MINIMIZING MATERIALS WASTAGE AT THE CONSTRUCTION STAGE OF A PROJECT THROUGH THE IMPLEMENTATION OF LEAN CONSTRUCTION

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COLLEGE OF ARCHITECTURE AND PLANNING,

DEPARTMENT OF BUILDING TECHNOLOGY

BY

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DECLARATION AND CERTIFICATION

I hereby declare that this submission is my own work towards the MPhil. Building Technology and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

Past research into the causes of waste in construction projects indicate that waste can arise at any stage of the construction process from inception, right through the design, construction and operation of the built facility. Waste in the construction industry has been the subject of several research projects around the world in recent years. It is commonly acknowledged that a very high level of waste exists in construction. Research indicates a wide variation in wastage rates of between 5%-27% of total materials purchased for construction projects in Ghana. Since construction has a major and direct influence on many other industries by means of both purchasing inputs and providing the products to all other industries, eliminating or reducing waste could yield great cost savings to the society. Lean construction considers construction materials wastes as potential wastes that hinder flow of value to the client and should be eliminated. The creation of this waste can be prevented by applying lean construction principles.

The aim of the study is to advance knowledge on construction site waste minimization through the application of lean principles. The objectives of the study among others included the identification of sources and causes of material wastes on construction sites, assessment of level of knowledge of the lean concept among construction practitioners and identification of barriers to successful implementation of lean construction.

The main tools for the collection of data included questionnaires, interviews and site observations. The target population for the data collection included project managers of building construction organizations and senior consultants of architectural and quantity surveying firms. Statistical package for social scientists (SPSS V 16) was employed to analyze data obtained. One sample t-test and mean score rankings were adopted to analyze data on sources and causes of materials waste respectively. Weighted average and coefficient of variation were adopted to analyze data on waste minimization measures.

Mean score rankings were adopted for the analysis of data on perception of professionals on lean concepts. Factor analysis was adopted to analyze data on barriers to implementation of lean construction. Finally measures to overcome potential barriers to implementation of lean construction were analyzed by mean score rankings.

Materials storage and handling, operational factors, design and documentation factors and procurement factors were considered as the main sources of waste on building construction sites. Among the causes of materials wastes are last minute client requirement, errors by tradesmen or operatives, purchased products that do not comply with specification and lack of onsite materials control. The structured questionnaire survey showed the existence of some level of awareness among professionals in the Ghanaian construction industry on the concept of lean construction. Lack of proper planning and control, lack of teamwork, poor project management, lack of technical capabilities, lack of professional motivation and poor communication between parties were considered as the six broad barriers that hinder the implementation of lean construction.

DEDICATION

To God Almighty and my parents, Mr. and Mrs. Anyafo

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ABBREVIATIONS

ARCG	Architects Registration Council of Ghana
APS	Average Practice Score
ASS	Average Significant Scores
BRE	British Research Establishment
BPR	Business Process Re-engineering
CAD	Computer Aided Design
CE	Concurrent Engineering
CE	Construction Excellence
CIRIA	Construction Industry Research and Information Association
CLIP	Construction Lean Implementation Programme
EE-	Electrical Engineers
EPA-	Environmental Protection Agency
EPD -	Environmental Protection Department
GE-	Geodetic Engineers
GhIA-	Ghana Institute of Architects
GhIE-	Ghana Institution of Engineers
GhIS-	Ghana Institution of Surveyors
HND-	Higher National Diploma
IMVP-	International Motor Vehicle Programme
JIT-	Just In Time
KNUST-	Kwame Nkrumah University of Science and Technology
LC-	Lean Construction
LCI-	Lean Construction Institute
LPS-	Last Planner System
MIT-	Massachusetts Institute of Technology
MIVs-	Minimization Index Values

