing lean in organisation. Therefore, lack of top management support and commitment is a major barrier in lean implementation. Other barriers identified in this study are poor team work skills, resistance to change, lack of management commitment and support, poor communication, lack of customer focus and process based performance management system, long lists of supply chain and lack of trust, lack of adequate skills and knowledge, lack of application of fundamentals techniques, inadequate training, lack of proper training, financial issues in terms of training cost, lack of adequate lean awareness and understanding, lack of implementation understanding and concepts, gaps in standards and approaches, long implementation period, government bureaucracy and instability, and fragmented nature of the industry. These barriers were classified into process, people, resource, management, technology and other related barriers.

8.5.2.3 Success Factors

The identified success factors in implementing lean are classified under leadership and management factors, organisational cultural factors and resource and expertise factors which cover the broad area of lean i.e. the people issues and the process issues. Everyone in the organisation needs to understand the success factors for lean implementation if the organisation is going to realise sustainable benefits. Once the success factors are understood and in place, then implementation becomes easy. The success factors identified in this study based on the questionnaire survey and the case study findings are Leadership and management commitment, organisational culture, good working environment, customer focus and integration, system and process change management, effective planning, regular training of work force, integration of team and end to end supply chain, adoption of continuous improvement culture, benchmarking of suppliers against each other, communication and coordination between parties, wide adoption of lean and sustainability concepts, understanding of lean benefits in sustainability and performance review and progress towards targets.

8.5.3 Implementation and Application (Section 3)

The implementation and application stage involves the development of training programmes and the application of lean tools and techniques. Once clear on readiness for change, the next step the organisation should take is to implement the lean tools and techniques or processes. Since lean construction is known as application of tools and techniques, these tools and techniques cannot be adopted in isolation. All the techniques in lean construction are developed to support the implementation of lean principles and overall organisational strategy.

8.5.3.1 Tools and Techniques

The key to sustainable lean performance is having the right practices (tools and techniques) in place (Vanghan-Jones, 2003). Likewise, Kaufman Global (2003) submit that an organisation that limits the amount of tools also limits the organisation’s ability to solve problems and improve processes as quickly as those organisations with a larger tool inventory from which all employees can draw on. There are many tools and techniques that can be applied within an organisation. They include value stream mapping, continuous improvement, total quality management, visualisation tools, 5S, Just in time, fail safe for quality, ‘kanban’, pull approach, value analysis and the total preventive maintenance. The use of some of these tools and techniques has been noted for enabling sustainability (see Section 5.2.5). The application of tools and techniques can be done once the organisation has established a stable process. Continuous improvement tools can be used to determine the root cause of inefficiencies whereby an effective countermeasure can be applied (Liker, 2004).

The introduction of lean techniques to any business activity should be the core of any organisation’s strategy as lean provides both the opportunity and the resolve to generate and sustain profitability growth. Donovan (2005) stated that the consequences of not adopting lean as a business strategy are so costly, so lean should become a high priority strategic objective.

8.5.3.2 Business Results

The benefits of implementing lean are considered as the business result which can be in various forms. These benefits could be in terms of customer satisfaction, employee satisfaction and the impact on the society.

8.5.3.2.1 Customer Satisfaction

Customer satisfaction is an emergent concern to many leading companies. Many companies use the satisfaction ratings as an indicator of product and services performance (Matzler and Hinterhuber, 1999). Customer satisfaction is the ultimate objective of every business and it is becoming more important. Consequently, companies need to embrace measures that facilitate balancing external pressures, i.e. customer satisfaction (Bhasin, 2008). Companies with a high level of customer satisfaction will increase their market share by a larger degree than those with lower satisfaction.

Womack (2005) stated that the concept of customer is central to lean thinking; lean always starts with the customer who wants value i.e. the right good or service at the right time, place, and price with perfect quality. A main principle is to consider all downstream operations as customers, while value is defined only as perceived by the final or end customer (often referred to as the "ultimate customer"). This involves some important implications when applying lean to construction, where "end customers" are multiple and the construction client rarely can be considered the single ultimate customer.

8.5.3.2.2 Impact on Society

Companies are under increasing pressure to do business in a responsible manner and not just to deliver profit improvement, taking into consideration the impact of their activities on society and the environment. Improved environmental performance and ethical considerations are becoming normal for business making processes (Simons and Mason, 2003). Therefore, it is essential for organisations to assess the effect of their businesses on the environment as well as track the social benefits of adopting the lean approach.

8.5.3.2.3 Employee Satisfaction

It is important to monitor the level of satisfaction of employees when a company is undergoing a lean transformation process. This is because employees most times have a wrong perception of lean as a job cutting exercise. Such employees may have the fear that lean will displace them from their job positions within the company and are therefore discouraged. It is important to understand employees' feelings and attitudes when implementing a new initiative such as lean. Employees might feel marginalised and unappreciated if not carried along in the implementation process (Womack and Jones, 2003).

The result from the case study carried out revealed that employees in the organisations are somewhat reluctant to receive the concept of lean. Some of the reasons given are lack of adequate lean awareness and understanding, lack of adequate skills and knowledge, lack of implementation understanding and concepts. All these reasons are related to the identified barriers of lean implementation. It was further revealed that the level of satisfaction of the employees increased following proper training which aids in the awareness and implementation understanding of the concept.

In implementing any improvement initiatives the level of satisfaction of employees need to be assessed. The results of the survey carried out within this study showed that 66% of the respondents were satisfied with the implementation of lean, 25% were indecisive, while 9% were dissatisfied.

8.5.4 Organisational Learning

Organisational learning takes place within all sections of the lean implementation framework. The use of the lean implementation assessment framework will enable organisations to improve their actions through feedback from lean implementation, better knowledge, and understanding of lean concepts (see Section 3.4).

8.6 Validation and Refinement of the Framework

The validation of the proposed framework was achieved through experts' feedback on various issues relating to the framework. Twelve (12) semi-structured expert interviews were conducted to validate the framework. The framework was assessed in terms of general comprehensiveness, usefulness, clarity, level of coverage of features of the framework as well as practical and possible adoption of the framework. Many practitioners complemented the semi-structured interviews by providing deeper insights as to how the framework differs from other implementation assessment frameworks.

8.6.1 Validation Approach

Validation has been described by many authors in similar manner. This includes the broad classification of validation into the internal validity and external validity as described in sub-section 4.6.2.7. Validation can be carried out using quantitative method or qualitative method. According to Smith (1983), complex and non-quantitative models can be validated using a qualitative approach through interviews and survey techniques while highlighting the pros and cons of the model in the validation process. Bock (2001) defined the validation phase of the scientific method as to decide whether the objectives of the research task had been achieved, and discussed peer reviews as a possible method for validation. This affirms that peer review is an acceptable technique of validation. The validation approach is achieved by seeking experts' opinion and feedback. This was conducted through semi-structured questions that reflect all the aspects of the framework and seeks the insights of experts in the field.

The collection of experts' feedback data in this research provides the basis for the internal and external validity of the developed framework. The experts included those that participated in either the survey or case study in the development of the framework, and experts external to the development of the framework. The aim was to see if there is a significance difference between the views of those that have participated in the study and those that did not participate in the study. The feedback from the experts who participated in the study served the purpose of establishing the internal validity.

Agreement of research findings with published works is another way of establishing internal validity, as described by De Vaus (2014). Some researchers have also demonstrated internal validity by establishing convergence between research findings, published research, and academic validation (for example Ankrah 2007 and Xiao 2002). The findings of this study have been validated through seminar presentations, academic conferences, and journal publications which are peer reviewed. The peer reviews provided opportunities for the methodologies and findings of the research to be critiqued and scrutinised by experts and independent judges in the field of construction. The academic forums also serve as means to receive valuable feedback and comments which were integrated into the research to improve its coverage and validity. As part of this research, some papers have been published and presented in reputable journals and international conferences (refer to Appendix 4).

As suggested by Rosnow and Rosenthal (1999), Validity is generally an indicator of how good an answer provided by research is for a given problem; that is, whether the instruments or measurements measure what they are supposed (or claim) to measure. Therefore, in order to establish the internal consistency, the respondents were asked to state their general perception of the developed framework. The benefit of gathering data from experts external to the development of the framework was to evaluate the external validity of the research, which relates to its possible generalisation beyond the research sample (Gill and Johnson, 2002).

8.6.1.1 The Validation of the Developed Framework

In order to obtain the feedback from experts, the validation question was sent to the experts. The experts chosen comprised both academics and practitioners. The number of academics chosen was 4 with involvement of 8 practitioners. Altogether, 12 practitioners were chosen for the validation of the framework (the criteria for selecting the experts are given in Section 4.8.3. This allowed for a useful feedback in incorporating a sound theoretical base to the initial developed framework. The developed framework was sent out to the interviewees before the interviews. The interview questions were conducted using a semi structured open and closed ended questions (see Appendix 3) which covered the following aspects:

- Level of coverage of main issues represented in the framework
- Level of coverage of each sections of the framework
- The easy of understanding, logic, or flow of the framework
- Overall usefulness of the framework in terms of applicability
- Comment on areas considered to be deleted/included/improved

Table 8.1 presents the result of the framework validation. Generally, the validation of the framework presented an overall positive feedback. The experts interviewed gave positive comments on the overall framework and its components, as well as its applicability to construction contracting organisations. The framework was classified as being a product of cutting-edge research with clear and comprehensive underlying relations. Additionally, the developed framework was seen to be compatible with present performance improvement techniques such as TQM, Six Sigma and sustainable construction.

The interviewees agreed that the framework has a high level of coverage of issues relating to the implementation of lean construction in sustainable construction. In reviewing how the resulting frameworks can assess the implementation efforts of lean, it was understood that it adopted the excellence models criteria. Overall the interviewees confirmed that the framework presented a useful tool for raising the awareness and understanding of lean implementation issues, benefits of lean in sustainable construction and assessing lean construction implementation efforts within construction organisation. Some of the comments of the interviewees are given below:

"*The framework emphasises issues that are relevant to lean implementation*" - P1

"*The framework is well structured with a very good logic, undoubtedly this strength can be seen*"- P5

The framework emphasises implementation factors that are relevant to lean construction, such as success factors, barriers and drivers. A business coordinator manager, one of the participant stated "*I think the framework is very easy to understand and it makes explicit what managers need to look at*". However, the participants commented that there can be great improvement in the aspects of policy and strategy positioning. This was described to be rather confusing in relation to strategic management.

Table 8.1: Framework Validation Results

Participants category	Codes given to participants	Area of experts	Level of coverage					Usefulness
			Content	Logic	Policy	Assessment	Application	
Academics	A1	Lean construction	4	3	3	4	2	Yes
	A2	Construction management	3	3	3	3	3	Yes
	A3	Lean project management	3	4	2	3	3	Yes
	A4	Construction management	4	3	4	4	3	Yes
Mean score			3.50	3.25	3.00	3.50	2.75	
Practitioners (Participants involved in the study)	P1	Head of project planning	4	3	3	2	3	Yes
	P2	Business/Project coordinator	3	3	3	3	3	Yes
	P3	Senior contract manager	3	3	2	3	2	Yes
	P4	Site manager	4	4	3	4	1	Yes
Mean score			3.50	3.25	2.75	3.00	2.25	
Practitioners (non-participants)	P5	Contract manager	4	4	3	2	3	Yes
	P6	Sustainability manager	3	3	2	3	2	Yes
	P7	Environmental manager	3	4	3	4	3	Yes
	P8	Senior project coordinator	3	3	1	3	3	Yes
Mean score			3.25	3.50	2.25	3.00	2.75	
Mean score / overall result			3.42	3.33	2.67	3.17	2.58	Yes

Meaning of scale (level of coverage): 4 (Very high), 3 (High), 2 (Low), 1 (Very low)

Statistical methods were employed between the academics and practitioners (i.e. all the 12 participants). Kruskal Wallis test was used. As shown in Table 8.2, all the p-values are greater than 0.05, which indicates that there is no statistically significant difference between the academics and practitioners (non-participants and participants). In differentiating the feedback from participants involved in the study and non-participants, Mann-Whitney test was used to examine if there is statistically significant difference among participating and non-participating experts. As shown in Table 8.3, all the p-values are greater than 0.05, indicating that there is no statistical significant difference between the two groups.

Since no statistical difference was found among all the twelve (12) participants of the framework evaluation result, it is assumed that their feedback is homogeneous and there is consistency in the result. Therefore the full set of experts was used to validate the framework. This result strengthens the external validity of the framework as described in Gill and Johnson (2002).

The feedback on the usefulness of the proposed framework was very positive. Some of the respondents described the framework as very interesting and expressed their willingness to recommend it for a potential company interested in implementing lean. One of the experts commented on the framework's EFQM adaption: '*definitely you have given a thought and consideration into the areas and issues to be considered as well as the measurement of assessment of lean benefits in sustainable construction, and seem to have presented a good approach to the whole process in general*'.

Table 8.2: Kruskal Wallis Test for Differences between the Framework Validation Participants

	content	Logic	Policy	assessment	Application
Chi-Square	.629	.688	1.509	1.238	1.042
Df	2	2	2	2	2
Asymp. Sig.	.730	.709	.470	.539	.594

a. Kruskal Wallis Test

b. Grouping Variable: Validation Participants

Table 8.3: Mann-Whitney Test for Differences between Participants and Non-Participants in the Study

	Content	Logic	Policy	Assessment	application
Mann-Whitney U	6.000	6.000	5.500	8.000	5.500
Wilcoxon W	16.000	16.000	15.500	18.000	15.500
Z	-.683	-.683	-.833	.000	-.833
Asymp. Sig. (2-tailed)	.495	.495	.405	1.000	.405

a. Grouping Variable: Participants and Non-Participants

8.7 Summary

This chapter presented a framework for assessing lean construction implementation efforts as well as the benefits of lean in sustainable construction. The proposed framework comprised three main sections addressing the (1) policy and strategy deployment, (2) assessment criteria and (3) implementation and application.

The developed framework provides checklists of the action required for practical implementation of lean construction at an organisational level. The framework is particularly useful for the management of organisations to take pre-emptive steps necessary to ensure the successful implementation of lean construction. It could also serve as a basis for remedial action to be taken as the case may be. The developed framework adopted the EFQM excellence model.

CHAPTER 9: CONCLUSIONS, RECOMMENDATIONS AND FURTHER WORK

9.1 Introduction

This chapter presents the main research findings in relation to the aim and objectives of the study, the research process, and area for further study. It also presents the conclusions and recommendations arising from the research findings.

9.2 Research Process

The concept of lean has been adopted by many organisations with significant benefits achieved. This has been reported by several authors and researchers in the field of lean. However, many of these studies investigated the application of lean principle on projects and few investigated the concept of lean and sustainability with a view of integrating both concepts on projects.

Therefore, the aim of this research was to examine the impact of lean construction in sustainable construction. The specific objectives set in achieving this aim are given below:

1) Review the concept of lean and its application to sustainable construction
2) Critically explore and synthesise the linkage between lean construction and sustainability in the existing literature
3) Identify and prioritise the barriers and success factors for the implementation of lean construction and sustainability
4) Determine the core drivers of lean construction
5) Critically evaluate existing models and frameworks associated with the adoption, implementation, and monitoring of lean construction.
6) Develop a conceptual framework to assesses the implementation effort of lean approach in sustainable construction
7) Test and validate the developed framework with domain experts

The research was carried out as described in Chapter 4 in order to fulfil the aforementioned aim and objectives and a four-stage approach was adopted. The review of literature was undertaken during the first stage of the study. The literature reviewed was in the area of lean and sustainable construction. This stage reviewed the concept of lean and its application to sustainable construction (Objective 1), explored and synthesised the linkage between lean construction and sustainability (Objective 2) and evaluated existing models/frameworks associated with the adoption, implementation, and monitoring of lean construction (Objective 5).

The second stage of the study employed a quantitative approach involving the use of a questionnaire survey administered to construction professionals representing their organisations. The third stage employed a qualitative case study approach involving twenty (20) semi-structured interviews with key participants within two contracting organisations. Stage two and three identified and prioritised the barriers and success factors for the implementation of lean construction and sustainability and determined the core drivers of lean construction (Objectives 3 and 4).

The fourth and the final stage of the study focused on the development of the Lean Implementation Assessment Framework (LIMA) for assessing the implementation efforts of lean and the benefits of lean in sustainable construction (Objective 6 and 7). The framework was refined and validated using structured interviews with four (4) academics and eight (8) practitioners.

9.3 Conclusions of the Study

The main accomplishment of the research is the development of a conceptual framework for assessing the implementation effort of lean and its benefits in construction contracting organisations, while linking it to the strategic management process of the organisation. The various methodologies for measuring organisational performance and various performance and process improvement techniques and lean frameworks were reviewed. This was carried out to establish the need for a more robust lean implementation assessment framework that is capable of assessing the implementation efforts of organisations and the benefits of lean in sustainable construction as well as adapting a suitable framework approach. The main conclusions drawn from the research study are presented in the following sections.

9.3.1 The Concept of Lean and Sustainable Construction Trends in the Wider Construction Industry

The study reveals the trend in the construction industry as to how sustainable construction and lean concepts have been implemented and the issues relating to their adoption. There is a general perception of the understanding of the lean concept and sustainable construction within the literature and among the construction professionals. As revealed during the case study interviews carried out as part of this research, there are many definitions of lean given by the interviewees. Many viewed lean as tools and techniques, a philosophy, and management practices while few viewed it as the combination of all as well a process improvement technique that is capable of moving their organisations forward. The principle of lean and sustainable construction can be implemented at various levels i.e. the operational level and the strategic level. It was found that less attention had been paid to the implementation of lean at the strategic level. This was probably due to the lack of understanding of the priorities of lean due to the dynamic, complex, and fragmented nature of the construction industry. This calls for a clear focus, and a resolution of the differing priorities of lean construction. The absence of a clearly defined priority of lean construction might impact a number of consequences for potential lean implementers, organisations, as well as researchers trying to explore the essence of the concept. The understanding of lean construction priorities among all stakeholders in the construction industry is very essential in order to derive maximum benefit from lean construction implementation.

1) The survey result and the interview conducted revealed that the construction industry is receptive to integrating lean and sustainability and there has been significant progress in the area. Awareness of the challenges and issues facing the construction organisation is greater than it has ever been. Some of the respondents commented that the implementation of lean and sustainability is essential for organisations if businesses are to remain competitive. The establishment of the Egan Report was seen as significant in promoting lean and sustainability initiatives. It was generally accepted that synchronising lean and sustainability will be beneficial to organisations and the society at large.
2) The increase in regulations pertaining to sustainable construction gives a wider consideration for businesses with less chance of avoiding sustainability and promotes lean construction. It was found that several organisations desire to

make progress on integrating lean and sustainability, but many organisations lack the knowledge or tools to move forward.

3) There is generally a low rate of adoption of the lean and sustainability principle among the small firms within the construction industry. Even most of the larger firms are yet to fully implement the concepts of lean and sustainability as evident in the low use of the tools and techniques and principles of lean for enabling sustainability.

9.3.2 Frameworks Associated with Managing, Monitoring and Implementation/Process Performance Measures

Different approaches to evaluating and assessing an organisation's performances were reviewed and evaluated. Also the common approaches in-use for developing frameworks in organisations was reviewed. The review revealed the need for a more comprehensive performance measurement framework for construction organisations. The use of appropriate performance measures and their contributions to the application of lean construction concepts is very important. The most common techniques used by UK construction organisations for performance measurement were identified. The EFQM, QFD, BSC are the commonly used performance measurement frameworks by many organisations in the UK. The descriptions of various process improvement methodologies such as the TQM, Lean, and Six Sigma are given. Some of these process methodologies share common characteristics of employee involvement and empowerment focus on work process to facilitate continuous improvement.

9.3.3 Main Barriers to Lean and Sustainability

1) A large percentage of the survey respondents' claimed that the industry remains resistant to change and is particularly reluctant to embrace lean and sustainability initiatives. Cultural barriers, lack of implementation understanding and concepts along with fragmented nature of industry were significant barriers to taking the first steps to towards lean and sustainability. Successful implementation of both concepts can be attained when the holistic principle of lean and sustainability are understood and integrated into strategic planning of the organisation's business. Other barriers included lack of management commitment, long implementation period, lack of proper training, lack of adequate skills and knowledge, lack of application of fundamental techniques,

gaps in standards and approaches, government bureaucracy and instability, long lists of supply chain, and lack of trust. These barriers were further categorised under people, process, and technology related issues in order to suggest how to overcome them.

2) Surprisingly, the key barriers to lean and sustainability were related to attitude. Resistance to change and cultural barriers were identified as one of the most significant barriers. The influence of an organisation's culture on its ability to change is essential for successful implementation of lean and sustainability. The attitude of employees and customers can encourage the implementation of lean and sustainability and companies also need employee involvement in changing corporate culture. Most of the interviewees submitted that organisational culture is a key element for promoting innovative initiates such as lean.
3) Some of the ways to overcome the identified barriers lie in the future development of strategies to finding a solution. This will require strong management support, including proper training and changing perception of employees attitude. Addressing these barriers will demand a significant and sustained investment in education and training alongside increased awareness. The suggested method of overcoming the knowledge barriers is through the use of external experts.

9.3.4 Success Factors and Drivers to Lean and Sustainability

1) Many of the respondents suggested that effective planning, regular training of the workforce, adoption of a continuous improvement culture, communication and coordination between parties, understanding of lean benefits on sustainability and review of performance and progress towards targets are the main success factors for the implementation of lean and sustainability. Other factors include good working environment, management commitment, customer focus and integration, system and process change management, integration of team and end to end supply chain, and benchmarking of suppliers against each other.
2) The success factors to the implementation of lean as further investigated were classified into three broad categories: leadership and management factors, cultural factors and the resource and skill and expertise factors.
3) Diverse drivers have been attributed to the implementation of lean. These are top level support, respect for people, attention to process and people and continuous

improvement, legislation, customer requirements, broad level support, reputation and brand integrity, regulators, shareholders or investors' expectations, increasing competitive advantage, business pressure, government policy and regulation, new client procurement policies, environmental concerns, long term survival of business, improved corporate image, cost savings/operational efficiency, enhanced relations with suppliers, peer pressure within the industry and increased realisation of the importance of construction image, waste elimination, continuous and efficiency improvement and value to customer. These drivers were further divided into internal drivers and external drivers.

4) Government policy and regulation, continuous improvement and increasing competitive advantage were seen as being strong drivers. Most of the organisations included in this study are in agreement with the identified drivers.

9.3.5 Linkages between Lean and Sustainability

1) There are several identified areas of linkage between lean and sustainability. These areas included 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, and cost reduction. Lean and sustainability share the same goal of waste elimination but with different approaches.
2) Several lean tools and techniques for enabling sustainability were ranked based on the frequency of use. The most commonly used lean techniques for enabling sustainability are just-in-time, visualisation tool, value analysis, daily huddle meetings, and value stream mapping.
3) The implementation of lean concepts and tools result in improvements in the environmental performance of organisations even when lean activities are not initiated for environmental reasons. However, the implementation of lean concepts and tools do not only result in environmental benefits such as performance improvement but also in economic and social benefits for the organisation.

9.4 Benefits and Impacts of Lean and Sustainability

1) The positive impact/benefits of lean and sustainability reported by organisations include waste reduction, improved corporate image, sustainable competitive advantage, improved process flow and productivity, increased compliance with customer's expectations, reduction in cost of environmental management, and improved environmental performance. Waste elimination, customer focus, employee empowerment, sharing of knowledge, reducing risks, and continuous improvement are the main principles on which lean and sustainability are built.
2) The adoption of lean and sustainability by any organisation is dependent on the awareness of the concept and the potential benefits that can be derived from implementing the concepts. The benefits of lean and sustainability are categorised under the social, economic and environmental benefits.
3) For an organisation to reap the full benefits, of lean there has to be proper implementation; not just implementing one or two elements of lean. It is also essential for the organisation to imbibe a right culture and this culture must exist among the organisation's employees. Effective communication and management commitment is also necessary.

9.5 Contributions of the LIMA Framework to Industry

The research developed a comprehensive framework for addressing the implementation issues of lean in sustainable construction. This framework serves as a non – prescriptive guide for implementing lean in organisational business strategy. The lean implementation framework is based on the nine criteria of EFQM, where guiding instructions are given to develop indicators in each, and causal linkages between them, as regarding the organisational and business strategy. The idea is that criteria and issues in the strategy deployment and positioning affect the organisation's internal business processes, which in turn affect those assessment criteria, and finally affects the application and implementation. Lean implementation assessment consists of the enabling and results criteria. Enabling criteria refers to the sub-criteria rated to provide an overall score for each performance criterion. Results criteria are expressed via classification into the social, economic and the environmental benefits of implementing lean. Furthermore, the criterion weights were calculated based on the score assigned and formed the basis for computing an organisational overall implementation effort and benefits derived.

Based on the validation of the framework, the main benefits of the framework can be presented in the following points.

1) It clarifies the role and functions of the management and leadership in the implementation process.
2) It identifies the main implementation issues in lean as well as any other process improvement methodologies.
3) It provides a knowledge base for companies intending to implement lean
4) It allows organisations to evaluate the strengths and weakness of their lean implementation efforts
5) It is adapted to suite construction contracting firms, and this makes its applicability more useful and easier to implement.
6) The underlying logic is easier to understand and more user-friendly. The framework adapted the EFQM excellence model component which is more comprehensive and has a wider coverage of performance criteria than other models or frameworks.
7) It serves as a good tool for aiding decision making process of lean uptake.
8) It reflects how an organisation is doing in terms of lean implementation efforts and identifies the benefits which are classified under social, economic and environmental aspects.
9) It allows organisations to manage, measure, and evaluate resources prior to implementing lean
10) The challenges of lean implementation abandonment by companies can be overcome with the adoption of this framework. This is because the framework has presented the issues relating to implementation in detail. It has to be noted that for an organisation to reap the full benefits of lean there has to be proper implementation. It is also essential for the organisation to imbibe a right culture and this culture must exist among the organisation's employees because it is critical to successful lean implementation.
11) It enables construction organisations to know the needed improvement efforts to be made and where efforts should be focused.