MWRWH-	Ministry of Water Resource, Works and Housing
PCs-	Product Circles
PIVs-	Practice Index Values
PPP-	Percentage Plan Complete
QS-	Quantity Surveyors
SE-	Services Engineers
St.E-	Structural Engineers
SPC-	Statistical Process Control
SPSS-	Statistical Package for Social Sciences
TFV-	Transformation Flow Value
TPS-	Toyota Production System
TQC-	Total Quality Control
TQM-	Total Quality Management
UK-	United Kingdom
USA-	United States of America
VE-	Value Engineering
WMM-	Waste Minimization Measures

LIST OF PUBLICATIONS EMANATING FROM CURRENT THESIS

JOURNAL PUBLICATIONS

- Agyekum, K., Ayarkwa, J. and Adinyira, E. (2012). Consultants Perspectives on Materials Waste Reduction in Ghana. **In Press Journal of Engineering Management, Canada.**

- Ayarkwa, J., Agyekum, K. and Adinyira, E. (2011) "Exploring Waste Minimization Measures in the Ghanaian Construction Industry". **Built Environment Journal, Vol 8, No. 2, 22-30, ISSN 1675-5022.**

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- Ayarkwa, J., Agyekum, K. and Adinyira, E. (2011). Barriers to sustainable implementation of Lean Construction in the Ghanaian Building Industry. **In: Proceedings of the 6th Built Environment Conference, 31st Jul- 2nd Aug. 2011. Johannesburg, South Africa, pp. 67-83. ISBN: 978-0-86970-713-5**

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

In the past few decades, great performance improvements have been obtained in the manufacturing industry by means of increasing productivity. A major factor in this achievement was the implementation of the new production philosophy, known as "Lean Production". This approach provides a continuous improvement in the production process by removing various types of wastes (Lee *et al.*, 1999). While manufacturing had attained great results, the construction industry still encounters severe problems resulting from huge amounts of waste (Polat and Ballard, 2004) hence, the need for lean construction to help curb the wastage issue.

Past research into the causes of waste in construction projects indicate that waste can arise at any stage of the construction process from inception, right through the design, construction and operation of the built facility (Faniran and Caban, 1998; Craven *et al.*, 1994; Gavilan and Bernold, 1994; Spivey, 1974). Waste in the construction industry has been the subject of several research projects around the world in recent years (Al-Moghany, 2006; Chen *et al.*, 2002; Shen *et al.*, 2000, 2002; Teo and Loosemore, 2001; Smallwood, 2000; Formoso *et al.*, 1999; Wong and Tanner, 1997; McDonald and Smithers, 1996; Ferguson *et al.*, 1995). According to Polat and Ballard (2004), it is commonly acknowledged that a very high level of waste exists in construction. Since construction has a major and direct influence on many other industries by means of both purchasing inputs and providing the products to all other industries, eliminating or reducing waste in the construction industry could yield great cost savings to the society.

WASTES IN CONSTRUCTION

Definition of waste

According to Koskela (1992), waste can be defined as "any inefficiency that results in the use of equipment, materials, labour or capital in larger quantities than those considered as necessary in the construction of a building".

Waste can be classified as *unavoidable waste* (or natural waste), in which the investment necessary for its reduction is higher than the economy produced, and *avoidable waste*, in which the cost of waste is higher than the cost to prevent it (Formoso *et al.*, 1999). The percentage of unavoidable waste depends on the technological development level of the company (Formoso *et aI.*, 1999; Womack and Jones, 1996). Formoso *et al.* (1999) stated that waste can also be categorized according to its source; namely the stage in which the root causes of waste occurs. Waste may result from the processes preceding construction, such as materials manufacturing, design, materials supply, and planning, as well as the construction stage (Formoso *et aI*, 1999). Bossink and Brouwers (1996) classified the main waste causes in construction into:

- Design
- Procurement
- Materials Handling
- Operation
- Residual

However, for the sake of this study, only materials wasted at the construction stage of projects would be considered. This is due to two main reasons:

1. Materials account for the largest input into construction activities in the range of 50-60% of the total cost of a project (Ibn-Hamid, 2002; Ganesan, 2000; Holm, 1998; Wong and Norman, 1997; Akintoye, 1995; Olubodun, 1995), and because

2. The raw materials from which construction inputs are derived come from non-renewable resources. Hence, rarely would these materials be replaced once they are wasted (Ekanayake and Ofori, 2000).

Materials Waste

The Environmental Protection Department (EPD) of Hong Kong (2000) defines materials waste as comprising of unwanted materials generated during construction, including rejected structures and materials, materials which have been over ordered or are surplus to requirements, and materials which have been used and discarded. Building material waste can also be defined as the difference between the value of materials delivered and accepted on site and those properly used as specified and accurately measured in the work, after deducting the cost saving of substituted materials transferred elsewhere, in which unnecessary cost and time may be incurred by materials wastage (Enshassi, 1996; McDonald and Smithers, 1998, Pheng and Tan 1998, Shen *et al.*, 2003). Furthermore, material waste can be defined as "any material, apart from earth materials, which needs to be transported elsewhere from the construction site or used within the construction site itself for the purpose of land filling, incineration, recycling, reusing or composting, other than the intended specific purpose of the project due to material damage, excess, non-use, or non-compliance with the specifications or being a by-product of the construction process" (Ekanayake and Ofori, 2000). Despite variations in construction projects, potential material waste is caused by similar inefficiencies in design, procurement, material handling, operation or residual on-site waste such as packaging (Formoso *et al.*, 1993; Gavilan and Bernold, 1994).

1.2 PROBLEM STATEMENT

Research indicates a wide variation in wastage rates of between 5%-27% of total materials purchased for construction projects in Ghana. The current liberal global economic order makes it challenging for Ghanaian building industries to remain competitive worldwide. The industry must therefore strive to deliver valuable products and services at the minimum possible cost for their customers in order to remain in the business. In order to achieve minimum cost in construction, the Ghanaian building industry must appreciate the difference between waste and value and how to eliminate waste in the projects which are carried out. Lean construction considers construction materials wastes as potential wastes that hinder flow of value to the client and should be eliminated. The creation of this waste can be prevented by applying lean construction principles. The question now arises as to whether professionals in the building industry in Ghana are aware of the amount of materials waste generated on site. What measures have they put in place to deal with the situation?

1.3 AIM

The study aims to advance knowledge on construction site waste minimization through the application of lean principles.

1.4 OBJECTIVES

To help achieve the aim, the following objectives were set;

- To identify the sources and causes of materials waste on building construction sites and to provide a compendium on waste arising from storage and handling of high waste generating building materials used in the Ghanaian construction industry.
- To assess the views of construction professionals on the level of contribution of some waste minimization measures to waste reduction, and the level of practice of such measures in the Ghanaian construction industry.
- To assess the level of knowledge on lean concept among construction practitioners in the Ghanaian construction industry.
- To identify and prioritize influential barriers to successful implementation of lean construction in the Ghanaian construction industry.
- To propose a framework that has the potential of minimizing materials waste through the implementation of lean principles.

1.5 RESEARCH QUESTIONS

To help achieve the objectives, the following questions were asked;

- What are the major sources and causes of materials waste on building construction sites?
- What are the views of professionals on materials waste minimization?
- What are the perceptions of construction professionals on the concept of lean construction?
- What are the potential barriers that hinder the implementation of lean construction in Ghanaian building construction organizations?

1.6 RESEARCH METHODOLOGY

The study used mixed research approach involving combination of questionnaire and interviews. The research methodology was assessed under each objective as follows;

Objective 1:

The objective of identifying the sources and causes of materials waste on construction sites was achieved through questionnaire surveys. Two main methods of analysis (one sample t- test and mean score rankings) were adopted to analyze data obtained from the study. The compendium on wastage of key construction materials and recommended ways of waste minimization were compiled by field observations through site visits.

Objective 2:

To achieve the objective of assessing the views of respondents on the levels of contribution of some waste minimization measures to waste reduction, and the levels of practice of such measures in the Ghanaian construction industry, a structured questionnaire survey was conducted. Data from the study were analyzed using weighted average and coefficient of variation criteria.