The developed framework is explicit and can be well understood by all levels of managers and staff in an organisation. It offers guiding information as to how lean implementation can begin by providing a valuable insight into the practice of lean. The framework serves as a platform which can enable construction companies identify gaps in their implementation efforts, focus attention on areas for improvements and assess the benefits of the lean approach in sustainable construction.

9.6 Limitations of the LIMA Framework

However, the framework does not pretend to address all the issues of implementation. The limitations of the developed framework can be summarised as follows.

1) The framework serves as a tool that clarifies implementation issues to be considered, but does not guarantee success of the organisation. For example, management of an organisation has to adopt the right strategy and imbibe a right culture. This culture must exist among the organisation’s employees as this is critical to successful lean implementation.
2) The framework does not allow organisations to benchmark against another.
3) Another limitation of the framework is that it does not provide a quantitative measure of the benefits that can be derived.

9.7 Recommendations and Future Work

9.7.1 Recommendations for Organisations

Having considered the overall findings of the research, some recommendations for construction organisations are presented as follows. This is to improve the implementation of the lean approach in sustainable construction.

1) Lean is a continuous journey that needs to start strong. For any organisation to achieve lean there is the need to go beyond traditional processes and redesign future processes majorly in the aspect of supply chain.
2) There needs to be some standardisation of business measures so that organisations can more effectively measure performance and progress towards a more sustainable approach through the adoption of lean principles.
3) There should be standardisation of sustainability and lean principles within businesses. This is important for proper integration of both concepts; at present organisations struggle to integrate the two concepts. Many organisations may require assistance to do this.

4) There has to be an adequate level of commitment, knowledge and skills within organisations including understanding the underlying concepts for successful implementation of lean and sustainability.
5) There is need for a strategic plan by organisations to develop a more long- term focus which will be used to evaluate the threats and opportunities for integrating lean and sustainability.
6) There has to be effective change management. The organisational culture, peoples' values, norms and attitudes must be amended in order to contribute to an appropriate collective culture of the organisation.
7) Lean training should also be extended to subcontractors. Lean concept and principles may be complex for the subcontractors to understand, but training can be targeted to how to implement instead of lean theories. Training should be seen as an important preventative cost which helps the overall lean implementation and proceeds to reduce the time to implement lean.
8) Every organisation is unique and is likely to have distinctive problems and constraints. Consequently trying to replicate another organisation's lean strategy would prove a futile exercise and instead efforts should be made to isolate particular factors and trends.
9) Organisations should understand that lean needs to be incorporated into their business strategies, so as to reap the benefits of implementing lean.

9.7.2 Recommendation for Academics and Suggestions for Future Work

1) The developed framework highlights the areas for improvement and the benefits of implementing lean in sustainable construction. The identification of issues of implementation and impacts were also presented but the framework does not provide steps for action to redress these issues and how to achieve these improvements nor link to further investigation of how to overcome this implementation barriers. Therefore, a further study can be carried out to investigate how these barriers can be overcome and develop a framework which is capable of providing guidance on the steps for improvements.
2) The developed framework can be improved upon to quantify the lean impact parameters in tangible numerical values which can enable organisations to make forecast on the probable cost of implementing lean in their organisation.
3) There is scope for the development and integration of a more robust framework for the integration of lean and sustainability issues at the strategic level.

4) There is more scope for further development of the framework for a cost-benefit analysis of companies whereby resources and manpower capacities are analysed based on the research methodology employed in this study.
5) The scope of the framework could be extended to suit the needs of other types of construction organisations, such as consultants and owner organisations. Research could be undertaken to modify the framework in order that the framework can be adopted by other types of organisation.
6) The lean and sustainability implementation issues such as the barriers and success factors tested in this study was on the assumptive base of the area of linkages between the two concepts. The main area of this study is the implementation of lean. Meanwhile, the concepts of lean and sustainability are not the same. Therefore, further studies can be carried out to develop a framework for implementing sustainability within construction organisations.

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APPENDICES

Appendix A – Guide to Ethics and Approval

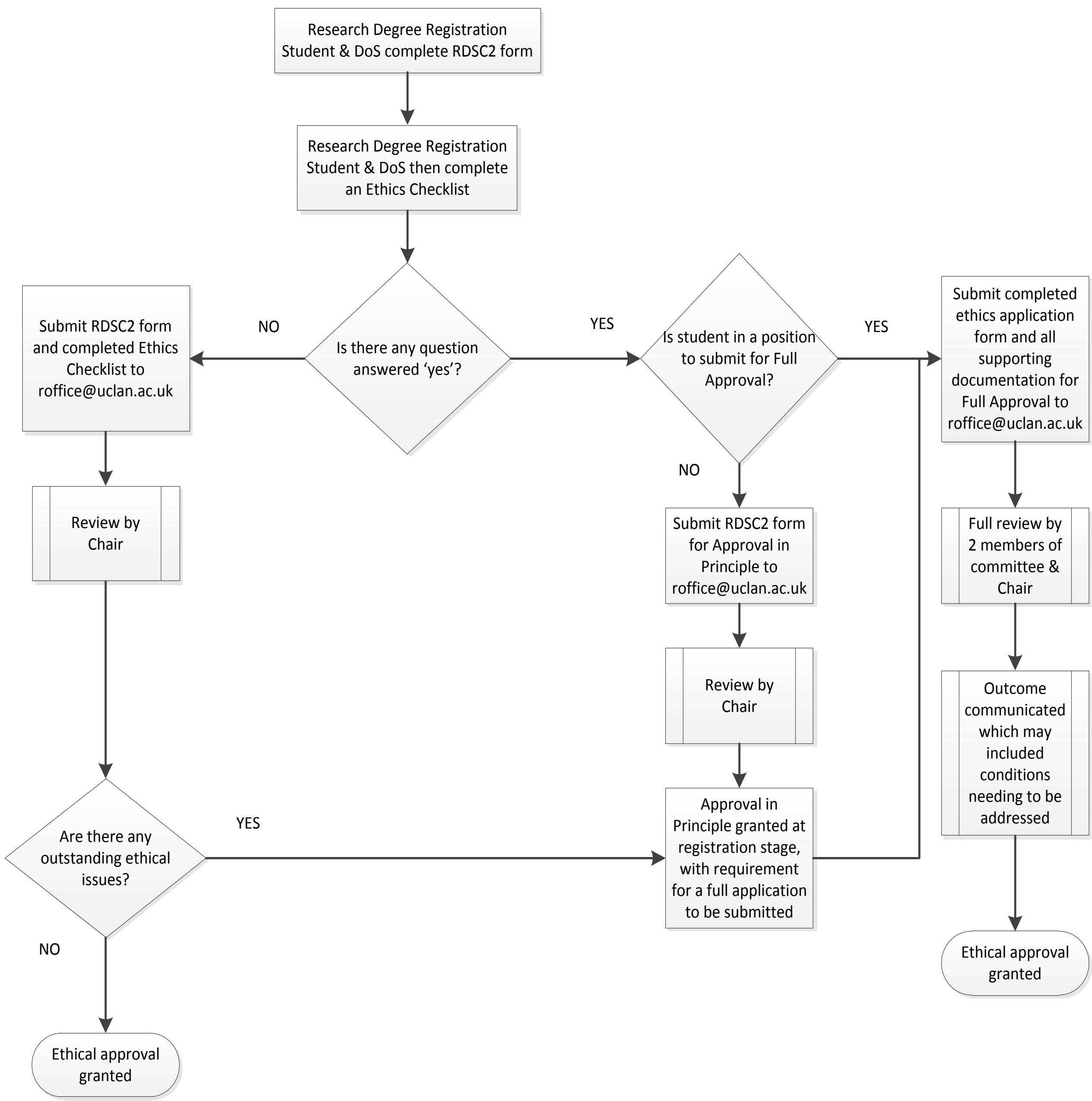
University of Central Lancashire

e-Ethics Guidance notes for Research Degree Students

Ethical Review

All research student registration proposals, irrespective of the nature or activity involved, will need to be reviewed by their relevant ethics committee.

Process (Flow diagram)



Approval Letter

Dear Oyedolapo,

This is to confirm that the Ethics Committee has approved your proposal.

Best wishes

Clare Altham
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Appendix 1a: Questionnaire used in this study

This questionnaire examines the impact of lean construction (LC) on sustainable construction (SC) to help identify how industry can benefit from lean and sustainability. Please tick appropriate answers based on your experience.

GENERAL INFORMATION

1. Name of organisation (optional)……………………………
   ……………………………………………………………
2. Number of employees
   ☐ up to 50 ☐ up to 250 ☐ above 250

3. Position of respondent………………………………………

4. Professional discipline Please tick
   a. Architect ☐
   b. Quantity Surveyor ☐
   c. Engineering ☐
   d. Building ☐
   e. Other (please specify)……………………………..

5. Number of years of professional experience
   ☐ 1-5yrs ☐ 6-10yrs ☐ 11-15yrs
   ☐ 16-20yrs ☐ 21yrs and above

6. What is the main activity of your business?
   ☐ Design
   ☐ Construction
   ☐ Both design & construction

Please indicate your level of agreement with the following statements based on your experience in your organisation (Questions 8- 14).

7. Lean Construction in Design

Lean Construction in Design	Strongly Agree	Agree	Disagree	Strongly Disagree
Leads to better technological efficiency				
Solves potential constructability problems				
Reduces product development time and cost				
Assures supervised quality control procedure				
Aids effective communication among design team				
Eliminates waste and non-value adding activities				

8. Lean in Construction

Lean in Construction	Strongly Agree	Agree	Disagree	Strongly Disagree
Improves safety and environmental issues				
Improves time, cost and quality				
Helps to identify constraint within construction				
Focuses on value than cost.				
Optimises resource delivery schedules				
Aids reduction in on-site transportation				
Results in standardisation of work practices				

9. Implementation of Sustainability within your Organisation

Sustainability Business Case	Strongly Agree	Agree	Disagree	Strongly Disagree
Requires new strategic initiatives				
Awareness has increased				
Involves the strategic issues of sustainability				
Has internal written business case for addressing it				
Has increased the efficient and effective operation				
covers the economic, social & environmental aspects				

10. Lean Construction Implementation in your Organisation

LC Implementation Business Case	Strongly Agree	Agree	Disagree	Strongly Disagree
Awareness has increased				
Is similar to the traditional practices				
Has improved competitiveness and market share				
Enables sustainability initiatives				
Motivates employees and shapes their behaviour.				
Has complemented marketing effort				
Innovates sustainable competitive advantage				
Is promoted by integration of supply chain				

11. Link between Sustainability and Lean construction

Link between sustainability and Lean	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
The concept of both is very closely linked				
LC is similar to the traditional practices				
LC leads towards sustainability initiatives				
Both eliminate material waste in construction				
LC enhances sustainability				
Integration of both improves construction process				

12. Barriers to Lean Construction and Sustainability

Barriers to LC & sustainability	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Lack of management commitment				
Long implementation period				
Lack of proper training				
Lack of adequate skills and knowledge				
Lack of application of the fundamental techniques				
Gaps in standards and approaches				
Fragmented nature of industry				
Cultural barriers				
Lack of implementation understanding & concepts				
Resistance to change				
Government bureaucracy and instability				
Long lists of supply chain and lack of trust				

13. Success Factors of Lean Construction and Sustainability

Success Factors of LC & Sustainability	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Management commitment				
Good working environment				
Customer focus and integration				
System and process change management				
Regular training of workforce				
Effective planning				
Integration of team and end to end supply chain				
Adoption of a continuous improvement culture				
Benchmarking of suppliers against each other				
Communication and coordination between parties				

Review of performance/progress towards targets				
Wide adoption of lean and sustainability concepts				
Understanding of lean benefits on sustainability				

14. Please indicate the level of use of Lean principle/Techniques for Enabling Sustainability in your organisation

Lean Principles/Techniques for Enabling Sustainability	**High Use**	**Medium Use**	**Low Use**	**Don't Use**
Value stream mapping				
5S				
Total preventive maintenance				
Kaizen				
Pull approach				
Last planner				
Six sigma				
Visualisation tool				
Daily huddle meetings				
Kanban				
Fail safe for quality				
First run studies				
Just-In-Time				
Value Analysis				
Total Quality Management				
Concurrent Engineering				

15. How important are the benefits of Synchronising Lean and Sustainability in your organisation

Benefits of Synchronising Lean & Sustainability	**Very Important**	**Important**	**Unimportant**	**Very Unimportant**
Improved corporate image				
Improvement in sustainable innovation				
Increased sustainable competitive advantage				
Reduced cost and lead time				
Improved process flow				
Increased compliance with customers' expectations				
Improvement of environmental quality				
Increased employee morale, and commitment				
Reduction in material usage				
Reduction in energy consumption				
Reduction in waste				
Reduction in water usage				
Increased productivity				
Improvement in Health and Safety				

16. How important are the identified areas of link between Lean Construction and Sustainability

Area of Link between LC & Sustainability	Very Important	Important	Unimportant	Very Unimportant
Waste reduction				
Environmental management				
Health and Safety improvement				
Value maximisation				
Cost Reduction				
Energy minimisation				
Quality improvement				
Continuous improvement				
Resource management				
Design optimisation				
Performance maximisation				
Elimination of unnecessary process				

17. Is lean construction linked to your business strategy?
☐ Yes ☐ No IF No GO TO QUESTION 19

18. Please indicate in what aspect
☐ Marketing ☐ Production ☐ Planning ☐ Supply chain
☐ Others (Please specify)…………………………………………

19. Indicate your level of satisfaction with the implementation of lean construction in your organisation
☐ Highly Satisfied ☐ Satisfied
☐ Dissatisfied ☐ Very Dissatisfied ☐ Not Applicable

Kindly supply any additional input/information you consider relevant to this questionnaire …………………………………………………………...
…………………………………………………………………………......

Thank you for completing the questionnaire

Please supply your email address if you would like to receive a summary of the survey results..

Appendix 1b: Barriers Correlation Table

Barriers		Lack of management commitment	Long implementation period	Lack of proper training	Lack of adequate skills and knowledge	Lack of application of the fundamental techniques	Gaps in standards and approaches	Fragmented nature of industry	Cultural barriers	Lack of implementation understanding & concepts	Resistance to change	Government bureaucracy and instability	Long lists of supply chain and lack of trust
Lack of management commitment	Pearson Correlation	1	.084	.389**	.340*	.371**	.413**	.346**	.363**	.452**	.256	.565**	.452**
	Sig. (2-tailed)		.541	.003	.011	.005	.002	.010	.006	.001	.059	.000	.001
	N	55	55	55	55	55	55	55	55	55	55	55	55
Long implementation period	Pearson Correlation	.084	1	.191	.265	.284*	-.069	-.366**	-.165	-.438**	-.274*	.354**	.225
	Sig. (2-tailed)	.541		.163	.050	.035	.616	.006	.228	.001	.043	.008	.099
	N	55	55	55	55	55	55	55	55	55	55	55	55
Lack of proper training	Pearson Correlation	.389**	.191	1	.752**	.720**	.090	-.107	.183	.182	.201	.500**	.130
	Sig. (2-tailed)	.003	.163		.000	.000	.516	.439	.180	.184	.142	.000	.345
	N	55	55	55	55	55	55	55	55	55	55	55	55
Lack of adequate skills and knowledge	Pearson Correlation	.340*	.265	.752**	1	.640**	-.015	-.171	.119	.095	.266*	.500**	.050
	Sig. (2-tailed)	.011	.050	.000		.000	.912	.212	.388	.491	.050	.000	.719
	N	55	55	55	55	55	55	55	55	55	55	55	55
Lack of application of the fundamental techniques	Pearson Correlation	.371**	.284*	.720**	.640**	1	-.031	-.181	.033	.154	.168	.346**	.044
	Sig. (2-tailed)	.005	.035	.000	.000		.820	.187	.810	.263	.219	.010	.750
	N	55	55	55	55	55	55	55	55	55	55	55	55
Gaps in standards and approaches	Pearson Correlation	.413**	-.069	.090	-.015	-.031	1	.480**	.428**	.060	.102	.078	.662**
	Sig. (2-tailed)	.002	.616	.516	.912	.820		.000	.001	.662	.457	.570	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55
Fragmented nature of industry	Pearson Correlation	.346**	-.366**	-.107	-.171	-.181	.480**	1	.654**	.438**	.181	.187	.456**
	Sig. (2-tailed)	.010	.006	.439	.212	.187	.000		.000	.001	.185	.172	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55
Cultural barriers	Pearson Correlation	.363**	-.165	.183	.119	.033	.428**	.654**	1	.434**	.403**	.386**	.319*
	Sig. (2-tailed)	.006	.228	.180	.388	.810	.001	.000		.001	.002	.004	.018
	N	55	55	55	55	55	55	55	55	55	55	55	55
Lack of implementation understanding & concepts	Pearson Correlation	.452**	-.438**	.182	.095	.154	.060	.438**	.434**	1	.394**	.188	.015
	Sig. (2-tailed)	.001	.001	.184	.491	.263	.662	.001	.001		.003	.170	.911
	N	55	55	55	55	55	55	55	55	55	55	55	55
Resistance to change	Pearson Correlation	.256	-.274*	.201	.266*	.168	.102	.181	.403**	.394**	1	.125	-.016
	Sig. (2-tailed)	.059	.043	.142	.050	.219	.457	.185	.002	.003		.365	.907
	N	55	55	55	55	55	55	55	55	55	55	55	55

	Barriers	Lack of management commitment	Long implementation period	Lack of proper training	Lack of adequate skills and knowledge	Lack of application of the fundamental techniques	Gaps in standards and approaches	Fragmented nature of industry	Cultural barriers	Lack of implementation understanding & concepts	Resistance to change	Government bureaucracy and instability	Long lists of supply chain and lack of trust
Government bureaucracy and instability	Pearson Correlation	.565**	.354**	.500**	.500**	.346**	.078	.187	.386**	.188	.125	1	.093
	Sig. (2-tailed)	.000	.008	.000	.000	.010	.570	.172	.004	.170	.365		.499
	N	55	55	55	55	55	55	55	55	55	55	55	55
Long lists of supply chain and lack of trust	Pearson Correlation	.452**	.225	.130	.050	.044	.662**	.456**	.319*	.015	-.016	.093	1
	Sig. (2-tailed)	.001	.099	.345	.719	.750	.000	.000	.018	.911	.907	.499	
	N	55	55	55	55	55	55	55	55	55	55	55	55

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Appendix 1c: Success Factors Correlation Table

Success factors		Management commitment	Good working environment	ustomer focus and integration	System and process change management	Regular training of workforce	Effective planning	Integration of team and end to end supply chain	Adoption of a continuous improvement culture	Benchmarking of suppliers against each other	Communication and coordination between parties	Review of performance/progress towards targets	Wide adoption of lean and sustainability concepts	Understanding of lean benefits on sustainability
Management commitment	Pearson Correlation	1	.824**	.374**	.321*	.737**	.599**	.642**	.495**	.438**	.608**	.631**	.414**	.631**
	Sig. (2-tailed)		.000	.005	.017	.000	.000	.000	.000	.001	.000	.000	.002	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
Good working environment	Pearson Correlation	.824**	1	.500**	.320*	.715**	.511**	.644**	.470**	.391**	.666**	.576**	.385**	.576**
	Sig. (2-tailed)	.000		.000	.017	.000	.000	.000	.000	.003	.000	.000	.004	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
Customer focus and integration	Pearson Correlation	.374**	.500**	1	.475**	.301*	.264	.531**	.533**	.545**	.590**	.477**	.646**	.536**
	Sig. (2-tailed)	.005	.000		.000	.025	.051	.000	.000	.000	.000	.000	.000	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
System and process change management	Pearson Correlation	.321*	.320*	.475**	1	.361**	.367**	.432**	.505**	.751**	.575**	.738**	.647**	.592**
	Sig. (2-tailed)	.017	.017	.000		.007	.006	.001	.000	.000	.000	.000	.000	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
Regular training of workforce	Pearson Correlation	.737**	.715**	.301*	.361**	1	.653**	.681**	.452**	.473**	.641**	.577**	.428**	.577**
	Sig. (2-tailed)	.000	.000	.025	.007		.000	.000	.001	.000	.000	.000	.001	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
Effective planning	Pearson Correlation	.599**	.511**	.264	.367**	.653**	1	.555**	.416**	.492**	.416**	.581**	.461**	.581**
	Sig. (2-tailed)	.000	.000	.051	.006	.000		.000	.002	.000	.002	.000	.000	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
Integration of team and end to end supply chain	Pearson Correlation	.642**	.644**	.531**	.432**	.681**	.555**	1	.547**	.702**	.684**	.695**	.710**	.695**
	Sig. (2-tailed)	.000	.000	.000	.001	.000	.000		.000	.000	.000	.000	.000	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
Adoption of a continuous improvement culture	Pearson Correlation	.495**	.470**	.533**	.505**	.452**	.416**	.547**	1	.638**	.773**	.696**	.581**	.617**
	Sig. (2-tailed)	.000	.000	.000	.000	.001	.002	.000		.000	.000	.000	.000	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
Benchmarking of suppliers against each other	Pearson Correlation	.438**	.391**	.545**	.751**	.473**	.492**	.702**	.638**	1	.774**	.880**	.836**	.738**
	Sig. (2-tailed)	.001	.003	.000	.000	.000	.000	.000	.000		.000	.000	.000	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
Communication and coordination between parties	Pearson Correlation	.608**	.666**	.590**	.575**	.641**	.416**	.684**	.773**	.774**	1	.775**	.710**	.696**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.002	.000	.000	.000		.000	.000	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
Review of performance/progress towards targets	Pearson Correlation	.631**	.576**	.477**	.738**	.577**	.581**	.695**	.696**	.880**	.775**	1	.790**	.835**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000		.000	.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55

Appendix 1c: Success Factors Correlation Table (Cont'd)

Success factors		Management commitment	Good working environment	ustomer focus and integration	System and process change management	Regular training of workforce	Effective planning	Integration of team and end to end supply chain	Adoption of a continuous improvement culture	Benchmarking of suppliers against each other	Communication and coordination between parties	Review of performance/progess towards targets	Wide adoption of lean and sustainability concepts	Understanding of lean benefits on sustainability
Wide adoption of lean and sustainability concepts	Pearson Correlation	.414**	.385**	.646**	.647**	.428**	.461**	.710**	.581**	.836**	.710**	.790**	1	.723**
	Sig. (2-tailed)	.002	.004	.000	.000	.001	.000	.000	.000	.000	.000	.000		.000
	N	55	55	55	55	55	55	55	55	55	55	55	55	55
Understanding of lean benefits on sustainability	Pearson Correlation	.631**	.576**	.536**	.592**	.577**	.581**	.695**	.617**	.738**	.696**	.835**	.723**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	
	N	55	55	55	55	55	55	55	55	55	55	55	55	55

Appendix 2a: Case Study Questions

Target Groups and sample

Senior level managers

Middle level managers

Bottom level managers (operational staff)

Underlying philosophy of the study:

The aim of this questionnaire is to gather knowledge for the purpose of understanding how construction firms employ lean construction approach within their organisations. The interview session is intended to include a number of key personnel within construction companies who are involved in implementing the concept of lean. The main objective of the interview is to enable the researcher to obtain information that will aid the development of a conceptual framework for the implementation of the lean approach in construction firms. It is expected that the outcome of this study will provide a valuable insight into lean construction practice and create a credible and practical framework which can help construction companies identify gaps in their lean implementation efforts, focus attention on areas for improvements and assess the benefits of lean approach in sustainable construction.

Note:

"The results to be obtained through the interviews will only be used for the

Purpose of this research study and will not be used for any other purpose.

All responses remain completely confidential."

Date…………………………………………………………………………………………….

Company Name (optional)……………………………………………………………..

Position ………………………..

Job Title………………………………………………………………………………...

Section one:

This section attempts to obtain the general information about the participant and some background information about the company.

1 What is your job description?

2 What is the main activity of your business? (e.g. Design, construction, both design and construction)

3 What number of employees do you have?

4 What is your annual turnover?

5 How long has the company existed?

Section two:

This section attempts to explore the understanding of lean issues and determine how mature the implementations are in the organisations.

6 What is your definition of lean construction and the principles that make up lean?

7 When did you start your lean implementation?

8 What has motivated the company to implement lean construction?

9 Can you please describe how the whole process started (was your expert in-house or consultant?).

10 How long did it take to implement lean construction? (please specify)

11 Which lean tools and techniques do you use?

Section Three:

This section attempts to identify the barriers and success factors to the implementation of lean

12 What were the barriers/challenges encountered during the implementation?

13 Can you please classify this barriers into people, process, management, cost and technology related barriers based on your experience?

14 What was the success factors encountered?

15 Can you please classify these success factors based on your experience?

16 What training, if any, did the staff undertake?

17 How many people were involved in the training exercise?

18 How was the concept received by the employees?

19 What was the level of satisfaction with the implementation of lean construction in your organisation?

Section Four:

This section attempts to identify the drivers and the benefits of implementing lean

20 What are the core drivers of lean construction in your organisation?

21 Did the implementation of lean construction lead to attainment of sustainability within your organisation?

22 Are there links between lean and sustainability, what are they?

23 What are the benefits of lean approach in sustainable construction in your organisation?

24 Please identify the social, economic and the environmental benefits of the lean approach in your organisation if any

25 How would you advice a potential company wishing to implement lean construction?

26 Any other comments on implementation of lean?

Kindly supply any additional input/information you consider relevant to this questions/study.

Appendix 2b: Rationale for Case Study Questions

Interview questions	Reason for questions
Lean questions	
What is your definition of lean construction and the principle that make up lean?	To understand the main focus for lean in organisations
When did you start your lean implementation?	To determine the level of implementation and how mature the implementations are likely to be
What has motivated the company to implement lean construction?	To explore the motivations for companies adopting improvement programmes such as lean and deduce what might motivate them to adopt "sustainability and lean'.
Can you please describe how the whole process started (was your expert in-house or consultant?).	To know how what companies mean by Lean, how they apply it and how they make it work for them. Also, to find out how companies like to get information.
How long did it take to implement lean construction? (please specify)	To ascertain if lean implementation is characterised by long implementation period.
Which lean tools and techniques do you use?	To identify the most common/popular lean tools and techniques used.
Barriers and success factors questions	
What were the barriers/challenges encountered during the implementation?	To identify the barriers to implementation of lean construction at organisational level
Can you please classify this barriers into people, process, management, cost and technology related barriers based on your experience?	To understand the nature of these barriers and possible cause in order to attempt solutions to them.
What was the success factors encountered?	To identify the success factors to implementation of lean construction at organisational level
Can you please classify these success factors based on your experience?	To identify the critical success factors to the implementation of lean at organisational level
What training, if any, did the staff	To determine if there is specific training

undertake?	required for the implementation of lean
How many people were involved in the training exercise?	To determine the extent of involvement of employees in the training
How was the concept received by the employees?	To determine the attitudes of employees towards a change initiative
What was the level of satisfaction with the implementation of lean construction in your organisation?	To determine the level of satisfaction by employees
Drivers and benefits of lean	
What are the core drivers of lean construction in your organisation?	To determine the need for lean and the business drive towards lean
Did the implementation of lean construction lead to attainment of sustainability within your organisation?	To verify the benefits of lean towards sustainability
Are there links between lean and sustainability, what are they?	To identify the area of linkage between lean and sustainability
What are the benefits of lean approach in sustainable construction in your organisation?	To ascertain if there are any tangible or intangible benefits that can be derived from the implementation of lean approach by construction organisations.
Please identify the social, economic and the environmental benefits of the lean approach in your organisation if any	To determine if these benefits can be classified under the social, economic and the environmental aspect.
How would you advice a potential company wishing to implement lean construction?	To understand the experience of the organisation from the implementation of the lean approach

Appendix 3: Structured Questions for Refining and Validating the Lean Implementation Assessment Framework

Purpose of the interviews:

The interview seeks to refine and validate the Lean Implementation Assessment Framework (LIMA) developed for assessing the implementation efforts and benefits of lean in sustainable construction within construction firms.

Sample:

The sample will be chosen from academics professional.

The total number of interviews to be conducted will be approximately Twelve (12)

Background Information

1. Present Job role/title: ……………………………………………………………..

2. Background: ☐ Academia ☐ Industry

3. Area of expertise (e.g. lean, sustainability, etc.)

   ………………………………………………………………………………………..

4. Organisation (optional): ……………………………………………………………..

Evaluation of the proposed framework:

Please indicate how you describe /rate the following questions on a scale of 1-4 by assigning a number in the box provided.

Meaning of scale 1 (Very low coverage), 2 (Low coverage), 3 (High coverage), 4 (Very high level)

5. In your view, how will you describe the level of coverage of the proposed framework in terms of its overall content? ☐

6. In your view, how will you describe the level of coverage (level of completeness) in terms of the logic (e.g. flow of necessary steps to be taken in assessing the implementation efforts of lean?) ☐

7. In your view, how will you describe the issues covered under Section 1: policy deployment and strategy positioning within the proposed framework? ☐

8. What is your opinion on the issues covered under section 2: Assessment criteria within the proposed framework? ☐

9. What is your opinion on the issues covered under Section 3: Application and implementation within the proposed framework? ☐

10. What is your overall opinion on the level of understanding of the proposed framework?

Meaning of scale 1 (Very difficult to understand), 2 (Difficult to understand), 3 (Easy to understand), 4 (Very easy to understand)

11. Do you have any further suggestions/comments for improving the proposed framework or any areas you consider to be deleted within the proposed framework?

12. Would you recommend the framework for use within the construction firms?

<u>Investigation of further issues in the implementation of lean in sustainable construction</u>

13. From the findings of this study, it is perceived that organisations struggle to integrate lean and sustainability. What is your view on this within the context of your own organisation? Yes No ☐ ☐

14. Are there any further inputs in forms of suggestions, comments regarding the issues of lean in sustainable construction?

Thank you for your time.

Oyedolapo Ogunbiyi

Appendix 4: Achievements and Publications

Achievements during the course of the PhD

1. Grant awarded by Allan and Nesta Ferguson Charitable Trust Scholarship, (2012-2013)

2. Overseas Research Student Award Scheme (ORSAS), University of Central Lancashire (2010-2013)

Journal paper published

1. Ogunbiyi, O., Oladapo, A and Goulding, J. (2014). An empirical study of the impact of lean construction techniques on sustainable construction in the UK. Journal of Construction Innovation: Information, Process, Management, Vol. 14, No 1, 88-107

2. Ogunbiyi, O., Oladapo, A and Goulding, J. (2013). A review of the lean approach in sustainable construction in the UK. International Journal of Sustainable Construction Engineering & Technology, Vol 4, No 2, 2013.

Conference papers published

1. Ogunbiyi, O., Oladapo, A and Goulding, J. (2013). The application and implementation of lean delivery methods in PPP projects. International Conference on Public Private Partnership (PPP) Body of Knowledge (3P Book) held at Westleigh Conference Centre, Preston, UK 18 to 20 March 2013.

2. Ogunbiyi, O.,Oladapo, A. A. and Goulding, J. S. (2012). Lean Procurement: The Use of Lean Construction Techniques in Project Value Enhancement. In: Joint CIB W070, W092 and TG72 International Conference on Facility Management, Procurement Systems and Public Private Partnership, 22-25 January 2012, Cape Town, South Africa.

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An empirical study of the impact of lean construction techniques on sustainable construction in the UK

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Abstract:
Purpose - The contribution of lean construction techniques in sustainable construction cannot be over emphasised, as sustainable development is now enshrined in Government policy. In addition, lean construction is now faced with the challenges of sustainable development, continuous improvement, waste elimination, a stronger user focus, increased value for money along with high quality management of projects and supply chains, and improved communications. This paper presents an exploratory study from extant literature and the results of the use of questionnaire survey among construction participants to explore the contribution of implementing lean construction techniques in sustainable construction. **Design/methodology/approach** – Surveys of UK based construction professional were conducted. The data collected was analysed with SPSS 19.0 version software using the percentile method, Cronbach's alpha reliability test, Kruskal Wallis test, Kendall's coefficient of concordance and one sample t-test.
Findings – Results from this study indicate that there are several benefits associated with implementation of lean construction and sustainable construction. The overall perspective of professionals within the construction industry, according to questionnaire survey shows that benefits such as improved corporate image and sustainable competitive advantage, improved process flow and productivity, improvement in environmental quality and increased compliance with customer's expectations are realised following integration of principles of lean construction and sustainable construction within construction industry. Just-in-time, visualisation tool, value analysis, daily huddle meetings and value stream mapping are the most common lean tools/techniques for enabling sustainability. This study also identified several areas of linkage between lean and sustainability such as waste reduction, environmental management, value maximisation, and health and safety improvement among others.
Originality/value – The originality of this paper lies in its consideration of lean construction principles to better understand its impact on sustainable construction. This research contributes to the awareness of the benefits that can be derived from the implementation of lean construction in sustainable construction within the construction industry.
Keywords Lean construction, sustainability, sustainable construction
Paper type Research paper

Introduction

The term lean has been borrowed from the Japanese and converted to suitable form for use within construction. Lean construction was pioneered by Koskela who developed the Transformation Flow View (TFV) theory of production in construction. Lean construction is a philosophy based on lean manufacturing concepts (Koskela, 1992). However, lean construction has been used with significant benefits in countries like UK (Mossman, 2009), Singapore (Dulaimi and Tanamas, 2001), Brazil (Silva and Cardoso, 1999), Chile (Alarcon and Diethelm, 2001), Netherlands (Johansen *et al.*, 2002), South Africa (Emuze and Smallwood, 2012), Turkey (Polat and Ballard, 2004), U.S. (Nahmens and Ikuma, 2009), and in many other countries. The aim of lean construction is to work on continuous

improvement, waste elimination, strong user focus, value for money, high quality management of projects and supply chains, improved communications (OGC, 2000).
Generally, the concept of sustainable development is broad. It concerns the attitudes and judgment to help ensure long-term ecological, social and economic growth in society through the efficient allocation of resources, minimum energy consumption, low embodied energy intensity in building materials, reuse and recycling, and other mechanisms to achieve effective and efficient short- and long-term use of natural resources when applied to project development (Ding 2008; RICS 2009). Bourdeau *et al.* (1998) stated that current sustainable construction practices are widely different depending on how the concept of sustainable construction is developed in various countries. Sustainable development has been defined as "*development that meets the needs of the present without compromising that ability of future generations to meet their own needs*" (Brundtland Report, 1987).

Principles of sustainable construction

The term 'sustainable construction' was originally proposed to describe the responsibility of the construction industry in attaining `sustainability' **(**Kibert, 2008). The concept of sustainable construction addresses three main pillars: environmental protection, social well-being and economic prosperity (Brownhill and Rao, 2002). Sustainable construction refers to the integration of environmental, social and economic considerations into construction business strategies and practice. Sustainable construction is the set of processes by which a profitable and competitive industry delivers built assets (buildings, structures, supporting infrastructure and their immediate surroundings) which: enhance the quality of life and offer customer satisfaction, offer flexibility and the potential to cater for user changes in the future, provide and support desirable natural and social environments, and maximise the efficient use of resources (OGC, 2000). In view of this, there are many benefits that can be achieved by applying sustainable construction and these include environmental, economic, social, health and community benefits. The environmental benefits are improved air and water quality, reduced energy and water consumption, and reduced waste disposal. The economic benefits are reduced operating cost, maintenance cost, and increased sales price and rent while enhanced health and occupants comfort, and reduced liability are the health and community benefit (Luther, 2005).

Drivers of sustainability

Improving the quality of life within the earth's carrying capacity to ensure equity within the current generation and between the present and future generation is the main focus of sustainability. Sustainability has been defined in terms of equity (Brudtland report, 1987), maintenance of natural capital (Dresner, 2002), the triple bottom line (Hopwood *et al.*, 2005) and the ecological footprint (Haberl *et al.*, 2004). The construction sector in the UK and in other countries is under increasing obligation to adopt the principles of sustainability in their activities and policies (Brandon, 2005). The UK construction industry has been rising up to the challenge of sustainability as they are under increasing legal and commercial pressure to become more sustainable (Bennett and Crudgington, 2003). Due to the impact construction industry has on economy, society and environment, increasing the sustainability of construction has become a key aim of countries aspiring to follow the path towards sustainable development (Mustow, 2006). The UK Government has been making progress towards more sustainable construction through a range of initiatives and policies (DTI, 2006). The drivers of sustainability identified in the literature include legislation, customer requirements, broad level support reputation and brand integrity, regulators, shareholders or investors expectations, increasing competitive advantage, business pressure, government policy and regulation, new client procurement policies, environmental concerns, long term survival of business, improved corporate image, cost savings/operational efficiency, enhanced relations with suppliers, peer pressure within the industry and increased realisation of the importance of construction image (Adetunji *et al;* 2003, Sustainable Construction Task Group, 2002; Yu and bell, 2007, Simpson *et al*. 2004).

Lean construction core drivers

Waste elimination, process control, flexibility, optimisation, people utilisation, continuous and efficiency improvement and value to customer have been presented as some of the key drivers of lean (Ross and Associates, 2004). However, lean construction has also been adopted by the construction industry as a means of supply chain improvement (Jorgensen and Emmitt, 2009). The adoption of innovative management practices, such as supply chain management and lean thinking, from a manufacturing context to the construction industry is not without challenges (Hook and Stehn, 2008). Eriksson (2010) studied how to increase the understanding of implementing various aspects of lean thinking in a construction project and how supply chain actors and their performance are affected. Furthermore, the core elements of lean construction were investigated, reflecting how the various aspects of lean construction can be grouped into six core elements: waste reduction, process focus in production planning and control, end customer focus, continuous improvements, cooperative relationships, and systems perspective.

Lean construction implementation efforts can be divided into three different stages, with increasing degree of sophistication. Green and May (2005) are of the view that lean stage one focuses on waste elimination from a technical and operational perspective. The second stage focuses on eliminating adversarial relationships and enhancing cooperative relationships and teamwork among supply chain actors. The essential parts are cooperation, long-term framework agreements, workshops and facilitator. Aspects related to stage two according to Erikson (2010) are: limited bid invitation, soft parameters, long-term contracts, collaborative tools, and broad partnering team. Lean stage two does not go beyond concept of partnering since it is about eliminating waste derived from sub-optimisations and adversarial relationships through increased integration and collaboration. The third stage identified is the most sophisticated, involving a structural change of project governance. Its essential parts are: information technology, pre-fabrication, last planner, bottom-up activities and emphasis on individuals, a rethink of design and construction, decreased competitive forces, long-term contracts, training at all staff levels, and a systems perspective of both processes and the product.

The principle of lean is primarily aimed at eliminating waste in every process activity to reduce process cycle, improve quality, and increase efficiency (Al-Aomar, 2010). Lean can be attained through a combination of the following practices, including Just-In-Time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM), continuous improvement, Design for Manufacturing and Assembly (DFMA), supplier management, and effective human resource management (de Treville and Antonakis, 2006; Narasimhan *et al.,* 2006). Shah and Ward (2007) defined lean production as ‘‘an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability.’’

Womack and Jones (2003) defined five lean principles to eliminate waste in organisations, as being:

- Specifying value from the perspective of customer
- Identifying the value stream
- Create flow
- Allow customer demand to pace and pull production
- Manage continuous improvement and purse perfection

Marzouk *et al*., (2011) assessed the impact of applying lean principles to design processes in construction consultancy firms to aid in decision making at early stages of construction projects using a computer simulation tool. It was concluded that applying lean construction principles to the design process significantly helped to improve process efficiency, in terms of reduced process durations and increased resource utilisation.

Integrating lean construction and sustainability

Huovila and Koskela (1998) raised the potential and profitability of lean principles to promote sustainable construction and a requirement framework was presented. The implementation of lean production concepts into construction seems to be a major factor in the attempt to eliminate accidents. The use of lean production concepts has been identified as a strategy for: 1. designing, controlling and improving engineering and construction processes to ensure predictable material and work flow on site, 2. improving safety management and planning processes themselves to systematically consider hazards and their countermeasures, and 3. improving safety related behaviours- instituting procedures that aim at minimising unsafe acts (Koskela, 1993). Safety is an important part of every production process, it relies on every action, material and person used, and therefore it should not be an afterthought or neglected (Nahmens and Ikuma, 2009).

The benefits of lean and sustainability have been considered by many authors mainly on improvement of environmental quality, reduction in waste and the health and safety. Benefits such as: increased competitiveness by means of effective use of resources, while improving quality, reducing cost, and increased responsiveness are also derived from both concepts (Womack and Jones, 1996; Larson and Greenwood, 2004). Hall and Purchase (2006) submit that many lean and sustainability practices, such as efficiency, safety, productivity, and waste minimisation are interconnected. As such, Koranda *et al*. (2012) investigated the relationships between sustainability and lean concepts from a perspective of a small construction project and developed a framework for integrating and implementing lean techniques and sustainability in a construction project.

Salem and Zimmer (2005) discussed whether lean manufacturing principles can be applied to construction and if similar benefits could result. They concluded that lean practices does indeed hold potential for improving construction after creating a lean assessment instrument with six case studies. Salem *et al*. (2005) carried out an evaluation on lean construction tools such as: Last Planner (LP), increased visualisation, daily huddle meetings, first run studies, 5s process, and fail safe for quality and safety. The benefits from implementation of 5S include improved safety, productivity, quality, and set-up-times improvement, creation of space, reduced lead times, cycle times, increased machine uptime, improved morale, teamwork, and continuous improvement (Spoore, 2003).

Ballard and Howell (2004) claimed that the use of lean based tools like LP reduce accident rates. According to Thomassen *et al.* (2003), crews that used lean construction tools, including LP, had about 45% lower accident rate than crews in the same company, performing similar work, who did not use the LP system. Dentz and Blanford (2007) stated that initial results from early industry practice show that the use of lean tools has great potential to boost the efficiency and quality of industrialised homebuilding operations. The integration of lean and sustainability results in reduction in waste (both process and material waste), reduction in energy consumption, reduction in water usage, reduction in cost and lead time and improvement in environmental quality(Koranda *et al.*, 2012).

Scherrer-Rathje *et al.* (2009) stated that despite the significant benefits lean offers in terms of waste reduction and improved corporate image, improved process flow in terms of communication and integration, implementing lean and achieving the levels of organisational commitment, employee autonomy, and information transparency is not an easy task. The integration of lean and sustainability can result in better cost savings, waste reductions and environmental improvement. There are synergies between lean and eco-sustainability. The strengths and weaknesses of lean and eco-sustainability suggest there are important opportunities for integrating initiatives, potentially to the benefit of both (Larson and Greenwood, 2004).

Waste is defined as "any inefficiency that results into the use of equipment, materials, labour and capital in larger quantities than those considered as necessary in the production of a building" (Koskela, 1992). Pheng and Tan (1998) defined waste in construction as "the difference between the value of those materials delivered and accepted on site and those used properly as specified and accurately measured in the work, after deducting cost saving of substituted materials and those transferred elsewhere". Construction waste is however, classified into 8 groups according to Lee *et al.* (1999): quality costs, lack of safety, unnecessary transportation trips, delay times, rework, long distances, improper choice or management of methods or equipment, and poor constructability.

According to Womack and Jones (2003), eight basic type of waste are classified as follows:

- Defect that must be corrected
- Over production (producing more or doing more that is needed)
- Inventory
- Unnecessary processing steps
- Transportation of materials with no purpose
- Motion of employee with no purpose
- Waiting by employees for process equipment to finish its work or for an upstream activity to complete
- Goods and services that do not meet customer needs.

Special emphasis has been placed on the attempts for reducing waste generation and improving techniques in minimisation of the harmful effects of construction activities on the environment since the construction industry has great impact on the environment (Tan *et al.*, 2010). Environmental burdens caused by construction can be minimised and construction technology can be used to remedy the environment (Huovila and Koskela, 1998). Environmental issues are gaining importance in the UK construction industry. The link between environmental and economic performance has been widely debated in the literature. One view is that improved environmental performance mainly causes extra costs for the firm and thus reduces profitability. The opposite has been argued for: improved environmental performance would induce cost savings and increase sales and thus improve economic performance. Theoretical and empirical researches have provided arguments for both positions and have not been conclusive so far (Schaltegger and Synnestvedt, 2002). CIRIA (2005) stated that the construction industry is coming under increasing pressure to make its activities more environmentally acceptable. Good practice on site to preserve our environment is now usually a high priority for clients, their professional advisors, contractors and regulators.

There are many areas of linkage between lean and sustainability as identified from their aims and priorities. For example, waste reduction is a common priority to both lean and sustainability (Koranda *et al*., 2012). Other linkages include environmental management, value maximisation, health and safety etc. (Hall and Purchase 2006, Luther 2005). Similarly, the evolvement of lean has caused emergence of new paradigm which will inevitably have an element of environmental sustainability. Value maximisation from resource use is an essential component of the general notion of sustainability (Found, 2009). Thus, an implied connection exists between the focus of lean on reducing non-value adding activities to “make value flow” (Womack and Jones, 1996). Other identified linkage between lean and sustainability include performance maximisation, design optimisation, quality improvement, resource management, continuous improvement, etc. These linkage areas are presented in this study, to determine their relative importance to both lean and sustainability.

The main goals of this study are to explore the benefits of implementing lean construction techniques in existing literature, identify the area of linkage between lean and sustainability and how it impacts on sustainable construction.

Research methodology

This study is based on extensive literature review and the use of questionnaire survey. The research questions are: what are the sustainable benefits of lean? Are there synergies and linkage between lean construction and sustainability? What are they? An initial set of hypotheses were developed through a review of relevant literature. The hypotheses and the questionnaire were refined through a pilot study comprising two practising professional in the area of lean and sustainability (experts at implementing sustainability and lean in their companies) and two other academics with extensive knowledge in the subject area. The questions were modified based on the comments received in the pilot survey. The pilot exercise carried out also revealed that the questionnaire could be completed within 15minutes. A full scale survey was then conducted following the pilot test exercise. The resulting hypotheses null, Ho, and the alternative Ha, are as follows.

- There is no general understanding of the concept of lean and sustainability in the construction industry
- The uptake of the lean and sustainability concept is not dependent on the awareness of the benefits that can be derived from their implementation.
- There are no synergies/linkage between lean construction and sustainability

The alternative hypothesis, Ha are:

- There is general understanding of the concept of lean and sustainability in the construction industry
- The uptake of the lean and sustainability concept is dependent on the awareness of the benefits that can be derived from their implementation.
- There are synergies/linkage between lean construction and sustainability

Literature supports the hypothesis that there are synergies between lean and sustainability and that this can provide sustainable benefits, but there are some contradictions found which includes the increase of environmental impact as a result of lean. Therefore, the set of null hypothesis were formed to test them in practice.

In a research setting, a paradigm is an overarching philosophical or ideological stance, and the assumptive base from which knowledge is produced (Rubin and Rubin 2005). Positivism research paradigm gained popularity in the early 1800s (Rohmann, 1999). It emphasises quantitative analysis of aspects of a large sample for the purpose of testing hypothesis and making statistical generalisations (Steenhuis and de Bruijn, 2006). So, quantitative (measurements of what, where and when) is often associated with positivism. However, qualitative research can be very empirical in nature if the methodology informing the research is positivistic (Rowlands, 2005). Therefore, positivism can be both qualitative and quantitative (McGregor and Murnane, 2010). For the purpose of this study, the positivism paradigm is the most appropriate approach to elicit information concerning the general and internal perceptions and motivations of organisations and the resultant benefits of the implementation of lean construction and sustainability. Therefore, a quantitative methodology was used; the unit of analysis in this study is 'construction firms'. Initial contacts were made to companies to explain the aim and objectives of the research, to find out if their company have implemented lean or is undergoing lean transformation, and to ask if they wanted to participate in the survey.

Purposive sampling (rather than random sampling) of UK construction organisations with experience or expressed interest in lean construction/sustainability was adopted, through the database of the UK 100 top construction firms directory. Convenience sampling is the terminology used to describe a sample in which elements have been selected from the target population on the basis of their accessibility or convenience to the researcher (Ross, 1978). It involves drawing samples that are both easily accessible and willing to participate in a study (Teddie and Yu, 2007). Higginbottom (2004) defined the convenience sample as consisting of participants who are readily available and easy to contact. Convenience sampling was found appropriate for this study since there is no comprehensive, nor any standard, database of UK construction organisation involved in lean construction. Besides, lean construction is evolving. As a result, the number of organisations involved is increasing, but not in a form that the overall number of these organisations involved can be determined easily. Convenience sampling was used as it was not easy to determine the population of the organisations involved in lean construction. Using random sampling would require that the number of organisations involved is reasonably large and that the population is known (Jackson, 2011)

70 out of the companies contacted indicated interest and were willing to participate and requested for the questionnaire. This number was considered good based on the statistical power required to report accurately significance or non-significance of survey sample size. Brewerton and Millward (2001) projected the required participants of a survey for various statistical tests to range from 14 to 50 for a large effect size, and to range from 35 to 133 for a medium effect size. The questionnaire was then sent electronically as an attachment to electronic mail directly to the sample. The respondents include project managers, contract managers, training, environmental and quality managers, sustainability managers and site managers as well as supervisors with various backgrounds ranging from architecture, quantity surveying, engineering, building surveying etc.

The first part of the questionnaire provided the general details of the respondents. This is to ensure the appropriateness of the person completing the questionnaire. The second part of the questionnaire was to draw out the general awareness and the opinions of the respondents towards the topic of this study. The main part of the questionnaire was a list of benefits of synchronising lean construction and sustainability, which the respondents were required to rank in order of their importance and to indicate the level of use of lean principle/techniques for enabling sustainability. The respondents were also asked to rate their perceptions on the implementation of sustainability and lean construction in their organisations. The four-point Likert scale adopted were drawn from 1-4 for example, 1= Very unimportant, 2= Unimportant, 3= Important and 4= Very important. This was adopted to indicate the extent to which the respondents agree to the importance of the benefits of lean construction and sustainable construction.

The data collected were analysed with SPSS 19.0 version software using the percentile method and the sample t-test to establish whether a sample mean is significantly deviant from a hypothesised mean. For a one sample test, the hypothesis is usually set as:

$$Ho: U=Uo$$
$$Ha: U<, >Uo$$

Where Ho represents the null hypothesis, Ha represents the alternative hypothesis and Uo denotes the hypothesised or population mean. This method has been used for construction research by many authors including Bing *et al.* (2005) and Ling (2002) to analyse data in a study similar to this. The mean ranking and standard deviation of each attribute/factors was tabulated in order to present a clearer picture of the consensus reached by the respondents. The null hypothesis for each attribute/factor was unimportant (Ho: U=Uo) and the alternative hypothesis was that the attribute was important (Ha: U>Uo). Uo represents the critical rating above which the attribute is considered important. Uo was fixed at an appropriate level of 2.5 as the rating scale adopted considered higher rating 3 and 4 to important and very important attributes/factors (see Ahadzie, 2007). Based on the four-point Likert scale, an attribute/factor was considered critical or important if it had a mean of 2.5 or above. In the case where two or more factors have the same mean, the one with the lowest standard deviation was assigned the highest importance ranking (see Ahadzie, 2007). The significance level was also set at 95% in accordance with the risk levels.

Also, the Cronbach's alpha reliability and Kendall's coefficient of concordance test was used to test the reliability of the survey and the agreement of the survey respondents respectively. The results of the fieldwork are presented in the following section.

Research findings

As shown in Table 1, 70 questionnaires were distributed to construction professionals in various construction firms. Fifty five (55) were returned and analysed.

Table 1 Survey return

	Number	Percentage (%)
Total number of questionnaire received	55	79
Total number of questionnaire unreturned	15	21
Total number of questionnaire distributed	70	100

Respondent's profile

Figure 1 shows the profile of the respondents. Out of the 70 respondents, 16% had less than five years of experience, 11% had six to ten years of experience with about 73%

(i.e.18+20+35) having over 10 years of experience.