Objective 3:

The objective of assessing the level of knowledge on lean concepts among construction practitioners in the Ghanaian construction industry was achieved by conducting a structured questionnaire survey. This was done to assess the perceptions of the respondents on the lean construction philosophy, identify the level of knowledge in the Ghanaian construction industry and identify measures to bridge the knowledge gaps. Data obtained from the study were ranked according to mean scores.

Objective 4:

A structured questionnaire survey was carried out to identify possible barriers to implementation of lean construction. These barriers were prioritized according to their mean scores. Factor analysis using SPSS Version 16 package was adopted to group the identified barriers.

1.7 RESEARCH PROCESS

This section describes the research process from start to end. The section explains the step by step methodology that was used in order to answer the research questions. The objectives and scope were determined in collaboration with supervisors and building construction organizations currently involved in construction activities in and around KNUST campus. The research questions were formulated based on challenges faced by the construction industries. Following the research question, an appropriate research design was selected. Literature review was performed in parallel with the data collection in order to develop a theoretical background connected to the research topic. Finally, the data was analyzed, discussed and conclusions and recommendations were drawn.

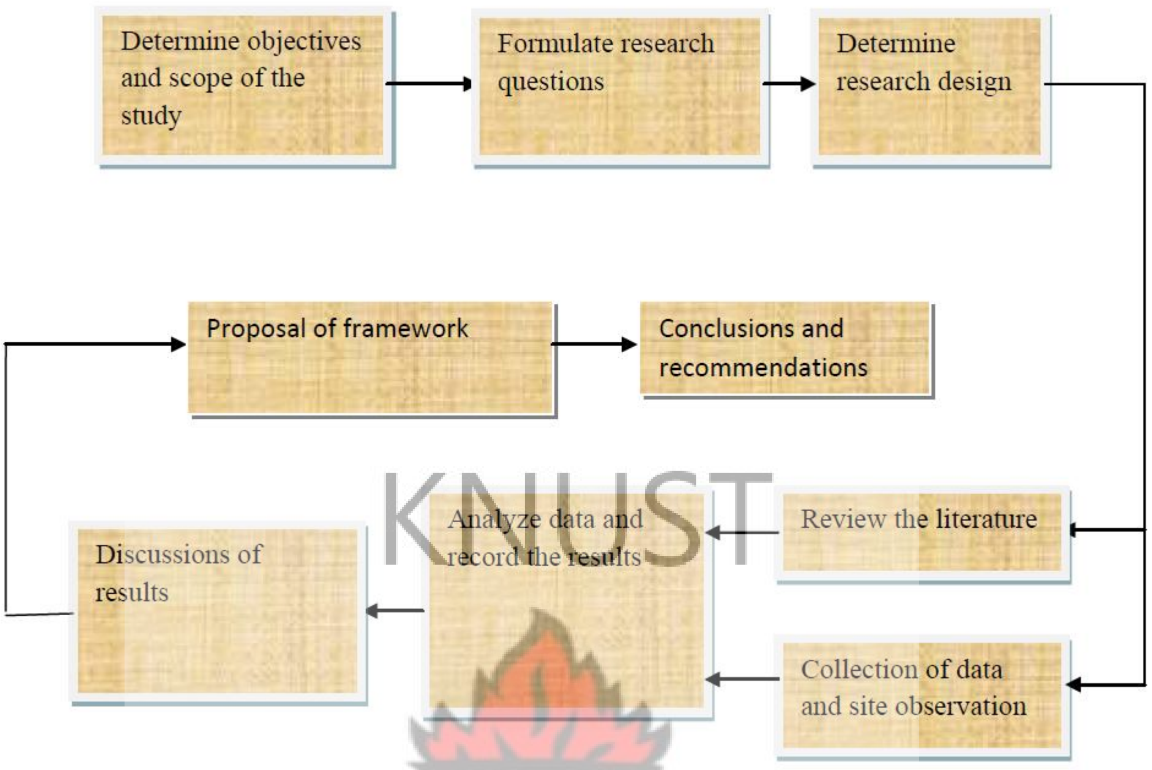


Fig. 1.1 The Research Process

1.8 SCOPE OF STUDY

The study covered only the construction stage of building projects with the assumption that lean design has already been considered at the design stage. Construction stage refers particularly to the building or construction of sub-structures, super-structures and architectural elements such as finishes. Surveys carried out at these phases enabled on-site observations to be conducted simultaneously. The materials considered were timber, cement/mortar, concrete and blocks. The research focused on the flow activities of these materials (storage and handling). Surveys in the forms of questionnaires and personal interviews were conducted with the proponents who were undertaking referenced projects. Proponents mentioned refer precisely to the site managerial staffs concerned such as project managers, quantity surveyors and architects.

The study focused on construction sites in and around KNUST campus due to site accessibility and availability of contacts. These sites were mainly made up of construction of lecture theatres, offices and high rise student hostels.

1.9 PRACTICAL IMPLICATIONS

The study seeks to have positive implications on the Ghanaian building construction industry. Among them are;

- The results will enable building organizations to improve construction quality and efficiency through the implementation of the measures suggested to remove potential barriers to the implementation of lean construction.
- Minimizing materials waste would improve project performance and enhance value for individual customers, and have a positive impact on the national economy.

1.10 OUTLINE OF THESIS

A brief outline of the thesis is presented. This research was divided into five (5) chapters.