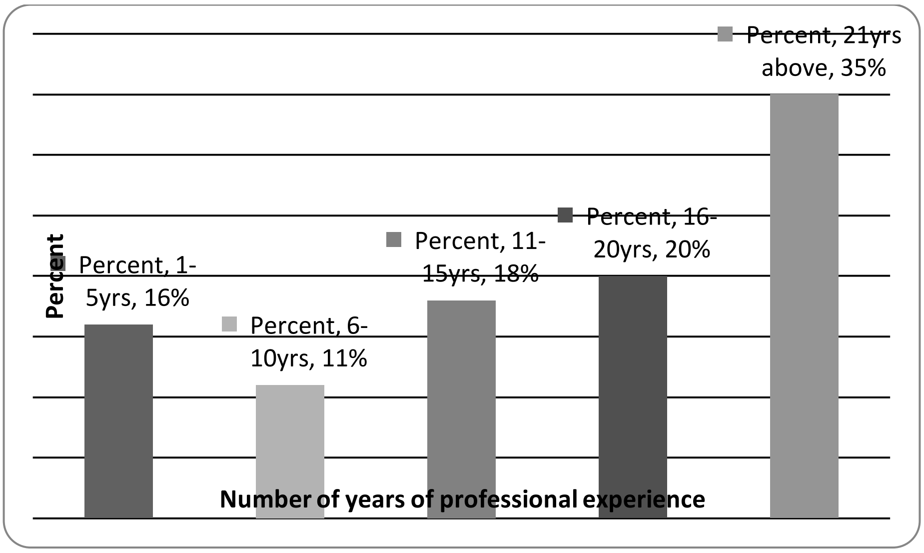

Figure 1 Respondents' number of years of professional experience

Table 2 shows the percentage of respondents' practice of lean construction on their organisation's project. 44% of respondents had up to 40%, while 14% had over 70% practice of lean on their organisation's project respectively.

Table 2 Percentage of lean construction practice on organisation's project

Lean construction practice	Percentage (%)
0-40%	44
41-50%	16
51-60%	13
61-70%	13
71-100%	14

Perceptions of lean construction and sustainability

The results (presented in table 3) show that sustainability covers the economic, social, and environmental aspects, as well as increased awareness in the respondents' organisation, while having an internal written business case for addressing sustainability issue is the least on sustainability implementation business case.

Table 3 Sustainability implementation issues within respondents' organisation

Sustainability business case	Mean	Standard deviation	Rank
Covers the economic, social and environmental aspects	3.33	.579	1
Awareness has increased	3.13	.668	2
Has increased the efficient and effective operation of your business	3.11	.712	3
Requires new strategic initiatives	3.09	.617	4
Involves the strategic issues of sustainability	2.98	.408	5
Has internal written business case for addressing it	2.73	.757	6

The results (presented in Table 4) show that the awareness of lean construction has increased while the least of all issues identified is that the implementation of lean construction is promoted by integration of supply chain. Nonetheless, these results suggest that all the identified issues are considered important by the respondents since the least issue had a mean above 2.5.

Table 4 Ranking of lean construction implementation issues within respondents' organisation

LC implementation business case	Mean	Standard deviation	Rank
Awareness has increased	3.38	.561	1
Enables sustainability initiatives	2.98	.490	2
Motivates employees and shapes their behaviour.	2.98	.680	3
Innovates sustainable competitive advantage	2.96	.470	4
Has improved competitiveness and market share	2.93	.690	5
Has complemented marketing effort	2.75	.775	6
Is promoted by integration of supply chain	2.62	.707	7

Benefits of synchronising lean and sustainability

The results (presented in Table 5) show that improved corporate image which is ranked (1) is the most important benefit of synchronising lean and sustainability while increased employee morale and commitment (ranked 12) is the least. The significance (i.e. p-value) of each of the benefits presented is displayed in Table 6. The p-value is for a two-tailed test, but the one-tailed test is required for the test of hypotheses (i.e. U>Uo). Therefore, the significance value in Table 6 has to be divided by two. However, since the 2-tailed test revealed that all the factors are significant, all the factors will still remain significant when the significance level is divided by two.

Table 5 Ranking of the benefits of synchronising lean and sustainability

Benefits of synchronising lean and sustainability	Mean	Std. deviation	Rank
Improved corporate image	3.29	.533	1
Increased productivity	3.27	.525	2
Reduction in waste	3.24	.543	3
Reduction in energy consumption	3.22	.567	4
Improvement in sustainable innovation	3.20	.558	5
Improved process flow	3.20	.558	5
Reduction in material usage	3.20	.590	7
Reduced cost and lead time	3.20	.678	8
Improvement in Health and Safety	3.18	.580	9
Improvement in environmental quality	3.16	.601	10
Reduction in water usage	3.16	.601	10
Increased sustainable competitive advantage	3.11	.567	12
Increased compliance with customers' expectation	3.16	.660	13
Increased employee morale and commitment	3.05	.731	14

Table 6 One-sample test showing test significance of the benefits of synchronising lean and sustainability

	Test value = 2.5					
Benefits of synchronising lean and sustainability	t	df	Sig. (2-tailed)	Mean difference	95% Confidence interval of the difference	
					Lower	Upper
Improved corporate image	11.003	54	.000	.791	.65	.94

Improvement in sustainable innovation	9.307	54	.000	.700	.55	.85
Increased sustainable competitive advantage	7.970	54	.000	.609	.46	.76
Reduced cost and lead time	7.660	54	.000	.700	.52	.88
Improved process flow	9.307	54	.000	.700	.55	.85
Increased compliance with customers' expectations	7.456	54	.000	.664	.49	.84
Improvement of environmental quality	8.184	54	.000	.664	.50	.83
Increased employee morale, and commitment	5.628	54	.000	.555	.36	.75
Reduction in material usage	8.798	54	.000	.700	.54	.86
Reduction in energy consumption	9.388	54	.000	.718	.56	.87
Reduction in waste	10.055	54	.000	.736	.59	.88
Reduction in water usage	8.184	54	.000	.664	.50	.83
Increased productivity	10.906	54	.000	.773	.63	.91
Improvement in Health and Safety	8.714	54	.000	.682	.52	.84

Lean principles/techniques for enabling sustainability

The results presented in Table 7, show the level of use of lean principle/techniques for enabling sustainability in respondents' organisations. 4= high use, 3= medium use, 2= low use and 1= don't use. The most used lean techniques are just-in-time, visualisation tool, value analysis, daily huddle meetings and value stream mapping while six sigma is the least used techniques.

Table7 Lean principle/techniques for enabling sustainability

Lean principles/techniques for enabling sustainability	Mean	Std. deviation	Rank
Just-in-time	2.75	.440	1
Visualisation tool	2.67	.818	2
Daily huddle meetings	2.60	.564	3
Value analysis	2.60	.830	4
Value stream mapping	2.51	.690	5
Total quality management	2.49	.605	6
Fail safe for quality	2.47	.742	7
5S	2.44	.714	8
Total preventive maintenance	2.38	.828	9
First run studies	2.29	.567	10
Last planner	2.29	.875	11
Concurrent engineering	2.09	.752	12
Pull approach	2.04	.543	13
Kanban	1.91	.823	14
Kaizen	1.91	.845	15
Six sigma	1.53	.742	16

Area of linkage between lean and sustainability

The results (presented in Table 8) show that waste reduction, environmental management and value maximisation is the most important area of linkage between lean construction and sustainability while cost reduction is the least. The 2-tailed test as shown in Table 9 revealed that all the factors are significant.

Table 8 Ranking of area of linkage between lean construction and sustainability

Area of linkage between LC and sustainability	Mean	Std. deviation	Rank
Waste reduction	3.55	.503	1
Environmental management	3.55	.503	1
Value maximization	3.53	.539	3

Health and Safety improvement	3.49	.605	4
Performance maximization	3.47	.504	5
Design optimization	3.45	.571	6
Quality improvement	3.44	.572	7
Resource management	3.38	.527	8
Energy minimization	3.31	.577	9
Elimination of unnecessary process	3.31	.635	10
Continuous improvement	3.29	.658	11
Cost reduction	3.20	.711	12

Table 9 One-sample test showing test significance of area of linkage between lean and sustainability

	Test value = 2.5					
Area of linkage between LC and sustainability	T	df	Sig. (2-tailed)	Mean difference	95% Confidence interval of the difference	
					Lower	Upper
Waste reduction	15.429	54	.000	1.045	.91	1.18
Environmental management	15.429	54	.000	1.045	.91	1.18
Health and Safety improvement	12.153	54	.000	.991	.83	1.15
Value maximization	14.125	54	.000	1.027	.88	1.17
Cost reduction	7.278	54	.000	.704	.51	.90
Energy minimization	10.376	54	.000	.815	.66	.97
Quality improvement	12.136	54	.000	.944	.79	1.10
Continuous improvement	8.921	54	.000	.791	.61	.97
Resource management	12.416	54	.000	.882	.74	1.02
Design optimization	12.387	54	.000	.955	.80	1.11
Performance maximization	14.317	54	.000	.973	.84	1.11
Elimination of unnecessary process	9.456	54	.000	.809	.64	.98

Table 10 presents the statistical divergence between the less experienced and the more experienced using Kruskal Wallis test for grouping variable. The shaded benefits (reduced cost and lead time, improvement in Health and Safety, increased compliance with customers' expectation and increased employee morale) are statistically significant.

Table 10 Kruskal Wallis test for statistical divergence between less and more experienced

Benefits of synchronising lean and sustainability	Chi-square	df	Asymp. Sig.
Improved corporate image	6.993	4	.136
Improvement in sustainable innovation	8.662	4	.070
Increased sustainable competitive advantage	9.321	4	.054
Reduced cost and lead time	10.248	4	.036
Improved process flow	6.225	4	.183
Increased compliance with customers' expectation	12.614	4	.013
Improvement of environmental quality	8.469	4	.076

Increased employee morale, and commitment	13.044	4	.011
Reduction in material usage	7.285	4	.122
Reduction in energy consumption	14.313	4	.006
Reduction waste	7.825	4	.098
Reduction in water usage	3.638	4	.457
Increased productivity	5.021	4	.285
Improvement in Health and Safety	11.856	4	.018

a. Kruskal Wallis test
b. Grouping variable: Number of years of professional experience

Test of hypotheses

The hypotheses of this research as mentioned above are tested using the Kendall's coefficient of concordance (W). In Table 11, 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). These results therefore make it possible to reject the null hypotheses. Therefore, the alternative hypotheses as follows were accepted:

- 'There are general understanding of the concept of lean and sustainability in the construction industry'
- 'The uptake of the lean and sustainability concept is dependent on the awareness of the benefits that can be derived from the implementation of lean and sustainability
- 'There are synergies/linkage between lean construction and sustainability'

Table 11 Kendall's coefficient of concordance test of agreement

No of cases	W	X^2	Df	Significance
28	.413	1249.362	108	.000

Discussion

The response rate of the questionnaire survey is 79%. Idrus and Newman (2002) submit that a response rate of 30% is good enough for research of this nature. The reliability value of the survey as derived by the Cronbach's alpha was 0.807. Sekaram (1994) considered a reliability of less than 0.6 as poor, in the range of 0.7 as acceptable and over 0.8 to be good, so the reliability of the data can be considered as good. Majority of the respondent's (83.6%) had more than five years of experience as shown in figure 1. This suggests that most of them are experienced and have a thorough knowledge of construction projects. 43.6% of the respondents had less than 40% practice of lean construction on their organisation's project, 41.8% of the respondent had above 40% to 70% practice of lean construction on their organisation's project, 14.5% of the respondents had over 70% to 100% practice of lean construction on their organisation's project. Only 14.5% of the respondents had over 70% of lean construction practice on their project. This could be because the concept of lean construction is still relatively new and yet to be fully adopted or implemented by construction industry as a result of barriers to the implementation of lean construction and reasons and excuses for the slow adoption of lean in UK construction as mentioned by Mossman (2009). The least value for the mean score for all the benefits of lean construction and sustainability was 3.20 which shows that generally all the respondents agreed with the benefits of synchronising lean construction and sustainable construction. Also, there is no statistically significant difference between the less and more experienced respondents on most of the benefits of synchronising lean and sustainability except for four of these benefits where the value of $P<0.05$ which connotes that there is significant differences between the less and more experienced (see Table 10).

The most used lean techniques are just-in-time, visualisation tool, value analysis, daily huddle meetings and value stream mapping while six sigma is the least used techniques for enabling sustainability. Previous studies show that environmental benefits, such as reducing waste of out dated components, reducing vehicle emissions, and reusable packaging are attributed to just-in-time (Ross and associates, 2004). Similarly, just-in-time has been identified as a major component of lean construction concept with the overall objective of ensuring that the correct quantities of materials are delivered to the exact location as at when needed (Eriksson, 2010). Conversely, there seems to be low use of some lean techniques, this could be attributed to the slow rate of adoption of the concept of lean.

The most important areas of linkage between lean and sustainability are waste reduction, environmental management and value maximisation while cost reduction is the least ranked area. From the analysis, it could be seen that waste reduction is the strongest area of linkage between lean and sustainability. This is probably because construction wastes are non-value adding and they constitute serious threats to sustainability and value maximisation. Cost reduction was the least ranked linkage probably because of the associated implementation cost in lean or the cost of operating in a sustainable manner. However, the respondents regarded all the identified areas of link as important, since the least mean value was 3.20. This suggests that there are synergies and linkages between lean construction and sustainability. Successful integration and implementation of lean and sustainability will foster the delivery of maximum benefits from both concepts, particularly in their areas of linkage.

One of the major limitations of this study is that the responses obtained are views of each respondent representing their respective organisation, and there might be differing views among respondents within the same organisation. However, this limitation would be overcome by the use of a qualitative approach. Different personnel ranging from strategic to operational staff within the same organisation would be interviewed in other to verify the results of the survey. It should also be noted, that the results presented are based on the perception of respondents of organisations that have had experiences with lean management application.

Furtherance to this study, the survey would be broadened and deepened by a more robust approach through the use of case studies and this will be validated by expert opinions in the area of lean and sustainability. The future research will scrutinise the barriers and success factors to the implementation of lean and sustainability, how the impact of lean construction can be assessed in sustainable construction, as well as the core drivers of lean and sustainability. Simonsson *et al*., (2012) illustrated the economic benefits of improving lead times, reducing inventories and lowering manufacturing costs on the effects of work flow improvements with increased profitability as the resultant output. The concept of lean construction has provided the conceptual basis and potential for exclusive techniques and tools for sustainable construction and alerts the construction professionals to the importance of sustainable development while delivering sustainable benefits. These benefits cut across the social, economic and environmental aspect of sustainable development. Other studies have established that the environment and society also benefit where lean and sustainability are linked, by working in a lean and cost efficient manner, and reducing usage and wastage of materials and utilities (Wu and Low, 2011; Construction Productivity Network, 2009; Bae and Kim, 2008).

Conclusion

Lean construction impacts on the three aspects of sustainable construction which are social, economic, and environment. This paper addressed the benefits of lean implementation in sustainable construction in terms of improvement in health and safety (reduction in accident rates) through the use of tools and techniques of lean construction, waste reduction, and environmental improvement. These benefits are not limited to the aforementioned. Social and economic benefits are also derived through the implementation of lean. For example, waste reduction usually leads to value generation and increased productivity. Improved health and safety will create a conducive working environment which is a social benefit. Also, the core elements of lean construction have been discussed extensively, reflecting the three stages of lean construction implementation and the associated benefits. The overall perspective of professionals within the construction industry, according to questionnaire survey shows that benefits such as improved corporate image and sustainable competitive advantage, improved process flow and productivity, improvement in environmental quality and increased compliance with customer's expectations etc. are realised following the integration of principles of lean construction and sustainable construction within construction industry. However, the most used lean techniques for enabling sustainability are just-in-time, visualisation tool, value analysis, daily huddle meetings, and value stream mapping. In descending order of ranking, the identified areas of linkage between lean and sustainability are 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, and cost reduction.

Further research will be carried out to establish the key drivers of lean construction and sustainability in order to develop a conceptual framework to assess lean implementation efforts, benefits of lean approach in sustainable construction and focus attention on areas for improvements. Thus, the contribution of lean construction techniques to sustainable construction cannot be over emphasised.

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A REVIEW OF LEAN CONCEPT AND ITS APPLICATION TO SUSTAINABLE CONSTRUCTION IN THE UK

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Abstract

The UK Government has recognised the importance of the construction industry in achieving the overall goals of sustainable development. Therefore the Government has put several policies and strategies in place to achieve a more sustainable construction. Sustainable construction is considered as the application of sustainable practices and sustainable development principles to the activities of the construction sector. Lean construction is a new production philosophy which has the potential of bringing innovative changes in the construction industry. The Lean principles focus on the minimisation of both material and process wastes which in turn contribute to sustainable construction in terms of energy consumption and improvement in health and safety etc. This study aims at exploring the concept of sustainable construction and examines how the lean approach can impact on the sustainability practices within the construction industry. The study uses literature review to achieve the stated aim. The findings revealed that the application of lean construction principle, tools and methods have direct contributions to the attainment of sustainable practices within the construction industry. However, the study postulates that the better understanding of lean concept, proper implementation and integration of lean and sustainability concepts are required for lean construction to contribute to sustainable construction.

Keywords: *Lean construction, Sustainable Construction, Sustainability*

1.0 Introduction

The UK construction industry is noted for its economic contribution with an output worth over £100billion a year. It provides employment for over three million workers and accounts for eight per cent of gross added value [1]. Nonetheless, the construction industry is also noted for its poor safety record evident from high rate of accidents on construction sites leading to workers injury or loss of lives [2]. This suggests the reason why more attention is paid to the sector. However, there are other benefits to be gained from a more sustainable construction industry. The adoption of a sustainable approach was suggested to lead to important business benefits and address the shortcomings of the construction industry identified in the Rethinking Construction report. This reflects that becoming more sustainable could lead to efficiency, profit-orientated practice and achieving value for money, as it is about helping society and protecting the environment. There is a growing awareness as to the competitive advantages that can be convened by businesses taking a sustainable approach [3].

Lean construction is a new production philosophy which has the potential of bringing innovative changes in the construction industry. The concepts and principles of lean is to generally make the construction process leaner by removal of waste which is regarded as nonvalue generating activities [4]. The removal of waste (process and material) and value generation in terms of adding value to the customer are the major contributions of lean construction to sustainable development [5]. This is achieved by the use of lean principles: pull system, flow, value stream mapping, continuous improvement and involvement of employees.

There are several key factors to be taken into action by the construction industry. These factors have been suggested by the UK Government in its strategy for more sustainable construction [6]. These factors include:

1. Design for minimum waste
2. Aim for lean construction
3. Minimum energy in construction and use
4. Pollution reduction
5. Preservation and enhancement of biodiversity
6. Conservation of water resources
7. Respect for people and local environment
8. Setting targets
9. Monitoring and reporting in order to benchmark the performance

Among several factors, the lean construction principles will be focused on, as the main area of this study is to critically review the concept of Sustainable Construction (SC), and examine how the application of lean principles can impact on the sustainability practices within the construction industry. Accordingly, this study pulls from two main bodies of literature: i.e. the literature on sustainable development and lean construction in the broader context of the construction industry (see Figure 1). As earlier mentioned, the construction industry is considered as a key sector for achieving sustainable development goals because it plays a vital role in the drive to promote sustainable growth and development.

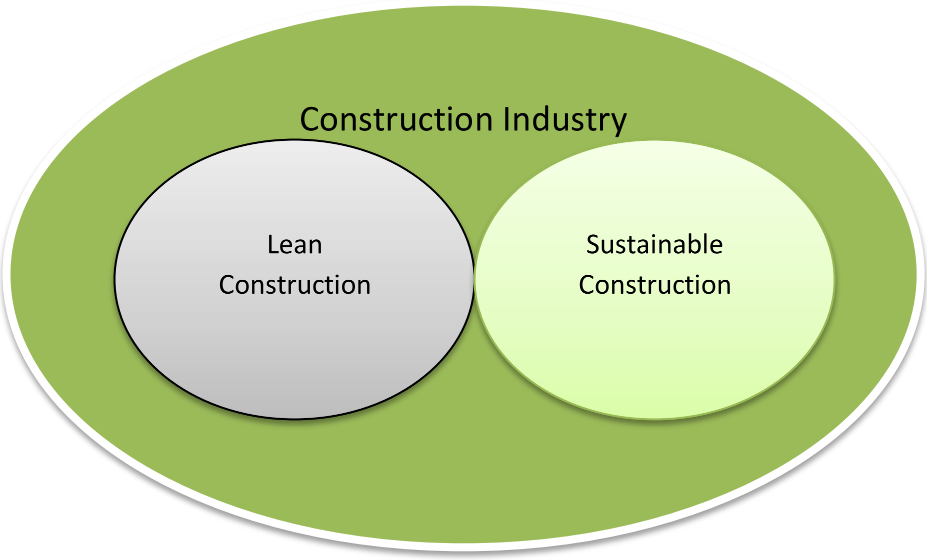

Figure 1: Literature review focus

The potential of lean to contribute to sustainable construction has been raised for discussion [5]. Therefore, it is of utmost importance to examine the possibilities of lean contributing to sustainable construction. Several studies have been carried out on lean and its application within construction at project level with great benefits achieved and there are many studies that have investigated lean construction and sustainability separately [7, 8]. However, studies that highlight the contributions of lean construction towards sustainability are few. The insufficiency of literature addressing this issue and the absence of research-based papers are assumed as a lack of awareness of the potential of lean construction as a means of achieving sustainability and an unrecognised relationship between sustainability and lean construction objectives. For instance, Forbes et al.[9] proposed a framework for providing technical support for lean methods application in some environments in developing countries. Sacks et al. [2] developed a research framework for analysis of the interaction between lean and BIM. However, there has been little or no study done to look at the impact of lean on sustainable construction in terms of developing a framework at the organisational level. Against this background, this study aims to examine the contributions of the implementation of the lean approach in sustainable construction.

2.0 Sustainable Construction

It is difficult to describe sustainable construction without defining or describing sustainable development. There are several definitions of sustainable development given in the literature [10, 11]. Sustainable development is a broad concept which has been adopted and interpreted in numerous contexts. For example many authors have seen the concept as vague and fuzzy [12, 13]. According to Sage [14], sustainable development refers to the fulfilment of human needs through simultaneous socio-economic and technological progress and conservation of the earth's natural systems. However, the most popular definition of sustainable development is the one given in the Brundant report "development that meets the needs of the present without compromising that ability of future generations to meet their own needs" [15]. Nevertheless, there are some areas of agreement in the various definitions. This reflects that the goal of sustainable development is to enable humanity all over the world to satisfy their basic needs and enjoy a better quality of life without compromising the quality of life of future generations. The concept of sustainable development has been described with three dimensions: economic, social and environmental aspect. Sustainable development and social responsibility have become increasingly important strategic issues for companies in virtually every industry [16].

The term sustainable construction means different things to different people as there are multiple definitions, and variance in terms of scope and context as well as practices [11, 12, 17]. Bourdeau et al. [17] stated that sustainable construction practices are widely different depending on how the concept of sustainable construction is developed in various countries. Therefore, simply put, sustainable construction is the response of the building sector to the challenge of sustainable development [5].

The implementation of sustainable construction is still under explored. The decision making process and the actors as well as the inter-relationship has to be understood when implementing sustainable construction [18]. The issues of sustainable construction are divided into 3 aspects: the environmental, economic and the social issues. CIEF [19] suggests sustainable construction as a solution for significant cost savings, to bring innovations and to enhance competitiveness for long time survival of any organisation. Sustainable construction practices not only provides increased market share and profitability but also brings many other intangible benefits such as visible brand name to the organisation in the industry, quality in construction, employee motivation and satisfaction, improved customer's satisfaction, and complements / awards from regulatory authorities and improved shareholder relations [19, 20].

3.0 Lean Thinking in Construction: Lean Construction

The application of lean thinking in construction was pioneered by Koskela who suggested that construction production should be seen as a combination of conversion and flow processes for waste removal. The concept of lean is attributed to the manufacturing industry and was introduced to construction [4].The use of lean concept has been advocated in the UK, several seminars and initiatives have been undertaken in an effort to encourage its uptake. The Construction Industry Research and Information Association (CIRIA), Construction Productivity Network (CPN), Construction Lean Improvement Programme (CLIP) and the Lean Construction Institute UK (LCI-UK) are some of the examples of institutions established. Seminars and conferences have been organised to tease out the main issues in the development and awareness of lean construction principles with real life case studies of some construction organizations presented [19]. In spite of these efforts, there seems to be some barriers to the successful implementation of lean construction. Generally the rate of lean implementation within the UK construction industry is relatively low and the application of lean in sustainable construction is still under explored [21]. Some studies have identified the barriers to the implementation of lean construction. These barriers need to be overcome in order for construction industry to reap the benefits of implementing lean construction. The application of lean principle to construction has been presented to result in benefits such as as improved quality, improved safety, waste reduction, increased productivity, more client satisfaction, increased reliability, and improvements in design.

A study carried out by Sarhan and Fox [22] reveals that there seems to be positive trends in the development of a lean culture among UK construction organisations. Lack of understanding of how to successfully apply lean thinking principles to specific construction processes was also revealed. This study of lean culture within the UK construction organisations was carried out after the study of Common et al., and Johansen and Walter [22]. Lean thinking has become an important concept within the UK construction industry following the Egans report. There has been significant improvement in the agenda for change in the UK construction industry. Few studies have been carried out in order to establish the current levels of awareness and implementation of lean thinking within the UK construction industry. An example of such studies is the application of the Last Planner into a UK construction project. Last Planner is one of the lean tools and techniques and perhaps the most developed tool. The tool was applied to a UK construction project to ascertain its value and its possible barriers. However, the study raised a number of important structural and cultural problems for the success of Last Planner in the UK [23].

Shah and Ward [24] pointed out that it is essential to differentiate between those studiesconsidering lean from a philosophical perspective related to guiding principles or overarching goals, and those analysing the concept from a practical perspective as a set of management practices, tools, or techniques that can be observed directly. The implementation of lean
construction have been targeted towards some specific tools and principles without a full integration on different aspects such as supply chain, safety, planning and control, production design and management, culture and human aspects [25-27]. Framing an encompassing definition that covers all aspects of lean is seen as a difficult task [28]. Alves et al., [26] stated that there are many meaning of lean when applied to construction. Therefore, this study deems it fit to scrutinize various definition of lean as applied to construction. Table 1 presents various definition of lean.

Lean offers significant benefits in terms of waste reduction and increased organizational and supply chain communication and integration. The elimination of waste leads to cost benefits advantage, however these are pre-requisite for creating a lean process. The lean implementation effort stage one focus on waste elimination from a technical and operational perspective [29]. Process Mapping, Value Stream Mapping, and 5S (Workplace Organisation) are some of the tools for achieving such processes. There are 7 types of waste identified under lean: overproduction, overstocking, excessive motion, waiting time, delay and transportation, extra-processing, defect and rework. In the same manner, there are various methodologies for attaining lean production: just in time (JIT), total quality management, concurrent engineering, process redesign, value based management, total productive maintenance and employee involvement.

Table 1: Definitions of Lean

Sources	Definition
Manrodt[30]	Lean is a systematic approach to enhancing value to the customer by identifying and eliminating waste (of time, effort and materials) through continuous improvement, by flowing the product at the pull of the customer, in pursuit of perfection
Ballard et al. [31]	Lean is "a fundamental business philosophy – one that is most effective when shared throughout the value stream"
Lean Construction Institute [32]	Lean construction is a production management-based project delivery system emphasising the reliable and speedy delivery of value
Radnoret al. [33]	Lean is a philosophy that uses tools and techniques to create a change of organisational culture in order to implement the 'good practice of process/operations improvement that allows the reduction of waste, improvement of flow, more focus on the needs of customers and whichtakes a process view'

Construction Industry Institute [34]	"The continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and pursuing perfection in the execution of a constructed project."
Shad and Ward [24]	''an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability.''

3.1 Lean Approach in Sustainable Construction

Lean construction is one of the strategies for improving the sustainability of construction, in other words one method of achieving sustainable construction. Lean approach in sustainable construction focuses on the removal of all forms of wastes from construction processes to allow more efficiency. Existing studies have suggested theories to support that lean is a method for optimising resources, improving safety, productivity, working condition and overall, the social, environmental and the economic bottom line [35]. There are several forms of waste under the lean terminology: processes, material and poor safety are considered as a potential wastes that hinder flow of value to the client. Construction should be seen as flow processes (consisting of both waste and conversion activities), not just conversion processes [4]. The promotion of health and safety practice can contribute to sustainable construction by enhancing workers' social life and minimising direct and indirect cost of accidents. Material waste elimination has been identified as the most efficient and cost effective approach to promote sustainable practice on construction sites. Similarly, the principles of lean construction focus on creating a sustainable change by stressing on efficient, waste-free and safe flow, storage and handling of materials to minimise cost, energy and resource consumption, and provide value for clients and end users [7].

Some of the key issues of sustainability identified in the literature include: global warming and climate change which is seen as one of the main threats to the environment as a whole [36]. Peng and Pheng [37], investigated the contribution of the lean concept to achieve low carbon in the construction sites using precast concrete products and found that the lean concept can be adopted to reduce carbon emission in terms of re-designing the site layout, improving the supply chain and installation work flow. Many studies have highlighted the contributions of lean construction towards the environmental aspect of sustainability. For example Huovila and Koskela [5] presented minimisation of resource depletion, pollution and matching business and environmental improvement as the contribution of lean construction to sustainable development. However, the contribution of lean construction to sustainable development is not limited to the environmental aspect but also to the social and economic aspect. The different lean applications might have different results on the three pillars of sustainable development.

The lean impact has been described to cover the economic, social and environmental aspect of sustainable construction. This include more value to client with less waste of time and resources, process improvement and overall project delivery, productivity improvement, cost reduction, improved quality and safety as well as promotion of continuous improvement. A good example of this is the case study of the modular home building by Nahmens [29] which was carried out to evaluate the use of lean construction to improve sustainability. Lean construction strategies serves as a platform for improvement in the delivery of the sustainable modular houses. Figure 2 presents the main effect of the application of the lean concept for the purpose ofsustainability in the aforementioned example.

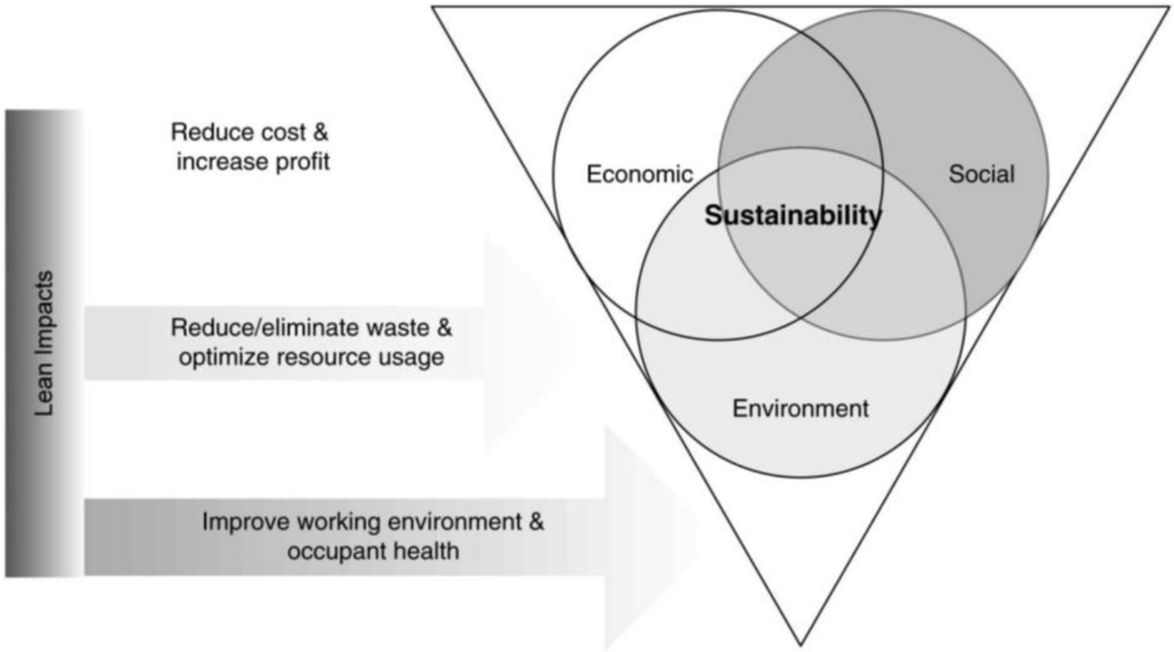

Figure 1: Conceptual model: effect of lean on sustainability
Source: (Nahmens and Ikuma, 2009)

As much as adopting lean concept has been attributed to positive influence on sustainable construction in terms of improved safety, many research works have shown both negative and positive effects of lean on safety. However, in terms of sustainability, lean and safety influence economic sustainability by reducing costs and increasing productivity, environmental sustainability by reducing or improving materials and social sustainability by affecting the wellbeing of workers.

3.2 Sustainable Practice and lean concept

According to Tan et al., [38], Sustainable construction practices include five major areas: compliance with sustainability legislation, design and procurement; technology and innovation; organisational structure and process; education and training; and measurement and reporting. The successful implementation of lean and sustainable concepts by an organisation depends on the level of commitment and knowledge. The implementation of sustainability throughout the organisation including the organisation's project will yield more result than when implemented only on the project [39]. Different company characteristics can influence the choices in sustainable construction practices. The selected sustainable construction practices should be consistent with the overarching strategy. The benefits of implementing sustainable practices include improved regulatory compliance requirements; reduction of liability and risk; enhanced reliability among customers and peers; reduction of harmful impacts to the environment; prevention of pollution and waste (which can result in cost reduction); improvements in site and project safety (by minimising injuries related to environmental spills, releases and emissions); improved relationships with stakeholders such as government agencies, community groups, and clients [40].

The benefits of implementing sustainable practices in construction can be grouped under environmental, economic and social aspects. Hall and Purchase [41] stated that numerous sustainability and lean practices, such as productivity, safety, efficiency, and waste minimisation, are interconnected. The conceptual relationship between lean and sustainability has been presented in the literature. Lean practices can be adopted in a construction project at design phase to reduce costs and enhance sustainability [42, 43]. Few studies have been carried out to investigate the application of sustainability and lean concept. Despite the pressure on the construction industry to adopt the concept of sustainability to improve the current unsustainable pattern of project delivery, its uptake is relatively slow i.e. the adoption of sustainable practice in construction project. Koranda et al., [8] developed a framework for implementing lean techniques and sustainability in a construction project as shown in figure 3. This framework captured the major sustainability issues at project level.

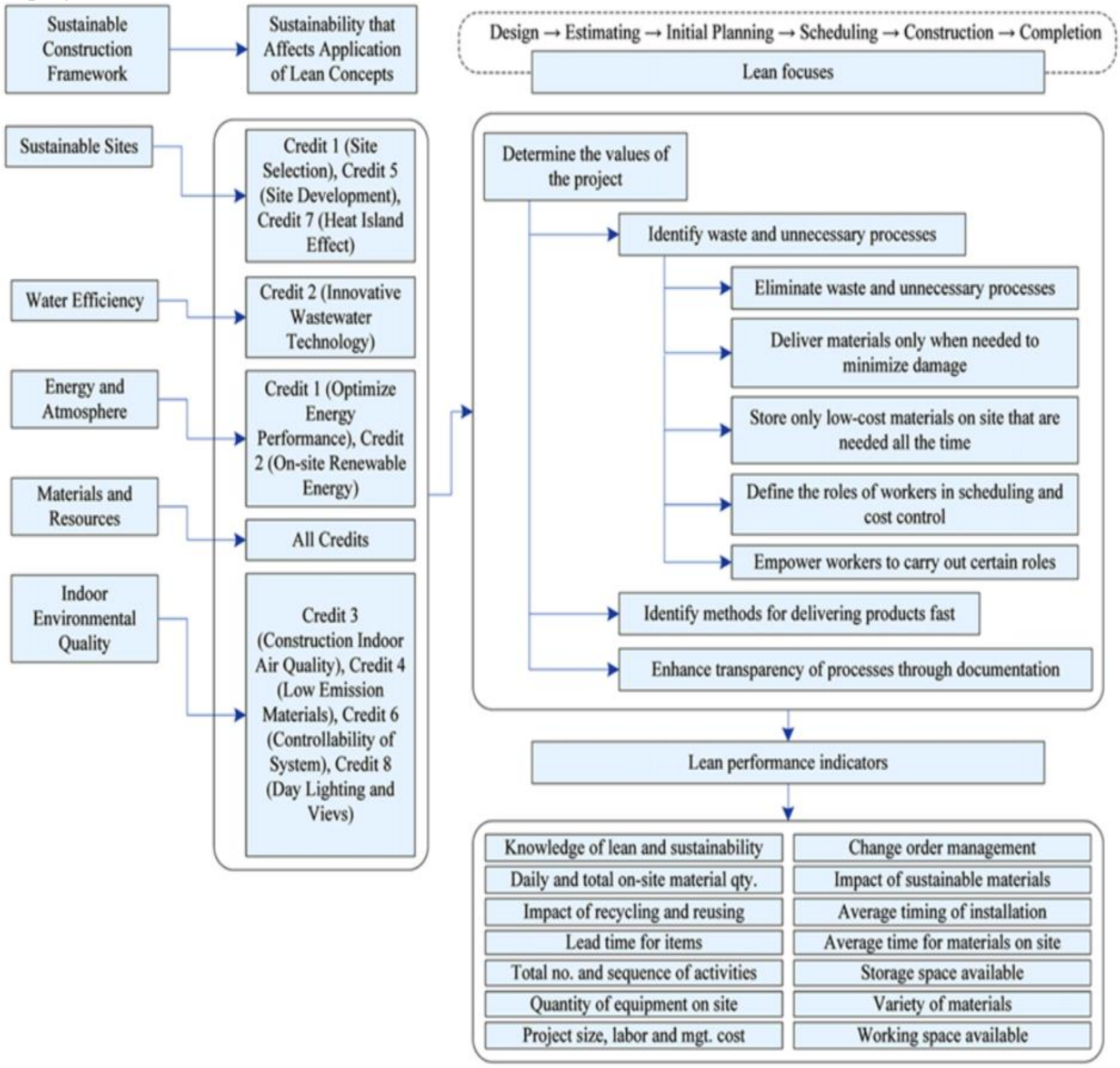

Figure 3: Framework for implementing lean techniques and sustainability in a construction project (Source: Koranda et al. 2012)

There is need for leadership participation in the quest for attaining a more sustainable construction as the leadership role in construction organisation is one of the paramount factors that can provide an overall vision, direction and vision towards the attainment of a sustainable construction. Therefore, it is highly essential that leaders have full knowledge of the concept of sustainability to be able to guide their organisations effectively [44]. Likewise, top level leadership commitment has been identified as one of the success factors for the implementation of lean. This suggests that thorough understanding of lean and sustainability concepts as well as principles are necessary for proper application on a construction project.

3.3 Lean Tools and Methodologies for Sustainable Construction

Various lean tools and techniques for enabling sustainability have been discussed by several authors. Some studies have explored various issues of sustainability by means of lean initiatives and established the benefits that can be derived by applying the lean principles/tools [42, 45]. Lean design methods such as Integrated Design, Design for Maintainability (DFM), Setbased Design, Target Costing and 3D Modelling can be used during the construction of sustainable project. Many studies have suggested integrated design method to be one of the most critical methods for sustainable construction [46-48]. Just-in-time (JIT) is a major component of the lean construction concept, the principle of just in time is to ensure that the correct quantities of materials are delivered as at when needed in the right quantity to the exact location in good condition [49-51]. Bae and Kim [43] carried out the quantitative assessment of lean methods and sustainability impacts of construction project. This was based on the lean project delivery phases which include: lean project definition, lean design, lean supply, lean assembly and whole delivery process. It was revealed that most lean construction methods provide positive economic impacts for sustainable projects while there are few negative impact as well as the combination of both impact (positive and negative) on the social and the environmental aspects.

There are many lean tools and techniques/principles among which 5S, value stream mapping, just in time, visualisation tool, last planner, value analysis, pull approach and continuous improvement appears to be the commonly adopted lean tools and techniques/principles [45]. Value stream mapping (VSM) is the mapping of wastes throughout the organisation. 5S and value stream mapping are commonly noted for environmental improvement. 5S helps companies to look at their workplace in a new dimension. Companies use 5S to clean and streamline areas within their works, removing unwanted parts, tools and general debris and setting a new standard for cleanliness and tidiness. It also helps in organising construction site, thereby resulting to environmental improvement and health and safety improvement.

4.0 Conclusions

The study has drawn from literature on both lean and sustainability reflecting the principles of lean and how it impacts on sustainable construction. Better understanding of lean concepts by the construction industry can contribute to improvement in all aspect of sustainable construction. The concept of lean and sustainable construction both seeks to minimise waste, but this is achieved through different approaches. There is need for construction stakeholders to set their priorities before the start of a project for better integration of the two concepts. More emphasis should be laid on lean approach in sustainable construction framework. There should be more level of commitment and knowledge by an organisation in order to successfully implement and derive maximum benefits from the concept of lean and sustainability. However, the application of lean in sustainable construction is not only possible on the operational level; it could also be applied at the strategic level. Therefore, this study will go on to further present the application of lean and sustainability at the strategic level and also explore the benefits that can be achieved.

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The Application and Implementation of Lean Delivery Methods in PPP Projects

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Lean Project Delivery (LPD) seeks to align interests, objectives, and practices through a team based approach where the primary team members are the owner, design professionals, prime contractor, and key subcontractors (trades partners). LPD is a project centric delivery in which the owner, engineers, and contractors sign a single contract for achieving project goals. LPD encompasses a number of Lean techniques where "Lean techniques" is a broad term that utilises a variety of tools, strategies and technologies to increase levels of integration and cooperation on construction projects while improving quality, shortening project duration and reducing costs. Lean Project Delivery (LPD), Integrated Project Delivery (IPD) and Integrated Lean Project Delivery (ILPD) are different terms being used to represent Lean delivery method. These terms all focus on the concept of creating a project / team centric approach to achieve project goals. This paper aims at exploring and describing lean techniques and the set of non-traditional project delivery approaches of achieving value for money in Public Private Partnership (PPP) projects through a systematic thorough literature review and case studies. It was revealed that the application of the lean project delivery to construction projects delivers a better integration of the individual management components to maximise project benefits. Therefore, LPD is suggested as a means of ensuring greater quality, lower costs, and quicker time to market for future projects.

Keywords: Lean techniques, design and build, value, lean project delivery, integrated project delivery

INTRODUCTION

There has been a continuous urge by the construction professionals seeking to apply better technologies and processes to improve project delivery, but there is a retarded rate in change due to lack of unified strategy. Lean concept was adopted from the manufacturing industry since the adoption of lean philosophy has made the manufacturing industry become globally competitive with improved performance (Shad and ward 2007; Achange et al. 2006; de Treville and Anatonakis 2006). Lean construction applies specific techniques in a new construction project delivery approach. Lean techniques describe a set of non-traditional project delivery approaches to managing the host of collaborative relationships that exist on a project. Lean project delivery method is based on collaboration between designers and constructors from a project's inception (Wodalski et al. 2011). It makes use of relational contract principles to join all of the strengths and capabilities of the owner, designers, and constructors and focus them on one goal: the efficient delivery of the project as a whole (Ballard and Howell 2005).

Project delivery method has been defined by the Associated General Contractor (AGC) (2004) as "The comprehensive process of assigning the contractual responsibilities for designing and constructing a project. A delivery method identifies the primary parties taking contractual responsibility for the performance of the work". The aim of this paper is to explore and describe lean techniques and the sets of non-traditional project delivery approaches of achieving value for money in PPP projects. Therefore, a brief introduction of the PPP arrangement in construction projects will be presented as well as the traditional project delivery system Design- build. This paper will be centred on the design build contractual agreement and the contractual provisions contained in IPD agreement for lean construction, for better understanding of how value for money is achieved in PPP projects.

PUBLIC PRIVATE PARTNERSHIP AND LPD

The term Public Private Partnership (PPP) has been used to describe a vast range of contemporary political and financial functions as well as the working arrangements within projects and organisations in several areas and industrial sectors globally. It involves bringing in creative skills and management efficiency from business practice and reducing government risk involvement in the provision of public services by using private companies for an effective approach to enhance project productivity (Cui and Lindly 2010).

There are several types of PPP arrangement that have been used on many projects; this includes the build-operate-transfer (BOT) and its variants such as build-transfer-operate (BTO), design-build-finance-operate (DBFO), build-own-operate (BOO), design-build-operate-maintain (DBOM), and several others (Yang et al. 2010). However, the five major types of PPP arrangements for delivering transportation projects are: Private Contract Services Approach, Alternative Project Delivery Approach, Multimodal Partnerships, Joint Development and the long-term Lease or Concession Agreements. There are several combinations based on the phases in which the private partner takes responsibility under the alternative project delivery approach. These combinations according to Yang et al. (2010) include the Design-Bid-Build (DBB), Construction Manager-at-Risk (CM at Risk), Design-Build (DB), Design-Build with a Warranty (DBW), Design-Build-Operate-Maintain (DBOM), Design-Build-Finance-Operate (DBFO), Build-Operate-Transfer (BOT), Build-Own-Operate (BOO).

Lean Project Delivery (LPD) seeks to align interests, objectives, and practices through a team based approach where the primary team members are the owner, design professionals, prime contractor, and key subcontractors (trades partners). LPD is a project centric delivery in which the owner, engineers, and contractors sign a single contract for achieving project goals (Wodalski et al. 2011). Lean Project Delivery (LPD), Integrated Project Delivery (IPD) and Integrated Lean Project Delivery (ILPD) are different terms being used to represent Lean delivery method. The allocation of project risk to the party that is best equipped to manage the risk instead of just passing the risk to the next contractor in line is one of the key ways that PPPs shift delivery toward LPD (Federal Highway Administration 2010).

THE SHIFT TOWARDS LEAN PROJECT DELIVERY METHOD

There are several methods of traditional project delivery approaches: this includes the Design-Bid-Build (DBB), Design-Build (DB), Construction Management (CM) (agency or at-risk) etc. The emergence of the Design- Build came into play due to the deficiencies of the DBB. Design-build has been selected by both public and private clients to save cost, reduce schedules and encourage design innovation (DBIA 2005).

Owners started to realise that project costs were higher than they needed to be with the DBB method as a result of the extra contingency money added by the contractor to cover for those unforeseen conditions like design changes and late project deliveries. Another challenge of DBB is the lack of collaboration among subcontractors in the form of resistant to taking responsibility for work coordination with other subcontractor (Bearup et al. 2007).

DB enabled the general contractor to manage the complete project, usually including the designers. DB projects tend to shift more risk and liability to the general contractor and may reduce the degree of owner participation (Gannon et al. 2012; Bearup et al. 2007; Elwardani et al. 2006). It is therefore evident that the DB was an improvement over the DBB. However, the DB did not solve all the challenges encountered, despite the wide range of options available including construction management option, many owners remain unsatisfied: thus, the introduction of a different project delivery opportunity which seeks to address some of the root causes that potentially limit the effectiveness of other models. The proposed method involves a contractual combination of "lean project delivery" and an integrated team. The Integrated Agreement for Lean Project Delivery offers improved project performance both from the owner's perspective (reduced cost and time, improved quality and safety) and from the viewpoint of the designers and contractors (increased profit and profit velocity, improved safety, and employee satisfaction) (Lichting 2006) .

Different terms are being used interchangeably in Lean delivery; namely, Lean Project Delivery (LPD) (Lichtig 2005), Integrated Project Delivery (IPD) (Post 2010; Darrington, 2011) and Integrated Lean Project Delivery (ILPD) (Walker 2009). These terms all focus on the concept of creating a project centric / team centric approach to achieve project goals. The application of lean construction techniques can result in risk reduction, collaborative innovation and schedule acceleration. The difference in the traditional approach and the integrated approach is represented in Table 1

Table 1: Comparison of Traditional approach and Integrated Approaches - Characteristics

Traditional Project Delivery		**Integrated Project Delivery**
Fragmented, assembled on "just-as-needed" or "minimum necessary" basis, strongly hierarchical, controlled	Teams	An integrated team entity composed of key project stakeholders, assembled early in the process, open, collaborative
Linear, distinct, segregated; knowledge gathered "just-as-needed;" information hoarded; silos of knowledge and expertise	Process	Concurrent and multi-level; early contributions of knowledge and expertise; information openly shared; stakeholder trust and respect
Individually managed, transferred to the greatest extent possible	Risk	Collectively managed, appropriately shared

Individually pursued; minimum effort for maximum return; (usually) first-cost based	Compensation / Reward	Team success tied to project success; value-based
Paper-based, 2 dimensional; Analog	Communications / Technology	Digitally based, virtual; Building Information Modeling (3, 4 and 5 dimensional
Encourage unilateral effort; allocate and transfer risk; no sharing	Agreements	Encourage, foster, promote and support multi-lateral open sharing and collaboration; risk sharing

Source: (American Institute of Architects (AIA) National and AIA California Council, 2007)

The four main general problems with the traditional approach identified in lean construction literature are that in the traditional contract there are contracting limits cooperation and innovation, pressure for local optimisation at the expense of the project as a whole, good ideas are held back, and an inability to coordinate (Matthews and Howell 2005) .

Integrated Project Delivery (IPD) is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimise efficiency throughout the design, fabrication and construction phases (AIA 2007). It can be applied to a variety of contractual arrangements. Integrated Project Delivery encourages early contribution of knowledge and makes use of principles such as: mutual respect, mutual benefit, trust, early goal definition, team success tied to project success, enhanced communication, clearly defined open standards, shared risks and reward, appropriate technology, value based decision making, high performance, and leadership.

IPD adopts a relational value based contracting approach. This approach stresses relationships, collaboration and mutual goals. Collaboration and innovation are encouraged between the various team members throughout the design and construction process through a mutual financial stake in the project outcome. The key project participants' interests are aligned with defined project objectives rather than individual responsibilities and the consequences of failure commonly emphasised in more traditional contracts (O'Connor 2+--009). Becerik-Gerber and Ghassemi (2011) presented the fundamental differences between the IPD and the traditional delivery methods in terms of the contracts, project team relationship and compensation structures. There are several advantages of the IPD; these advantages are not only for the owners but for all the parties involved in the design and construction process. It eliminates the redundancy of design as efficiencies in the design are maximised and reduces future conflicts. Additionally, Sive (2009) (as cited in Becerik-Gerber and Ghassemi 2011) argues that for IPD to be realised in its purest form, all its characteristics must be combined in a project. These characteristics are: early involvement of key participants, jointly developed project goals, shared risk/reward among key participants, joint and collaborative decision making, a multi-party contract and reduced liability exposure (AIA 2007).

LEAN INTEGRATED PROJECT DELIVERY IMPLEMENTATION THROUGH DESIGN-BUILD CONTRACT

Darrington (2011) suggested that design-build contracts can be useful means for the implementation of Lean Integrated Project Delivery. Various methodologies and contracts have been formed by The American Institute of Architects to back up the integrated project delivery. This provides the framework for a collaborative environment in which the parties operate in furtherance of cost and performance goals that the parties jointly establish (AIA 2005). The IPD agreement is influenced by lean construction. Lean construction is the application of lean thinking to the design and construction process creating improved project delivery to meet client needs and improve profitability for constructors (Howell 1999).

Becker et al. (2012) presented the similarities and differences in the contractual form of agreements of design-build and lean construction with a structured framework for intensive review. These similarities and differences are based on the contract topics contained in the lean construction agreement and the design-build agreement. This comparison and the contract-based framework as shown in Figure 1 are presented for the purpose of promoting deeper dialogue and knowledge generation regarding lean construction.