- The first chapter (Chapter 1) explained the problem statement, the aim, objectives, research questions, research methodology, research process, scope and practical implication of the study.

- The second chapter (Chapter 2) reviewed literature on the construction industry in the world, the Ghanaian construction industry, waste in the construction industry, lean thinking, lean production, lean construction, benefits of the implementation of lean construction and barriers to implementation of lean construction.

- The third chapter (Chapter 3) explains the methodology that was used throughout the study. The structure of the questionnaire as well as the determination of the sample sizes are explained. The methods used to analyze the data are also explained.

- Chapter four (4) presents and discusses the results that were obtained from the data.

- Chapter five (5) which is the last chapter concludes the overall research and suggests recommendations for future research.

1.11 Conclusion

This chapter introduced the thesis. After a brief background, the research problem was highlighted followed by the research aim, objectives and research questions. The chapter further described the research methodologies that were adopted and went on further to describe the research design. The scope of the study, practical implications and the theses outline were presented in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Since the inception of Lean Manufacturing Concepts as far back as the 1900s, lean construction has been discussed and debated by many researchers worldwide. According to Abdullah *et al.* (2009), Lean Construction is a concept that needs to be introduced within the construction industry, specifically to increase the sector's productivity level through the elimination of activities and actions deemed to generate waste in the construction process. This chapter reviews literature on the global construction industry, the Ghanaian construction industry, materials waste, materials waste minimization strategies and lean concepts.

2.2 The Global Construction Industry

The construction industry includes all companies primarily engaged in construction such as general contractors, heavy construction (airports, highways, and utility systems), and construction by specialist trades. Also included are companies that engage in the preparation of sites for new construction and in subdividing land for building sites. Construction work may include new work, additions, alterations, or maintenance and repairs. Construction work is often described by either type, residential (home building) or non-residential (commercial and government buildings and infrastructure projects), or by funding source, public or private (Conway *et al.*, 2005).

The construction sector represents, for many countries, a core economic activity. It not only provides the infrastructure for all other industries, but also constitutes one of the largest single sectors in the economy on its own. Closely linked with public works, governments have relied on the construction sector as a strategically important industry for creating employment and sustaining growth. For the developing economies, the construction sector carries particular importance because of its link to the development of basic infrastructure, training of local personnel, transfer of technologies, and improved access to information channels (International Investment and Services Directorate, 1999).