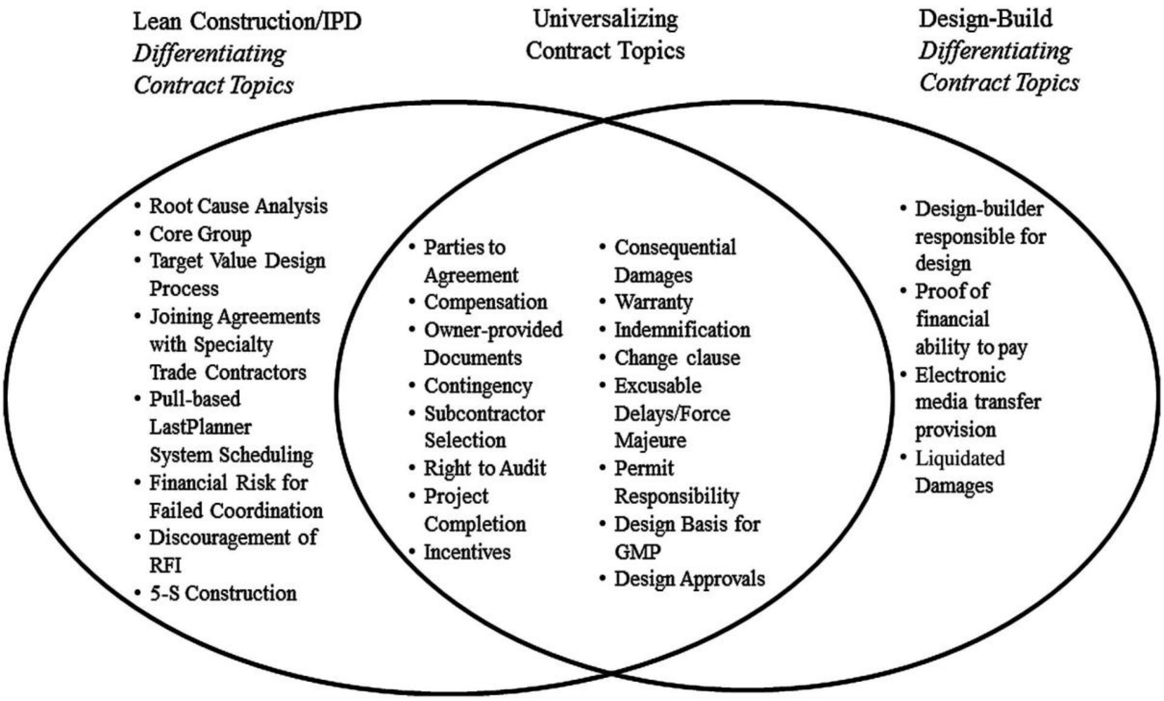

Figure 1: Comparative analysis of contractual topics contained in representative lean construction and design-build contract agreements (Source: Becker et al. 2012)

PPPS, LEAN TECHNIQUES AND INNOVATION IN CONSTRUCTION PROJECTS

One of the characteristics of the construction industry which inhibit innovation is the traditional competitive bidding in which functional responsibilities are separated (Leiringer 2001). According to Asad *et al*. (2005), it is generally recognised that the promotion of innovation across the supply chain can offer the clients and service providers in the construction industry key benefits in terms of adaptability, financial growth and improved service delivery. Hence as clients demand more value for money in an increasingly competitive and challenging economic climate, the ability of construction firms to survive and grow will depend very much on their ability to successfully create, manage and exploit appropriate innovation (Barrett and Sexton 2006). In this regard, it is very significant that Leiringer (2001) argues that PPP can be a useful tool for overcoming some of the proven inhibitors of innovation in construction. This is because, according to Leiringer (2006), PPPs are believed to provide tangible incentives for stakeholders as well as a conducive business environment to promote innovation. PPPs are therefore seen as one of the ways of promoting lean construction, which is no doubt one of the emerging innovations in sustainable construction. On the other hand, the lean approach facilitates the allocation of project risks to the party best able to manage them, which is one of the key features of PPPs.

More specifically, a recent report by Papadopoulos (2012) on PPP projects in the UK National Health Service (NHS) has revealed that lean techniques helped to establish trust among PPP partners to facilitate dispute resolution. The report added that the benefits of LPD such as increased interaction and communication between project participants, making processes more efficient through waste reduction, etc. helped to develop collaborative relationships and speed up the resolution of conflicts among the PPP partners.

LEAN CONSTRUCTION TECHNIQUIES FOR ACHEIVING VALUE IN PPP PROJECTS

The lean construction techniques have been categorised into: incremental and transformative techniques. Adopting lean practices requires behavioural change amongst all participants, from top-level management to bottom-level worker; this can be achieved by both regularly practicing lean and orienting new participants through discussions. Wodalski et al. (2011) examines the benefits of lean techniques in the delivery of transportation projects and suggested that the implementation of lean techniques with a lean project delivery (LPD) can promote the achievement of higher quality, faster completion and more efficient delivery for future projects.

The provision of value added to the consumer and public at large has been considered as one of the advantages of PPP. Subsequently, many researches have posed the research question of how value for money and risk transfer can be achieved and operationalised (Broadbent, 2003). However, studies that highlight the possibility of lean techniques in achieving value in PPP projects are few. This makes it difficult to describe to what extent the lean techniques have been employed a present in PPP projects. Additional value can be achieved in PPP projects if there is an effective implementation structure and if the objectives of the parties can be met within the partnership using lean techniques. Emmitt et al. (2004) stated that work in lean has focused on the management of value in construction projects by using process tools to identify and minimise uncertainty and improve work flow in production. Craving for value maximisation starts from the initial team composition. The following section discusses the aforementioned lean techniques. This study does not intend to give any new or more precise usage of lean techniques or either explores the level of usage of lean techniques employed in PPP projects but to present a generic description of some lean techniques which have been applied in PPP projects. The view is that it will be of great importance to present or emphasise the applicability of lean approach to increase/promote the awareness of the use of lean techniques in project value enhancement.

Collaborative planning

Collaborative Planning is the process of involving all stakeholders in a project at the same time in order to ensure that all participants are on the same level. In this manner, the design team and owner, the general contractor, sub-contractors and suppliers gather as a team to form a master plan, and then to develop a detailed analysis of the activities planned for the first quota of the project. This is similar to partnering, the International Partnering Institute (IPI) (2010) defined "patterning as a collaborative process that works to develop a "culture" of partnership between the organisations and teams that must work together to achieve the successful delivery of construction projects." A collaborative partnership model for facility owners during design and construction has also been developed. Collaborative planning has been introduced in an endeavour to discontinue the traditional hierarchical and 'bureaucratic' processes, to involve new groups and networks, new 'partnerships' (Healey, 2003). Collaborative relationship and partnership have been described in the literature as preferential situations which are beneficial to all parties involved (lamming, 1996; Bowen, 2000).

Value stream mapping

Value Stream Mapping (VSM) is a special type of flowcharting tool that is valuable for the development of Lean processes. The technique is used to visualise product flows through various processing steps. The tool also illustrates information flows that result from the process as well as information used to control flow through the process (Rother et al. 2009). To create a Lean process, one needs to have a full understanding of the construction process, including production processes, material flows, and information flows. VSM is a two part process, first depicting the "current state" of the process, and second a possible "future state" (Jacobs et al. 2010). The concept of value needs to be understood early in a project during the design phase. The process of determining value will be a learning process between the client and the design professionals as it is a new concept. Value stream mapping is a lean thinking analogue tool for depicting production processes and for understanding and improving conditions for reducing variability and waste (Rother and shook 2000).

Last planner / collaborative scheduling

The use of lean methods and Last Planner is promoted in the Integrated Form of Agreement that was first published in 2005. The Last Planner System of Production was developed by Ballard based on Koskela's work (Ballard 2000). An essential behaviour for lean construction is promise keeping, project is delivered by people the 'Last Planner' i.e. the lead tradespeople in a network of commitment having the parties to construction make promises to carry out assignments, and keep their promises. Then, the outcome is increased productivity, predictable work flow, reduced waste, and projects can be completed more rapidly. "Last Planner" technique reveals that the use of formal and flexible production planning procedures is the first step to keep the production environment stable. It emphasises the use of the Daily Production Plans, Constraint Analyses, Lookahead, and the Percentage of Planned and Concluded items (PPC) as tools for immediate implementation on any jobsite (Ballard, et al. 1994). The use of Last Planner will create commitments at a personal level where individuals would be responsible for specific work items and allow for any variances to the schedule to be analysed because a specific reason for not completing the work would be identifiable. This allows individual tasks to be tracked, the PPC of each task to be easily measured and any problem could be addressed immediately instead of reoccurring throughout the project.

The notion behind the Last Planner is that the project team works together to help identify and remove those constraints that are keeping teams from achieving all of their tasks in a given week. The Last Planner functions with the use of "should, can, will, did." The "should" part comes from the master schedule which generally identifies when certain tasks should be performed. “Can” identifies those tasks which are ready to be performed. “Will” represents the tasks that each partner will be performing during the week, and “did” represents the tasks that were successfully completed during the week. The understanding on how each task is completed and continuous evaluation of the project is made possible by the “should, can, will, did” cycle. The true outcome from the Last Planner method is that it allows commitments to be measured throughout the project. This is extremely useful in measuring reasons why work was not completed. The process can reveal poor planning, poor execution, unreasonable promises, and numerous other reasons that work is not completed on time. By identifying these problem areas during the project instead of after, allows for a proactive approach to developing solutions.

Just-in-time delivery (JIT) and supply chain management

Just-in-time delivery is an inventory strategy that reduces in-process inventory and reduces carrying costs. The principle is to deliver the right material, at the right time, at the right place; in the exact amount needed (Ohno 1988).The best tools to address this problem are Just-in-time Delivery (JIT) and Supply Chain Management, which are very closely related to each other. JIT coordination of the supply chain is required to manage the flow of workers, materials, parts, components, and subsystems procured to and from a site during construction (Davies et al. 2009). There have been shift from traditional arms-length relationship to relationships based on trust and cooperation (collaborative relationship). This has been presented by several literature. The fragmented nature of construction industry regarding the supply market and the adversarial relationship of participants has been traced to lack of integration between design and construction, and the way problems are addressed in a contractual manner between supply chain actors.

Supply chain collaboration has been defined by Cao et al. (2010) as “a long term partnership process where supply chain partners with common goals work closely together to achieve mutual advantages that are greater than the firms would achieve individually”. Admittedly, many researches have been carried out on supply chain management in the aspect of the benefit of cooperation on project performance in terms of time, cost, buildability, quality and innovation (Hines et al. 2000; Bennett and Jayes 1995; Thipparat, 2011). Integrated supply chain management (ISCM) often referred to as lean thinking or supply, has been regarded as best practice (Hines et al. 2000; Womack and Jones 1996).

Daily huddle meeting

A daily start-up meeting is carried out to achieve the full involvement of employee in issues regarding the project and solving problems. The team presents brief of what they have been working on since the last meeting and brings to attention any problem that hinders the achievement of target (Schwaber 1995). The huddle meeting increases employee’s job satisfaction, since it encourages two way communications. Two-way communication is the key of the daily huddle meeting process in order to achieve employee involvement. It empowers workers to respond to problems straight away.

Pull schedule

Pull techniques have been applied to construction for managing work flow. It was first developed in manufacturing. A primary technique of the new production management thinking is pull. The main objective of a "pull-driven" approach is to produce finished products as optimally as possible in terms of quality, time, and cost, so as to satisfy customer demand (Ballard 1999). Pulling is a technique for matching up the various elements needed to actually perform work. "Pull" technique has been shown to improve performance of a construction process. A successful lean pull technique has been reported in a pipe-spool construction process (Tommelein 1998). The pull technique assumes that all participants in the project supply chain are willing and able to respond to each other's needs in order to optimise overall project performance, not just their own. This requires rethinking of contractual relations and providing appropriate incentives. The benefits and the obstacles of applying pull techniques have been reviewed in extant literature and a question have been posed about its application in the design of a construction project (Ballard 1999). The benefits reported when properly implemented include: earlier project completion, smaller buffers and increased productivity (Tommelein 1998).

Transformative Techniques

Target costing

Target costing is a management practice that drives design to deliver customer values, and develops design within project constraints. It is also referred to as target value design (Ballard 2007). It is intended to reduce the overall cost of a product over its life-cycle. Target costing draws on many disciplines, including engineering, research, design and production management. The target costing approach makes cost an input into the design process instead of an outcome.

Target costing begins in the design phase of a project. In target costing, the cost is defined before the design is complete. As a result, the cost requirements are closely interlinked with the project requirements. The cardinal rule of target costing is that the target cost must never be exceeded (Cooper et al. 1997).

CASE STUDIES

Case studies of public projects have been carried out in order to gain more insight about the application of lean techniques. Various lean techniques that have been used in case studies includes process mapping, 5-S strategies, value stream mapping, pull operations, standard work, improved supply chain logistics, JIT and Last Planner etc. to achieve projects benefits such as greater quality, lower costs, and quicker completion time. The case study examples in this study were selected based on relevance, unit of analysis (which in this case is public projects) and the most popular lean techniques. For example Last planner is the most developed lean techniques and JIT is commonly used on many projects.

Heathrow Airport (case study)

Many lean techniques were adopted during the Heathrow Airport terminal 5 project in the United Kingdom in order to finish the project on time and within budget. The supply chains and value streams were mapped to determine the quantities of materials and resources required for the civil phase of the project from the initial stage. There was high security measure during the construction work as Heathrow was a known terrorist target (Wodalski 2011). Construction traffic was restricted to 7:00 AM – 9:00 AM and 4:00 PM-6:00 PM due to public involvement in the project. This lead to limiting onsite storage of inventory to one day or less, and system of materials supply was classified into three categories:

- Made to stock – Suppliers produced based on forecasted market demand;
- Made to order – Suppliers produced standard products upon receipt of an order; and
- Engineered-to-order – Engineering must be completed prior to producing the order.

This classification was essential as coordination of the supply system was indispensable. The resulting production management system was coordinated by daily production control meetings and weekly forecast meetings. These were used to pull materials from engineering through fabrication and delivery to site installation. The identified potential problems on the job site and overlapping activities were addressed by discussions during the weekly meetings. Actions agreed to at the meetings were recorded in minutes and were reviewed the following week. According to (Ballard et al. 2007), the end results of the civil phase of the project show that there was an 8%-9% overall savings from planned expenses and all major milestones were achieved on or ahead of schedule. This case study was an example of JIT techniques, although many other lean techniques were applied during the project.

Proyecto de Adecuación de la Refinería Cardón (PARC) case (source: Ballard et al. 1996)

The Proyecto de Adecuación de la Refinería Cardón (PARC) was a case study example of Last Planner implementation on a project. This project was a 2.1 billion dollar refinery expansion that included approximately 300 national subcontractors, three major EPC (engineering, procurement and construction) contractors, and consumed 50 million field hours (Ballard, et al., 1996). The project was reported to be the first major construction project on which Bechtel implemented Lean strategies such as the Last Planner and demonstrated the potential effectiveness of a Lean tool on a construction project.

Three questions were asked by the author to improve productivity on the project:

1. How well is the project supplying the basic elements of work (information, materials, tools, equipment, etc.) to the crews?

2. What is the method used by the crew to perform the work?

3. How well does the accomplishment of the work itself fill the needs of the workers?

The improvement strategy focused on improving reliability in order to improve performance. Thereby, making the predictability of work flow on the project more easily determined.

CONCLUSION

This paper has identified the set of lean project delivery approaches which could be used to enhance value and improve collaboration in PPP projects. PPP procurement has been seen as an effective way to achieve value for money (VFM) in public infrastructure projects. The several types of PPP arrangements that have been used on many projects have also been explored although; these are not described in detail. The lean techniques for achieving value for money in PPP projects are not limited to those described in this paper. From the case study examples and the literature review, it was revealed that the application of the lean project delivery to construction projects delivers a better integration of the individual management components to maximise project benefits. This suggests the need for the adoption of LPD as a means of ensuring greater quality, lower costs, and quicker time to market for future projects. This study recommends more use of lean construction techniques for project value enhancements in PPP projects as the adoption of these techniques can result in risk reduction, collaborative innovation and schedule acceleration. However, LPD has emerged since 1990 and it is being presently used in project delivery but the concept is relatively new compared to the holistic approach of project delivery. This study will contribute to the awareness of the adoption of LPD in PPP projects as there are relatively few studies that have examined or evaluated the use of lean techniques specifically in PPP projects. Therefore, this study tries to bridge this gap by describing lean techniques in general and presenting case study examples of where it has been applied in public projects. Further studies can be done to evaluate the level of usage of lean techniques on PPP projects and quantify the benefits of adopting LPD on PPP projects.

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Lean Procurement: The Use of Lean Construction Techniques in Project Value Enhancement

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Abstract:

Lean construction is characterised by a set of clear objectives in project delivery involving the concurrent design of products and processes, and the application of production control throughout the project life cycle to maximise value for money to customers. The successful delivery of construction projects requires the effective use of project management techniques such as risk and value management to achieve the optimum performance of a constructed facility over time. However, it has been argued that lean construction came about as a result of the failure of current project management to provide an integrated project delivery process in which design, construction, operation, and maintenance are considered as a whole with an understanding of how to enhance value delivery to clients, stakeholders (including occupants), and society in general. This paper explores in depth the lean construction techniques that support environmentally sustainable benefits and value enhancement in the design and construction processes (including supply chain management). It also explains how the implementation of lean techniques in construction project delivery and procurement strategy (including partnering relationships between contractors, consultants and manufacturers) delivers a high level of benefits and value.

Keywords

Construction project, lean construction, procurement, value, value management

INTRODUCTION

Lean construction is a production management-based approach to project delivery; a new way to design and build capital facilities which is based on the principles of lean thinking and production. The implementation of lean within construction is a value seeking process that maximizes value and continually redefines perfection. Lean construction came about as a result of the failure of current project management to provide an integrated project delivery process in which design, construction, operation, and maintenance are considered as a whole with an understanding of how to enhance the delivery of value to clients, stakeholders (including occupants), and society in general. This has brought a significant reform to construction process in terms of waste minimisation, value maximisation/enhancement, performance optimisation, environmental management etc. through the use of lean construction techniques that support environmentally sustainable benefits and value enhancement in the design and construction processes (including supply chain management).

This paper explores in depth the lean construction techniques that support environmentally sustainable benefits and value enhancement in the design and construction process (including supply chain management). It also explains how the implementation of lean techniques in construction project delivery and procurement strategy (including partnering relationships between contractors, consultants and manufacturers) delivers a high level of benefits and value.

A key component of lean thinking is to identify all the value adding time and reduce the non-value added activities as there is a glaring and indisputable need to improve the delivery of value to clients, stakeholders, and society in general while at the same time driving down cost and the time to deliver operational constructed facilities (Bicheno, 2007).

Research methodology

The research is a theoretical one which is based on a systematic literature review. The literature sources were accessed through web of knowledge which provides access to leading citation databases covering numerous journals and conference proceedings. Also, some textbooks were found useful in the research process.

Lean production and current practices

Current project management views a project as the combination of activities while lean thinking forces attention on how value is generated rather than how any one activity is managed. Production in lean construction is managed so that actions are aligned to produce unique value for the customer. Lean production is defined by Todd (2000) as “initiative, whose goal is to reduce the waste in human effort, inventory, time to market, and manufacturing space to become highly responsive to customer demand while producing world class quality products in the most efficient and economical manner”.

Value to the customer and throughput, the movement of information or materials to completion are the primary objectives. According to Womack and Jones (2003), lean thinking can be summarized as to correctly specify and enhance value, identify the value stream, make the product flow, let the customer pull value, and pursue perfection. Lean thinking has been considered to be one potential approach for improving organisational performance in terms of value generation (Womack et. al. 2003). The research of Hines et. al. (2004) which was based on the framework suggested by McGrill and Slocum (1993) reflect the relationship of value and cost and reaching the cost-value equilibrium created awareness in the managers’ vision of evolving towards lean thinking.

Supply chain management

Supply Chain Management (SCM) has been defined by Tommelein et.al (2003) as “the practice of a group of companies and individuals working collaboratively in a network of interrelated processes structured to best satisfy end customer needs while rewarding all members of the chain” SCM is characterised with achieving increased competitive advantage in the construction market. Supply chain participants such as owners, contractors, suppliers etc are still in search of a better understanding of supply chain, its dynamics and how they can increase their competitive advantage by applying it (Arbulu and Ballad, 2004). SCM is closely related to lean supply (Lamming, 1996). The basic concept of SCM includes tools like Just-In-Time delivery (JIT) and logistics management. The current concept of SCM is very broad but still largely dominated by logistics.

Arbulu and Ballard (2004) proposed a strategy to improve the management of supply systems in construction using lean principles and techniques with the objective of assuring on-time delivery of information and materials to project sites at least cost and maximum value for the final customer. This strategy includes the use of lean techniques like Kanban to pull selected materials on a just-in-time basis from suppliers or logistics centres to site. Moreso, an extensive literature search has been carried out by Mollenkopf et al (2010). It revealed the barriers, drivers, converging, and contradictory points across the three supply chain strategies namely green, lean, and global supply chain. Sharing of information among partners of a supply chain will not only reduce the operation costs of each of the partners, but the efficiency of this `trust' based business transaction will give rise to a sense of `customer satisfaction' along the value chain.

Lean construction techniques for environmentally sustainable benefits

Vinodh et al (2010) carried out a study on tools and techniques for enabling sustainability through lean initiatives by exploring various issues of sustainability as well as the strategies/ techniques that would enable the achievement of sustainability objectives using lean initiatives. It has been revealed through literature that lean principles are aimed at waste reduction and therefore results in capital gain, achievement of sustainable benefits as well as improving sustainability of an industry. Some of the sustainable benefits from lean principles include: reduction in material usage, energy consumption, hazardous waste, water usage etc. these benefits are presented in Table 1 below. According to The Environment Protection Agency (EPA) (2011), many organisations have found that implementing lean concepts and tools results in improvements in environmental performance, even when lean activities were not initiated for environmental reasons. However, since environmental savings are often not part of the "business case" for lean improvement activities, organisations implementing lean do not necessarily quantify the environmental performance gains associated with their lean initiatives case studies and best practice.

Some of the case studies and best practice examples of environmental benefits that resulted from lean initiatives are presented in Table 2 below. In addition to these case studies, a study was carried out on US construction companies investigating whether lean thinking principles were been adopted and if so, what results were being achieved and what were the perceived barriers in the approach. Four company case studies were completed and results show that office construction times reduced by 25% within 18 months, schematic design reduced from 11 weeks to 2 weeks, turnover increases of 15-20%, productivity increased, satisfied clients looking to place repeat orders increased, and project costs reduced. The study showed that although there was different application of lean principles which showed some interesting initial result, all companies were partnering and a number of the suppliers were very keen to undertake lean work and were fully co-operating (Garnett et al, 1998).

Lean Construction Techniques/Strategies for Value Enhancement

The suitability of lean construction techniques to promote value in construction has been raised for discussion since the issue of value in construction is a complex one requiring the combination of several different value strategies within one project (Ogunbiyi et al, 2011). The main strategies for implementing a value management approach to improve on lean construction methodologies in order to contribute to sustainability implementation and performance improvement has also been explored. Egbu et al (2004) stated that Value

Management and Value Engineering are techniques for enhancing value within a project by defining what will deliver value in a specific project, engineering a best value solution to meet those defined value parameters, and then delivering a cost effective solution. Green (1999) has put forward the concept of value generation during the early stage design phase as a learning process between the client and the design professionals such that there was a joint understanding of client's value parameters and their realisation in the design.

Table 1: Environmental benefits of lean principles (Source: Vinodh et al, 2010)

Lean Principles/tools	Sustainable benefits
Pull approach	Reduction of work-in-process, elimination of potential waste from damaged products, lesser floor space utilization
Cellular manufacturing	Reduction in set-up times and change over time hence low energy and resource usage, reduction in defects
Value Stream Mapping	Reduction in waste through fewer defects, less scraps, low energy usage, etc.
5s	Reduction in lighting requirements due to clean windows, leaks attended to immediately, reduced consumption of materials and chemicals
Total preventive maintenance	Less hazardous waste due to decreased spills and leaks, increased longevity of equipment
Six sigma	Fewer defects hence less waste, improvement in product durability and reliability hence increase in product lifespan
Pre-Production Planning	Reduction of waste at design stage, usage of right sized equipments, reducing the complexities of production processes and product design
Kaizen	Elimination of hidden wastes and unwanted activities
Visual controls	Identification and elimination of unwanted entities hence less material usage and wastes
Lean supplier networks	Introduction of lean to existing suppliers would lead to better realization of environmental benefits
Poka Yoke	Reduction in defects hence less waste, low energy usage, less scrap

Value management is one of the performance improvement tools and techniques. It is a structured method of eliminating waste from the brief and from the design before binding commitments are made. Value management is now used by up to a quarter of the construction industry to deliver more effective and better quality buildings, for example through taking unnecessary costs out of designs, and ensuring clearer understanding of the brief by all project participants and improving team working (DETR 1998) .

Table 2: Case studies of environmental benefits of lean principles (Source: http://www.epa.gov/lean/environment/studies/)

Case company	Sustainable benefits
DuBios- Johnson Diversey and Steel case	Lean practices resulted in: Energy savings of a 60 percent reduction in the BTUS required Reduction in water usage by 80 percent Waste stream was cut by 85 to 95 percent
Canyon Creek Cabinet Company	Expect savings of almost $1.5million annually from process changes

	Process improvements included reduction in lead time, work-in-progress, defect, overproduction, downtown, operator travel time, and material loss and damage Decreased VOCs which will reduce permitting requirements
Columbia Paint &Coating	Reduction of 15,000 lbs of paint solids from wash water saved 18,000 lbs of shrink wrap Removed 2,820 lbs of hazardous materials from the waste stream
Lockheed Martin	Reduced hazardous waste resulting in cost savings due to the elimination of RCRA permit requirements Reduced facility size by 1/3 (a reduction 550,000 square feet) Reduced chemical storage capacity to 2% of it's original size

Lean project delivery system

A new system of delivering building projects on the basis of the principles of lean production has been proposed. This new system is termed Lean Project Delivery System (LPDS), which is seen as a project delivery method that conceptualizes design and construction projects as lean production systems (Ballard, 2000). Figure 1 illustrates the Lean Project Delivery System. The five interconnecting phases of the LPDS model include: Project Definition, Lean Design, Lean Supply, Lean Assembly, and Use. Each of the phases contains three modules and is represented as a triad. Each triad overlaps the succeeding triad to include at least one common module. For example the Project Definition phase includes purposes, design criteria and design concepts and overlaps with the Lean Design phase which includes design concepts, process design and product design. Also, two modules of Production Control and Work Structuring extend throughout the lifecycle of the project. Some important features of LPDS include downstream players in the planning process, conceptualizing the project delivery as a value generating process, and creating a reliable workflow amongst the project participants.

The domain of Lean Project Delivery is defined by the intersection of projects and production systems and is therefore fully applicable to the delivery of capital projects which include the formation of a temporary production system in the form of a project team that consists of owner, architects, engineers, general contractor and sub-contractors. The lean philosophy minimising waste and maximising value should be applied as early as possible in the design and construction process, i.e. at the briefing and early planning phases. In lean approaches, the desire to maximise value and reduce waste starts at the beginning (initial team composition).

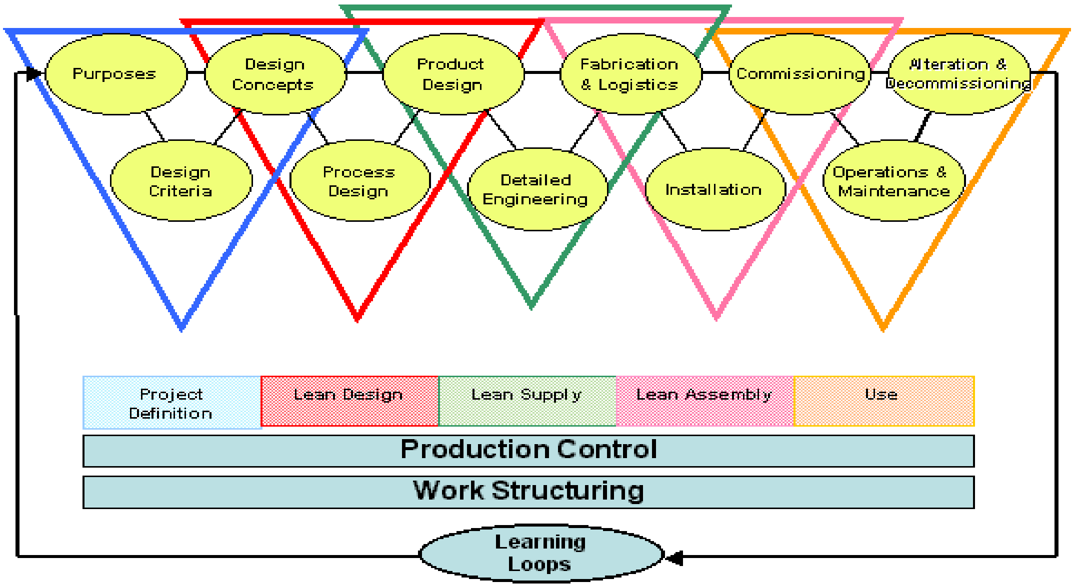

Figure 1: LPDS system (Source: Ballard, 2000)

According to Garnett (1998), there are five lean principles which were described by Womack and Jones (1996) within which lean construction techniques can be successfully applied. This is represented in figure 2 below.

In construction, specifying value comes before design and value is defined by the ultimate customer's needs through tools such as value management, quality function deployment and simulation (Ballard and Howell, 1998). The key technique behind value stream is process mapping for a very specific reason: i.e. that of understanding how value is built into the building product from client's point of view. Flow is concerned with achieving a holistic route by which a product is developed. The basic units of analysis in lean construction are information and resources flow. Improvement is possible by reducing uncertainties in workflow. Redesigning the planning system at the assignment level is the key to assuring reliable workflow and this step has to be implemented early. The principle of pull makes use of just in time applications to meet the client needs and subsequently customising and delivering them more predictably when the client requires them.

Lean construction methodologies/tools

Salem et al. (2005) carried out an evaluation on the Lean Construction tools such as: Last Planner, increased visualization, daily huddle meetings, first run studies, 5s process, and fail safe for quality and safety. The effectiveness of the lean construction tools was evaluated through the lean implementation measurement standard and performance criteria. It was found that last planner, increased visualization, daily huddle meetings, and first run studies achieved more effective outcomes than expected.

Last Planner System

The Last Planner system of production control, introduced in 1992, which emphasizes the relationship between scheduling and production control, is the most completely developed lean construction tool (Ballard 2000). The Last Planner System has been described by Ballard and Howell (2000) as one method for applying lean techniques to construction.

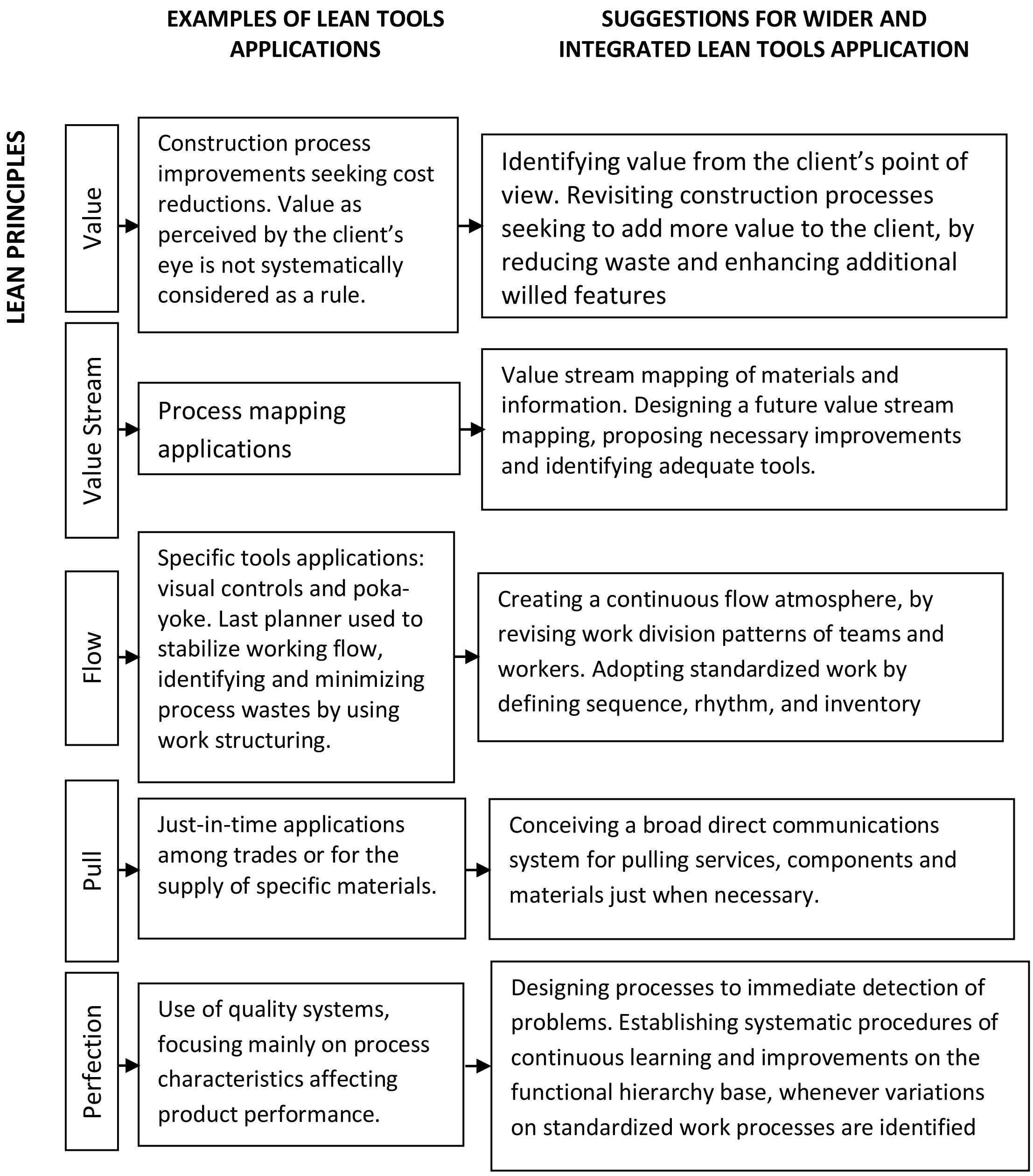

Figure 2: Examples of lean tools already reported in construction implementation and suggestion for wider and integrated application for the sector (Source: Picchi and Granja, 2004)

It provides productive unit and workflow controls and facilitates quick response to correct for deviations from expected outcomes by using root cause analysis. According to them, the Last Planner is based on three levels of schedules and planning tools:

- The master pull schedule serves as the overall project schedule, as contrasted with the detailed critical path schedule that is the more traditional management tool.
- The look-ahead schedule reflects major work items that need to be completed for the milestone dates in the master pull schedule to be met. This schedule is usually based on a six to eight week time frame, and uses items “pulled” from the master pull schedule; they are carefully reviewed to ensure that they are free of constraints that cannot be removed within a given time.
- The weekly planner schedule delineates the work activities or assignments “pulled” from the look-ahead schedule that must be initiated to meet the completion dates in

that schedule. Eligible activities or assignments are those that have no current constraints, and that have resources available and assigned.

Several examples of the application of lean construction techniques were presented by Forbes et al (2002). These include a Brazilian company which collaborated on a research program with the University of Sao Paulo to improve the integration of design and production processes, Verticon Construcao e Empreendimentos Ltda who used last planner on a 90 days construction project and the application of the Last Planner Control System on a housing project in Quito, Ecuador. Some of the benefits achieved are presented respectively: Communication and motivation among the design team influenced the integration of design features with process considerations directly, the implementation of lean construction and control procedures significantly improved production efficiency, in terms of buildability and production cost control, and elimination of not only material waste, but non-adding value tasks as well. A reduction in project duration from 90 days to 83 days, reduced rework etc. The last planner facilitated improved quality control and the application of lean methods, The Percent Plan Complete (PPC) and Performance Factor (PF) improved. It was proven at the construction site that look ahead planning enables one to keep current activities linked with the master pull schedule.

The main idea of the lean construction process is that the same team of suppliers, contractors and consultants work on a series of projects, continually developing the product, applying quality improvement and waste reduction techniques, and incorporating arrangements for learning and continuous improvement. The early stages of partnering are a necessary pre-requisite for improving construction but without the concept of flow production applied at a strategic level, partnering remains only a partial solution. Organising to achieve seamless flow delivery of a product gives purpose to a partnering relationship.

Partnering

Partnering is a long term commitment between two or more organisations for the purpose of achieving specific business objectives by maximising the effectiveness of each participant's resources. The relationship is based on trust, dedication to common goals and an understanding of each other's individual expectations and values. Expected benefits include improved efficiency and cost effectiveness, increased opportunity for innovation, and the continuous improvement of quality products and service (Packham et al, 2003). Partnering has been described by Bubshait (2001) as an innovative and effective project organisation concept and the key elements that contribute to the success of partnering to reduce cost and minimise conflict in the construction industry were discussed. The relationship between main contractors and subcontractors is mainly a transactional one where all parties try to obtain additional value at lowest cost.

This view has been supported by Miller et al (2002) who argued that most subcontractors are small and are fundamentally different to larger main contractors but that the traditional nature of the relationship has seen main contractors attempt to take advantage. Miller et al (2002) reflect on two case studies based on transactional and relational approaches and contrast the levels of trust and willingness to engage between the two. Suggestion was thereafter made that there is need for some form of harmonisation (such as partnering) for lean construction innovations to succeed. Partnering has been presented as a potentially important way of improving construction project performance through the benefits it brings to clients and contractors (Bresnen and Marshall, 2000). Partnering the supply chain is a mechanism process by which the alliance is managed and by which it provides value to its customers. Partnering establishes a base level of trust which allows people within a system to shift their attention to improving at the system level instead of simply defending their interests. But trust is hard to maintain in the absence of reliable work flow. Complex, uncertain and quick projects are likely to fail when only traditional approaches are used with lack of a comprehensive underlying theory, efforts such as partnering are little more than patches (Howell and Ballard, 1998).

CONCLUSION

The lean construction techniques that support environmentally sustainable benefits and value enhancement in the design and construction processes have been extensively explored. It has been established that supply chain management leads to improved understanding of the characteristics of construction supply chain problems and that lean principles and techniques are capable of assuring on-time delivery of information and materials to project sites and value maximisation for the final customer. The implementation of lean principles and techniques at the early stage of construction process will lead to improvement in environmental performance, waste reduction resulting to capital gain, achievement of sustainable benefit as well as improving sustainability of an industry.

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Construction Innovation: The Implementation of Lean Construction towards Sustainable Innovation

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Abstract

The prevalent theory of construction has been seen as a hindrance to construction innovation. The concept of lean construction is concerned with the application of lean thinking to the construction industry. However, in lean construction there are many arguments supporting the view that 'the prevalent theory of production (or specifically, theory of construction) is counterproductive, and leads to added costs and reduced overall performance through the deficient production control principles based on the theory'. Presently, the construction industry and all other organisations face various problems as a result of the uncertainties of the global economic climate; including labour redundancies, delayed projects and zero margin contract bids. The construction industry is seen as one of the worst performing industry as regards innovation. This calls for concern about the poor state of construction innovation. The emergence of lean construction is to bring significant reform to the construction industry to achieve the objectives of sustainability within the built environment in the critical social, economic and environmental aspects. Increasingly, lean construction offers new techniques of constructing sustainable projects. It is about reducing costs by cutting waste, innovating by engaging people and organising the work-place to be more efficient. Hence, the aim of this paper is to highlight the cost and benefits of the potential contribution of lean construction to the attainment of sustainable innovation in construction. An exploratory method of investigation is adopted in achieving the aim of this paper by critically reviewing, exploring, and synthesising literature and industry case studies related to the subject matter. Evidence from the literature reveals that innovation through lean improvement in construction processes has provided proof of sustainability outcomes in terms of reduced waste, effort and time. Hence, lean construction impacts significantly on innovation by enhancing competitiveness, innovativeness, and resource efficiency within the construction industry.

Keywords: Construction industry, Construction innovation, Lean construction, Sustainability

Introduction

Construction industry has been tagged with a poor record of innovation when compared with manufacturing industry. In the UK, the Department of Trade and Industry (DTI, 2007) stated that innovation is "the successful exploitation of new ideas" and that "it is the key business process to compete effectively in the increasingly competitive global environment". Innovation in construction is 'the act of introducing and using new ideas, technologies, products and/or processes aimed at solving problems, viewing things differently, improving efficiency and effectiveness, or enhancing standards of living' (CERF, 2000). This means that innovation can be of two types; namely, change in the product or service being provided, and change in the process by which the product or service is created. However, organisation's ability to promote both process and product has been argued to be no longer sufficient and a third type of innovation has been introduced as strategy innovation (Baker, 2002).

According to Sturges et al (1999), construction faces the challenge of minimising the environmental impact of its consumption of materials and energy; therefore there will be need to become more innovative to meet this challenge. However, complexities within the construction industry make introducing these innovative technologies difficult. For example, each technology may have to be compatible with numerous parties and the residential-construction industry contains a particularly high degree of uncertainty in innovative product adoption (Koebel, 2004; Conference Board of Canada, 2004). The result of the Third UK Community Innovation Survey (DTI, 2004) showed that the construction industry was the worst performing industry in five out of six categories of innovation compared to 11 other industry. This calls for concern about the poor state of innovation, as shown in Table 1.

Table 1- Percentage of construction companies exhibiting innovative activities (Source: DTI, 2004)

Innovative activity	Construction	All industries
Product innovation	6%	18%
Process innovation	6%	15%
Long term activity	3%	9%
Co-operation	7%	8%
Innovation expenditure	27%	36%

Lean construction approach of construction project delivery is aimed at eliminating waste by removal of all non-value adding activities; it's concerned about the environmental management as well as the social and economic aspect of sustainability. Even though innovation has been seen from diverse perspective, researchers and practitioner have agreed on the importance of innovation as a pre-requisite for competitive advantage (Egbu and Ilozo, 2007).

Methods

The methodology adopted in this paper is the review of relevant literature and industry case studies relating to lean construction implementation and sustainable innovation. In-depth exploration and review of research publications on lean construction implementation and innovation was carried out on origin of lean thinking in construction, history of innovation within construction, and impact of lean construction on sustainable innovation.

Innovation history in construction context

According to Koebel and McCoy (2006), researches on innovation have failed to establish standard definitions of associated terms and practices, thus creating confusion. So, innovation is a complex phenomenon which has long history in the literature. The organisation's ability to respond and adapt to external and internal changes have been addressed by early research. Koskela and Vrijhoe (2000) analysed the prevalent theory of construction production from innovation point of view and emphasised the need for more innovation in construction industry.

However, according to Koskela and Vrijhoe (2000), there are many argument in lean construction supporting that 'the prevalent theory of production (or specifically, theory of construction) is counterproductive, and leads to added costs and reduced overall performance through the deficient production control principles based on the theory'. Different types of innovation according to Slaughter (1998) are presented in Table 2 below. Koskela and Vrijhoe (2000) further argued that the incremental and modular innovations are the most frequent in construction.

Table 2: Types of Innovation

Types of Innovation	Explanation
Incremental	Small change with limited impacts on surrounding elements.

Modular	More significant change in the basic concept, but also with limited impact on its surroundings.
Architectural	May consist of a small change in the respective component, but with many and strong links to other surrounding components
System	Consist of multiple linked innovations
Radical	A radical innovation is based on a breakthrough in science or technology and changes the character of the industry itself

Sustainability vs Sustainable innovation

According to de Sousa (2006), innovation can be defined as the outcome of a set of activities that use knowledge to create new value to those benefiting from its use. The keyword here is the creation of new value to those using the innovation. This distinguishes innovation from invention in that innovation is not so much the novelty of a given product or process but the creation of new value to those using the innovation.

According to the Pulse Survey Report of Towers Perrins (2008), there are three factors that can engender sustainable innovation:

1. An understanding that innovation has both external (market-facing) and internal (process and structure) components that must work in tandem and require different organisational competencies.

2. Leadership commitment to the internal side of innovation and to building and sustaining a ‘‘machine.’’

3. Recognition that different groups in the organisation enter and exit the innovation process at different points in time and in different ways. Alignment between what is required in each phase and related organization capabilities and resources is essential to turn ideas into reality.

Barrett and sexton (2006) stated that there appears to be an ongoing shift from viewing innovation as an ‘end’ in itself, to innovation being a ‘means’ to achieve sustainable competitiveness. An organisation’s innovation capability is defined as its ability to mobilise the knowledge possessed by its employees (Kogut & Zander, 1992), and combining this to achieve product or process innovation. Usually, innovation is seen as the conceptualisation of a new product or service, but this is not necessarily always the case. Conversely, Bowonder et al. (2010) argued that a form of innovation was also the introduction of the lean production system in the automotive industry, or even forming collaborative partnerships with suppliers or competitors was a form of innovation when it first occurred.

Hovgaard and Hansen (2004) stated that innovativeness can be manifested in the form of new products, new processes, or new business systems. Example of this is the adoption of an existing technology or product by a company or newness to the market as in the case of an invention (Crespell and Hansen, 2008). Even though doing business in an environmental sound way is often associated with additional costs, there are many driving factors for construction industry to engage in sustainability. The improved corporate image derived from offering a sustainable product is one of the driving factors (Yu and Bell, 2007). Cost savings generation and need to achieve a competitive advantage are other motives (Simpson et al. 2004; Masurel, 2007).

Lean thinking in construction

Lean construction is the application of lean thinking to the design and construction process creating improved project delivery to meet client needs and improve profitability for constructors. It places 'optimising the total value' instead of 'minimising the cost' as the main goal. Within lean, cost cutting has to be seen in perspective of eliminating non value adding activities (Womack and Jones, 2003). According to Höök and Stehn (2008) the adoption of innovative management practices, such as supply chain management and lean thinking, from a manufacturing context (based on continuous processes and relationships) to the discontinuous and project-based construction industry is, however, problematic.

Eriksson (2010) carried out a study on how to increase the understanding of how various aspects of lean thinking can be implemented in a construction project and how they affect supply chain actors and their performance. The core elements of lean construction are investigated reflecting how the various aspects of lean construction can be grouped into six core elements: waste reduction, process focus in production planning and control, end customer focus, continuous improvements, cooperative relationships, systems perspective.

Lean construction and Sustainable construction

There is a growing awareness of the need for sustainability within construction process; similarly, there have been an increased awareness of the implementation of lean construction. These issues have been raised for discussion in the extant literature. Several studies have established the benefits of lean construction in achieving the sustainability objectives in the critical aspect of environmental, social and economic. Huovila and

Koskela (1998) state that sustainable construction is the response of the building sector to the challenge of sustainable development. The term ‘green’, and ‘sustainable’ construction are often used interchangeably. Sustainable construction does not only refer to the buildings and spaces themselves but also the processes or activities used to construct them (Presely and Meade, 2010). Thus, sustainable construction can be defined as a construction process which is carried out by incorporating the basic objectives of sustainable development (Asad and Khalfan, 2007; Parkin, 2000).

According to Sjöström (1998), construction, buildings and infrastructure are the main consumers of resources: materials and energy. In the European Union, buildings require more than 40 % of the total energy consumption and the construction sector is estimated to generate approximately 40 % of the man-made waste. However, the construction industry is bound to bring about positive changes, with the implementation of sustainable construction i.e. less pollution and waste, and even contributes to the well-being of future generations (Said et al, 2011). Sustainable development is a term generally associated with the achievement of increased techno-economic growth coupled with preservation of the natural capital that is comprised of environmental and natural resources. It requires the development of enlightened institutions and infrastructure and appropriate management of risks, uncertainties, information, and knowledge imperfections to assure intergenerational equity, and conservation of the ability of earth's natural systems to serve humankind (Sage, 1998). It was noted by the Sustainable Construction Task Group (SCTG) in its *Reputation, Risk and Reward* report published in 2002, that pressures on businesses in the property and construction sectors to respond to the sustainability agenda were increasing from the environmental, social, governmental, and investment sectors (SCTG, 2002). Sustainable construction has evolved as the industry seeks alternative environmental ways to fulfill current levels of consumption (Presely and Meade, 2010). The business benefits of sustainable construction were considered by the CIRIA Report C563 (CIRIA, 2001). This revealed that adopting a sustainable approach would address the failings of the construction industry identified in the Egan’s report *Rethinking Construction,* (DETR, 1998b), and lead to significant business benefits, including better understanding of client needs, identification of opportunities for innovation, increased shareholder value, reduced costs, reduced risk, enhanced public relations and community liaison, and increased employee motivation. This shows that becoming more sustainable is as much about efficient, profit-orientated practice, achieving value for money, helping society, and protecting the environment.

Impact of Lean construction on Innovation

The effect of lean practices on an organisation competitiveness have been carried out by Lewis (2000) using industry case studies. Two out of the three case studies conformed to the hypothesis that lean practices will result in an overall decrease in organisation's innovativeness while one of the companies maintained an innovative process while applying some lean concepts. Based on the study it was disclosed that the more successful lean principles are applied in an organisation, the more focused the organisation tends to be on incremental production changes, and the less innovative activities are involved. Consequently, another study was carried out by Christensen (2006) to investigate innovations that sustain or disrupt a company's existing competitive advantages. It was established that a sustaining innovation improves existing products along the dimensions of performance that the main stream customers value while on the other hand, a disruptive innovation underperforms in most desired areas by the main stream customers for at least short terms, but offers other valuable features.

In the review of three case studies on lean principles for rapid construction carried out by Yahya and Mohamad (2011), the benefits from lean principles into rapid construction were highlighted as including the shortening of order fulfillment leading times, less project downtime, more innovation, and true reduction in the chronicle predecessor.

Case study 1: (Source: Constructing Excellence by Watson, 2004)

In construction excellence by Watson (2004), the Neenan Company, a design and build firm was identified as one of the fastest growing and most successful construction companies in Colorado. The firm has worked to understand and apply lean construction principles to its business, resulting in reduced project times of up to 30%. The changes were attributed to developments such as:

1. Facilitation of innovation in design and assembly for example via the use of off-site manufactured pre-fabricated bricks.

2. Improvement in site work flow by proper definition of production units, and visualisation of processes

3. Use of dedicated design team on any design from beginning to end.

Case study 2: (Source: Construction in Fortaleza, Brazil by Jose and Alves, 2007)

In the case study of Construction in Fortaleza, Brazil carried out by Jose and Alves (2007), Ceara State Brazil (a construction company in Fortaleza) adopted lean concepts and tools for innovation based on the work of the Lean Institute, Brazil. This was in the early years of the 21st century, and the initial implementation was supported by academics and experienced consultants. The implementation translated into fast and huge productivity gains for the company, and led to organisation of international seminars and events (International Seminar of Lean Construction 2004, 2006) about innovative practices in lean construction, which raised the interest of local and national construction companies.

With time, it became established and glaring that adoption of lean principles facilitated the progress of companies, sustains the innovative practices that have been introduced and implemented, and engenders the introduction of new ones. The inability of some companies to sustain the benefits arising from the use of lean construction principles this way was attributed to lack of integration of lean construction implementation within their business strategy.

Case study 3: (Source: Shepherd Construction in CIRIA, 2009)

In the case study of the difference introduced via lean construction in practice, Shepherd Construction adopted and implemented lean construction in the development of the company's sustainability strategy, waste management procedures, lean construction and resource efficiency practices, and the ISO 9001 and ISO 14001 registered quality and environmental management systems.

The company's *view* of lean construction is elimination of all forms of waste and inefficiency from the construction delivery process while sustainable construction is seen as building the present without compromising the future. Collaborative planning is at the centre of the company's *lean approach* with aim of eliminating unnecessary work and maximising value adding work. Tools and tasks set in place to achieve the lean approach include programming workshops, process mapping, standardized work, workplace organisation, problem solving, data analysis, work sequence analysis, and visual management. The sustainable approach to Shepherd's activities is demonstrated through the triple bottom line of sustainability which is the social, environment, and economics. The links between lean and sustainability are clearly demonstrated in work processes of Shepherd Construction (See Figure 1 below) as there is direct integration of the essences of lean construction with construction sustainability. Thus, lean construction and sustainable construction run concurrently within the company and has led to happier stakeholders, supply chain, and environment.

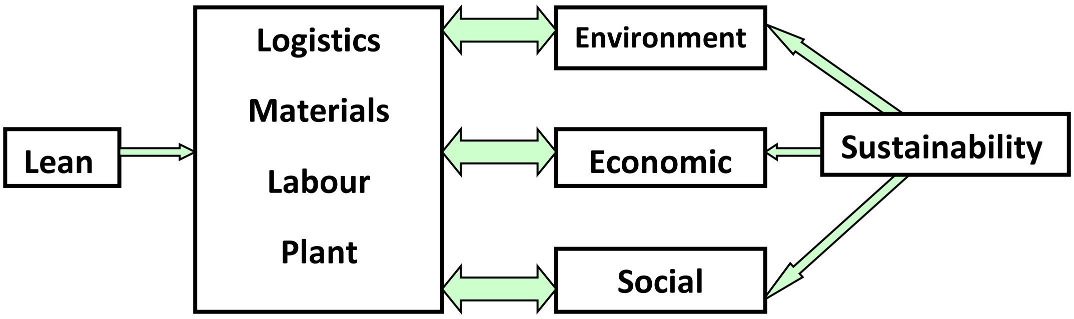

Figure 1: Shepherd's link between lean and sustainability (Source: CIRIA 2009)

Results and Discussion

It has been established through review of existing literature that lean construction contributes to the attainment of sustainable innovation in construction by means of innovation through lean improvement in construction processes. Likewise, review of industry case studies has shown that implementation of lean construction principles facilitates company's progress and engenders sustainable innovation practices in construction design and assembly. Even though the prevalent theory of production (or specifically, theory of construction) is seen as counterproductive, leading to added costs and reduced overall performance, the huge positive impact of lean implementation on sustainable innovation within construction have been quantified and provided proof of sustainability outcomes in terms of reduced waste, effort and time. With Lean construction, there is achievement of more for less by continuous reduction of waste in the construction process.

Conclusion

The lean principles/concepts have been identified and how lean construction impact on innovation towards a sustainable development. The concepts of sustainable construction have also been discussed reflecting the three aspect of sustainable development which are the environmental, economic and social sustainability. However, companies implementing lean construction tools and practices from an operational stand point are unable to sustain its use or derive maximum benefits from lean construction implementation since its practice is not grounded on a solid basis i.e. in their business strategy. To overcome this barrier, bridge the gap, experience the streams of benefits from lean thinking, and sustain the innovative practices within construction, there is need to integrate lean construction principles and tools within the company's business strategy.

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Innovative Value Management: Assessment of Lean Construction Implementation

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Abstract:

Lean construction has been predominantly employed by companies to increase their responsiveness to customer needs, through a variety of conduits, including capital and operating reduction mechanisms aligned to quality improvement measures. In this respect, clients and the construction industry need to be aware of the potential benefits of lean construction to projects to encourage them to employ lean construction techniques on their projects. This paper examines the challenges of maximising 'value' in lean construction implementation. Lean construction concepts and principles have proven to be particularly effective; and the suitability of lean construction techniques to promote value in construction is raised for discussion. The paper reveals the main strategies for implementing a value management approach to improve on lean construction methodologies in order to contribute to sustainability implementation and performance improvement. The paper also explores the theories behind value management and the concept of value optimisation within construction.

Keywords:

Client value system, customer value management, value management, value, lean construction techniques

1 Introduction

The construction industry has adopted lean techniques to eliminate waste and increase profit due to the success of lean production in the manufacturing industry (Salem *et al* 2005). Most of the work in the early history of lean construction has been dealing with reduction of waste; a little work has been looking at project management principles and even less has addressed the issue of maximising value for the client (Bertelsen 2004).

At present, most construction companies in the UK have started implementing lean construction with the hope of achieving better result, following the 'Egan Report' (DETR, 1998) which has strongly influenced the idea of lean thinking in the UK. Lean thinking now seems set to dominate the UK construction industry's quest to improve quality and efficiency (Green 1999). Several studies have assessed the implementation of lean with respect to reduction of waste but few empirical studies investigated the effect of lean construction techniques in terms of value to the client. The construction industry and its clients need to be aware of the perceived benefits of lean construction on projects to encourage them to employ lean construction techniques on their projects.

Value Management and Value Engineering are techniques for enhancing value within a project by defining what will deliver value in a specific project, engineering a best value solution to meet those defined value parameters, and then delivering a cost effective solution (Egbu et al, 2004).

This paper explores the theories behind Value Management and the concept of value. It is part of an ongoing doctoral study on: the impact of lean construction techniques on sustainable construction.

2 Value Management and Value System

Value Management is considered as an important tool in managing a project. According to Kelly et al (2002), Value Management has been defined as a proactive, creative, problem-solving service. It involves the use of a structured, facilitated, multi-disciplinary team approach to make explicit the client's value system using functional analysis to expose the relationship between time, cost and quality.

Emmitt *et al* (2005) stated that value is the end-goal of all construction projects and therefore the discussion and agreement of value parameters is fundamental to the achievement of improved productivity and client/user satisfaction. Achieving best value in construction has long existed as the aim of clients and contractors. At present, it has become a raised area for drastic performance improvement in the public and private sector (Egbu et al 2004). Supporting this view, Berstelsen (2004) stated that much work remains within the area of value and Value Management including how to maintain and communicate the projects' specific value parameters during the whole project life cycle. The framework developed by Emmitt et al (2005) as shown in figure 1 reveals the 7Cs of value based building process. This shows that the client role is important in the value design stage and to the success of construction projects. OGC (2007) submits that value in its broadest scope is the benefit to the client.

Emmitt et al (2005) view value as an output of the collective efforts of the parties contributing to the design and construction process; which is central to all productivity; and providing a comprehensive framework in which to work. Value must be established before doing anything else. Emphasis is on value creating activities as the initial framework for the entire building process and the reduction of waste in the later value delivery phases.

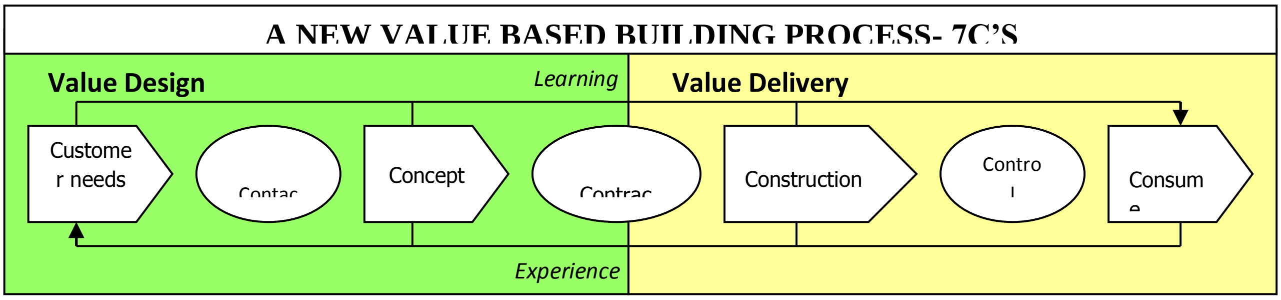

Figure 1: A value-based building process (source: Emmitt, et.al 2005)

According to Gohil et. al (2010), the concept of value can have many definitions but generally, they are not conflicting. These definitions majorly address "hard" features or elements of values and not the "soft" attributes discussed by Emmitt and Christoffersen (2008). Bruno and Lay (2008) stated that the importance of values is that once it is internalised, it becomes, consciously or subconsciously, a criteria for guiding one's beliefs. Values exist in relation to the values held by others and are thus not absolute but are in constant transformation. Hence, agreement of an objective best "value" for a group can differ from the individuals' perception of value (Gohil et. al, 2010). Even though most people have a feeling of what is meant by the term "value", it seems to be difficult to formulate a common definition (Thyssen et al. 2010). Some definition of value from a range of perspective such as marketing, Lean Thinking, Value Management and customer relation approach are presented in Table 1.

Table 1: Definitions of value

Authors/year of publication	**Definition/description/understanding and explanation of value**
Woodruff and Gardial (1996)	Value can be considered as the final result of the exchange of negative and positive consequences as perceived by customers
Neap and Celik (1999).	Value can be considered as an innovative concept whose definition includes mainly two parameters: cost and soft measure such as worth, functionality or satisfaction (depending on the expected project out comes)
Weinstein and Johnson (1999)	Value is the satisfaction of customer requirements at the lowest total cost of acquisition, ownership, and use
Lindfors (2000)	Value is the products/services that increase profit, decrease time and cost, and improve quality for the company and generate profit/value for the customer.
Kelly and Male (2001)	Value is defined as the equivalence of an item expressed in objective or subjective units of currency, effort, exchange, or on a comparative scale that reflects the desire to obtain or retain the item.
Womack and Jones (2003)	Value refers to materials, parts or products – something materialistic which is possible to understand and to specify
Kelly (2007)	Value equals to function divided by cost
Buttle (2009)	Value is the customer's perception of the balance between benefits received from a product or service and the sacrifices made to experience those benefits.

2.1 Client Value System

Construction industry's procuring clients are largely pursuing innovative approaches to ways in which their projects are planned, designed and delivered to facilitate their business strategies. They are looking for a structured method to manage their project process within the context of their organisation business strategy, and also to work closely with the supply chain to maximise value and achieve continuous improvement in construction performance (Kelly et al, 2002). This has also been put forward by Brimson and Antos, (1999) that value depends on the supply chain synchronisation. This is because the supply chain synchronisation of supplier to organisation to customer is a key to adding value. Zimmerman (2001) widens the theory of intrinsic value in which it is stated that in any value system no parts of the variables are correlated and all variables should have intrinsic value. Value, as defined in Lean Thinking (Womack and Jones 2003), refers to materials, parts or products – something materialistic which is possible to understand and to specify (Koskela 2004).

According to Emmitt *et al* (2005), value may be divided into external and internal value: External value is the clients' value and the value which the project should end up with, while internal value is the value that is generated by and between the participants of the project delivery team (contractor, architects, designers etc.). In this regard, the concept of understanding value generation during the early stage design phase as a learning process between the client and the design professionals has been put forward by Green (1999) such that there was a joint understanding of client's value parameters and their realisation in the design.

2.2 Customer Value Management

According to Gale (1994), there are four stages to customer value management: conformance quality stage, customer satisfaction stage, market-perceived quality and value relative to competitor's stage, and quality - a key to customer value management. Creating value that customers can see start from understanding customer needs in a well defined market and results in the overall goal of profitability, growth, and shareholders value.

Various ideas on Value Management have been put forward with emphasis on the initial project stages where the value parameters are specified (Emmit et al 2004). It is very important to understand the construction process as comprising of two distinct processes: value creation and value delivering i.e. Concept and Construction. The client has a set of requirements and budget limit and in the concept phase the challenge is therefore to maximise the value within this financial constraint (Bertelsen, 2004). A comprehensive customer value analysis was presented taking into consideration the seven customer analysis tool. The seven customer analysis tools according to Gale (1994) are:

1. The market-perceived quality profile
2. The relative price profile
3. The customer value map
4. The won/lost analysis
5. A head-to-head area chart of customer value
6. A key events time line
7. A what/who matrix

Bertelsen (2004) stated that manufacturing identifies the market's value parameters and develops the product accordingly, while construction is often creation of unique works. Construction integrates the product development with the actual production for example a flow of work and creation of value as well (Koskela, 2000). A Value Based management approach was proposed by Wandhal (2005) in which the value for the customer is considered as product value and the value for the workers and project participants is termed process value. Value Management is currently only associated with the early stages of projects, focusing on the analysis of functions to achieve the value defined by the customer without diminishing cost and quality (Salvatierra-Garrido et al, 2008).

The aim of Value Management is to optimise the points of view of different participants — from stakeholders to final users— into the process in order to achieve the final goal with minimum resources. "The concept of Value is based on the relationship between satisfying needs and expectations and the resources required to achieve them" (The Institute of Value Management UK, 2011).

2.3 Value Management Strategies

Value Management uses a unique combination of concepts and methods to create sustainable value for both organisations and their stakeholders. Value Management provides a means to define projects clearly and unambiguously in terms of the client's and the end user's long-term business needs, and provides opportunity for options to be considered. Value Management supports crucial decision-making based upon maximising value (Smith, 2008). According to The Institute of Value Management, UK (2011), some tools and techniques are specific to Value Management and others are generic tools that many organisations and individuals use. The following are some of the main tools and techniques: Brainstorming of Mind Shower, cost benefit analysis, criteria weighting technique, excursion/metaphors, functional analysis system techniques, objectives hierarchy, issues generation and analysis, pair wise comparison, Pareto analysis, process mapping, risk analysis, SCAMPER, stake holder analysis, SWOT analysis, value analysis, and 5W's & H.

In value improvement process, value analysis or producing the FAST model and analyzing functions with the value analysis matrix are the first steps in the process. However, work begins with brainstorming, developing and analyzing potential improvements in the product.
Salvatierra-Garrido et al (2008) concluded that additional research is needed to develop Value Management enabling techniques and procedures.

3 Lean Construction and Value

Koskela (2000) carried out a detailed exploration of the use of the term 'value' and deduced that value can be related to either market value and/or utility value. This view of value is supported by many other researchers as presented in the lean construction (LC) papers (Wandahl and Bejder, 2003). Value Management is described as, "Conceptualization of production (from value viewpoint): As a process where value for the customer is created through fulfilment of his requirements." (Bertelsen and Koskela, 2002). Nonetheless, Koskela (1992) suggested that construction production process should be viewed as transformation of input and outputs, a flow of material and information, and a value generation process. Thus, value creation and generation is the major component of the Transformation-Flow-Value (TFV) of production that was put forward by Koskela (1992). Ballard and Howell (1998) stated that value is generated through a process of negotiation between customer's ends and means. According to Lindfors (2000), value is the products/services that increase profit, decrease time and cost, and improve quality for the company and generate profit/value for the customer. Leinonen and Huovila (2000) mentioned three different kinds of values; exchange value, use value and esteem value. The first two can be translated directly into market value and utility value. The third value has a broader scope than only the product-customer perception. A model for reinforcing the manager's belief is applied by Marosszeky et al (2002), and it is concluded that each organisation tends to view quality from its parochial perspective due to the culture. Figure 2 shows the difference in perception of product and process values.

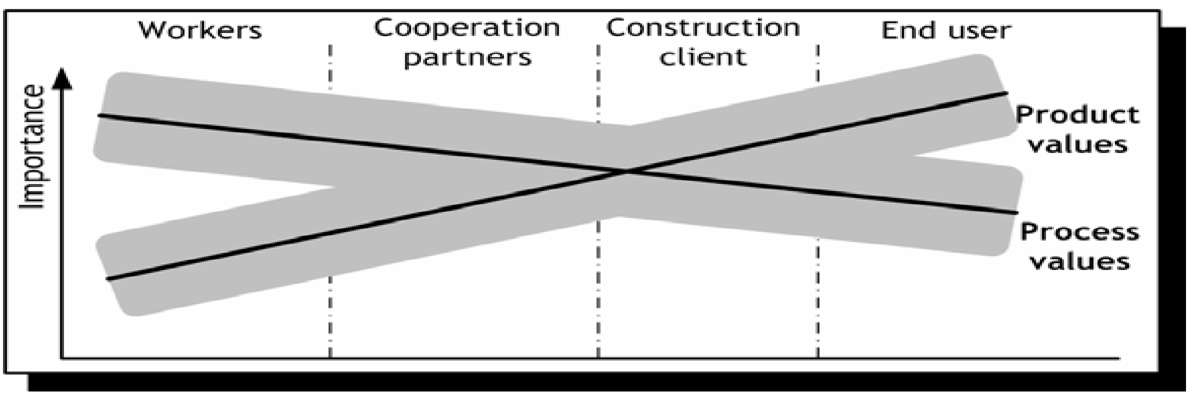

Figure 2: Difference in perception of values (Source: Wandahl 2002)

3.1 Value Delivery through the Implementation of Lean Construction Techniques

Work flow control through the Last Planner system, Value Stream Mapping (VSM), Just-In-Time (JIT) production and Supply-Chain Management (SCM), and Pokayoke or the Five Why's technique are the most commonly referred lean techniques in construction (Björnfot and Stehn, 2007). The work in lean has focused on the management of value in construction projects by using process tools to identify and minimise uncertainty and improve work flow in production (Emmitt et al 2004). According to Koskela (1992), there are two main processes in a construction project: design process and construction process. Design process is a stage wise refinement of specifications where vague needs and wishes are transformed into requirements, then via a varying number of steps, to detailed designs. Simultaneously, this is a process of problem detection and solving. It can be further divided into individual sub processes and supporting processes. Construction process is composed of two different types of flows: Material process consisting of the flows of material to the site (including processing and assembling on site), and Work processes of construction teams (Lee 1999). Koskela (1992) stated that the processes may be characterized by their cost, duration and the value for the customer. The value consists of two components: product performance and freedom from defects (conformance to specification). Value has to be evaluated from the perspective of the next customer and the final customer. Cost and duration depend on the efficiency of value-adding activities and the amount of non value-adding activities. Several principles that enable of the share of non-value-added activities conducted was summarised by Koskela (2000) as follows: increase output value through systematic consideration of customer's requirements; reduce variability; reduce cycle time; simplify by minimising number of steps; parts the linkages, increase output flexibility; increase process; transparency; build continuous improvement into process; balance flow improvement with conversion improvement; benchmark. Emmitt et al (2004) stated that in design management and lean approaches, craving for value maximisation starts from the initial team composition.

3.2 Challenges of Value Maximisation in Lean Construction Implementation

According to Mok et al (2010), few researches have been conducted pertaining to the improvement of value maximisation in the construction industry. As projects become complex, dynamic, and fast, managing value becomes a challenge in lean construction. Literature has revealed that over the years, some authors have made an approach to this challenge, mostly with an outset in methods found in value engineering or similar disciplines (Bertelsen 2004; Salvatierra-Garrido et al 2008). The creation of this waste can be prevented by applying lean construction principles. Salvatierra-Garrido et al (2008) stated that more research efforts are needed to better understand the concept of value generation and how to implement it. This is because the major challenge in research dealing with value is the fact that the term itself has escaped a canonical definition. According to Josephson and Saukkoriipi (2005), a Swedish study reports that only about 20 % of performed work is directly value adding, showing a striking rate of pure waste in traditional construction projects. Lean construction considers both construction waste and poor safety as potential wastes that hinder flow of value to the client and should hence be eliminated. Several barriers to the implementation of lean construction have been identified as shown in Table 2. Subsequently, these barriers to the implementation of lean construction will be narrowed down to those challenging maximisation of value to client. Bashir et al (2010) classified these barriers into six different categories: Management issues, financial issues, educational issues, governmental issues, technical issues, and human attitudinal issues.

Table 2: Challenges of Lean Construction Implementation

Authors	Barriers Identified
	-how to come to grips with the specification of desired or required behaviour beyond the task level
Seymour (1999)	-how to articulate, through some kind of representation, what is intended and how it is to be achieved.
Common et al (2000)	- A distinct lack of understanding and application of the fundamental techniques required for a lean culture to exist
Salem et al (2005)	-The unfamiliarity with or misunderstanding of lean concepts and implementation -Cultural barriers in many organisations act as obstacles to change.
	-Lack of adequate skills and knowledge -Management issues -Government issues such as bureaucracy and instability -Attitude issues such as wrong attitude to change and poor team spirit among professionals
Olatunji (2008)	-Resources related issues such as lack of basic amenities, equipment, and funding for project. -Logistics issues such as delay in delivery and material scarcity
	-Lack of attentiveness and commitment from top management -Difficulties in understanding the concept of lean construction -Lack of exposure on the need to adopt the lean construction concept -Lack of proper training -Weak communication among clients, consultants, and contractors -Tendency of construction firms to apply traditional management concepts
Abdullahi et al (2009)	-Poor attitude and teamwork -Long implementation period
Mossman (2009)	-Fragmentation -New thinking vs. old habits -Squeezing Middle Management -Low level literacy and computer literacy -Lean education, competing consultants -There's not so practical as a good theory -Fear
	-Technological barriers -Financial barriers
Tourki (2010)	-External barriers -Internal barriers such as human factor, culture factor, and learning factor

This challenge is taken up by lean construction which has proved to be a valuable philosophy for construction by better meeting customer demands and improving the construction process (Howell, 1999; Ballard and Howell, 2004). Successful implementation of lean has been reported by Emmitt *et al* (2005) and a number of definitions have been suggested which may be used generally for discussing and implementing value through lean construction.

4 Value Management, Lean Construction and Sustainability

Value Management and lean construction have been seen as the way forward to improve delivery of value to clients and building users (Emmitt et al, 2005). Value Management seeks to maximise project value within time, cost and quality for the customers with an item that satisfies the basic function they require at the best value for the money spent. The term "Value Management" encompasses both Value Engineering and Value Analysis. However, it should be noted that improving whole-life project value sometimes requires extra initial capital expenditure (OGC, 2007).

Value Management is about enhancing value and not about cutting cost, although this may be a by-product. The principles and techniques of Value Management aim to achieve the required quality at optimum whole-life cost during the process of developing a project. The principles centred on the identification of the requirements that will add demonstrable value in meeting the business need (OGC, 2007). The idea of creating value is mainly focused on value engineering to ensure that the value specified will be delivered to the client while the cost is kept as low as possible (Bertelsen, 2004). Lean construction practices is intended to complement value engineering and therefore, do not compete with value engineering. Lean construction aims at maximising value and minimising waste (Lehman and Reiser 2004).

According to Senaratne and Wijesiri (2008), the core principles of lean construction are elimination of non value adding flow activities and making conversion activities more efficient. Leong and Tilley (2008) carried out a study to explore the notion of measuring next customer needs as part of a lean performance measurement strategy in order to try to achieve end user customer satisfaction. It was concluded that the failure to implement appropriate measures is common within the industry and can lead to not only wrong conclusions or behaviour, but also poor decision making due to inadequate information. Furthermore, they stated that in order to drive behaviour towards value through the elimination of waste, the industry needs to understand the principles of systems thinking and variation and implement appropriate measures to identify where system improvements can be made.

Lean thinking places ‘optimising the total value’ instead of ‘minimising the cost’ as the main goal. Within lean, cost cutting has to be seen in perspective of eliminating non value adding activities (Womack and Jones, 2003). Salvatierra-Garrido et al (2008) stated that when defining value, there are different disciplines such as the Lean Thinking and Value Management, which aim to incorporate value in the process of developing a successful final product and satisfying user’s real need. They further stated that integrating Value Management and Lean Thinking at the early stage of social housing project in Chile is proposed as the solution to achieving better results in projects where cost, quality and social responsibility are drivers. Lean Thinking in construction focuses on process tools to identify and minimise uncertainty and hence improve workflow in production (Emmitt et al., 2004).

Similarly, Sustainability is about securing our long-term future, by following the four main tenets of sustainable development which are: protection of the environment, prudent use of scarce resources, promotion of access to services for the benefit of all, and production of a healthy local economy, including high levels of employment (Royal Institution of Chartered Surveyors, 2009). According to MaSC (2002), Sustainability promotes a balanced approach by taking account of the need to continue in business, but does not seek profitability at the expense of the environment or society’s needs. Thus, sustainability concerns protecting environmental quality, enhancing social prosperity and improving economic performance (Addis and Talbot, 2001). According to the members’ report of the workshop organised by Construction Productivity Network (2009), lean and sustainability concepts are basically compatible through waste minimisation. Cost savings from waste reduction can provide both real added value to the business as well as paying for sustainability actions.

According to Al-Yami and Price (2006), it is highly beneficial to adapt Value Management for use in uplifting sustainable construction principles so as to implement in the early stages of building projects. As such, there is need for a change of thinking from clients, operators and managers in the construction industry during implementation of sustainable construction principles in a project from short term to future impact; shareholders to stakeholders; product to service; and cost to value. These changes, according to Hayles (2004), are the key priorities of a Value Management project. Al-Yami and Price (2006) concluded that soft Value Management is an essential tool to be used in identifying and developing the briefing of a building project to reduce negative impacts on the environment, assure optimised whole life cost of a project, and satisfy good indoor environment in the project thus achieving the aims of sustainability.

5 Discussion

The perception of value to stakeholders in construction differs but Value Management, through the implementation of lean principles, resolves differing priorities to meet the expectation of stakeholders. So, lean construction is not only concerned with minimising waste but it directly contributes to value creation. Even though the adoption of lean construction principles seem to lay a foundation for Value Management, concerted effort should be made to further emphasise Value Management approach to improve on lean construction methodologies in order to contribute to sustainability implementation and performance improvement. Thus, there is need to determine the linkage between Value Management and lean construction, priorities of lean construction, and how implementation of lean construction principles leads to value maximisation.

6 Conclusion

Construction projects are intrinsically prone to changes and innovation. They are understood in theory to deliver value to customer/client. Currently, lean construction loses sight of the innovative and ingenious dimension of Value Management and the effect of lean construction techniques on sustainable construction in terms of value to the client. The suitability of lean construction to promote sustainable construction in terms of value to the client is discussed. The main strategies of Value Management approach to improve on lean construction methodologies in order to contribute to sustainability implementation and performance improvement are been explored, thus reflecting the concept of value maximisation at the early stage of the project.

Integrating lean construction principles in Value Management is essential for the optimisation of value for end users, construction clients and all the stakeholders as the process and the product value is of utmost importance to them. When lean construction and Value Management are effectively integrated they form an intrinsic tool to be used for project briefing and development. This paper is part of an ongoing research which aims to examine the impact of lean construction on sustainable construction in order to further promote the understanding of lean construction principles and facilitates its adoption and implementation as regards value generation, maximisation, and delivery within the construction industry. This integration will impact on the three dimension of sustainability in a project: environmental, social and economic. The ongoing research will proceed to identify the priorities of lean construction and sustainability and also identify the success factors and barriers to the implementation of lean construction.

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