Construction services, in a large number of countries, are primarily supplied through the establishment of service suppliers at or near the site for the work by local or regional operators. On-site establishment is normally confined to the duration of the particular project, while regional or local presence may be ensured on a permanent basis to service or promote several projects. Joint ventures between foreign and domestic firms are quite common - often out of necessity for financing of projects; transfers of technology and know-how; and assistance in meeting local laws, regulations, and practices (International Investment and Services Directorate, 1999).

In many countries, construction services may be carried out by general contractors who complete all the work for the proprietor of the project, or by specialized sub-contractors who undertake parts of the work. Analysis by the World Trade Organization Secretariat indicates that most countries have a small number of large firms, a moderate number of medium-sized firms, and a large number of small firms who specialize in certain fields or who operate in small geographical areas (International Investment and Services Directorate, 1999).

The International Supply of Construction Services

The global construction industry is the single largest industry in the world. In 2004 the total value of the global construction industry exceeded four trillion dollars (Gary, 2004). Of even greater importance, 25% of the world's workforce worked directly for the construction industry or an entity supporting construction. Construction work is a tool to stimulate economies and project foreign policy. From 2003 to 2004, the global construction industry grew by 6.6% (Conway *et al.*, 2005). In 2003 the largest global construction firms were *Vinci* of France ($12 Billion (B) domestic/$8B international revenue), and *Skanska* of Sweden ($3B domestic/$14B international) (Conway *et al.*, 2005). The largest international construction market is Europe. The second largest international construction market is Asia/Australia with China being the single fastest growing market. Transportation is the largest sector in the international construction market (27.5%), followed by general building (25.4%) and petroleum infrastructure (18.7%) (Conway *et al.*, 2005).

According to the World Trade Organization Secretariat, the international supply of construction services involves large movements of workers at all levels of skill. Although statistics regarding the movement of workers related to the industry are not readily available, analysts believe that large portion of the movement of workers into the industrialized countries and the Middle East from Asia, Latin America and other developing regions are construction-related (International Investment and Services Directorate, 1999).

Because of the type of work involved, the majority of construction services are either supplied by the commercial presence of a foreign company or through the presence of natural persons. The cross border supply of construction services is assumed to be practically non-existent as a result of technical infeasibility (i.e., construction services cannot be supplied without the movement of service providers). However, some services (such as land surveying and blue-print designing) may become increasingly traded over telecommunications infrastructures. As electronic commerce develops there may be some changes in the way that construction services are supplied (International Investment and Services Directorate, 1999).

2.2.1 The Ghanaian Construction Industry

The construction industry in Ghana, as in other parts of the world, is huge and a crucial segment in economic development. No matter what one does, there is construction, as it cuts across all sectors. Being among the top drivers of the Ghanaian economy, including agriculture, manufacturing and mining, its importance cannot be over emphasized, especially as the country is one of the most active economically in West Africa. From a low point in the1970s and 1980s the share of construction in the GDP has moved up from 4.5% in 1975 to 8.5% by the turn of the century and has been doing about the same levels since. The sector grew by 10% in 2008 but registered a negative growth rate of 1% in 2009 due to the global economic recession (Gyadu-Asiedu, 2009).

The key stakeholders in the construction industry in Ghana are clients, professional consultants and contractors (Gyadu-Asiedu, 2009).

Clients

In Ghana four main clients are distinguishable: the Government (being the major client), Real Estate Developers, Investors and Owner occupiers. Between 2000 and 2008 the government of Ghana identified construction as a priority sector for foreign and private investment as part of its vision to promote the private sector as the engine of growth. According World Bank (2003) as provided by Anvuur and Kumaraswamy (2006), an approximate annual value of public procurement for goods, works and consultant services amount to US$600 million. This represent about 10% of the country's GDP. This amount forms part of the bulk of the expenditure of all government agencies, namely, the Ministries, the Assemblies, Departments, Institutions and other agencies. The government as a client is represented by the Ministry of Road and Transport (for road works) and the Ministry of Water Resources, Works and Housing in giving out projects. The Real Estate developers are also the other group of clients who undertake large investment in building. Usually, these take loans and undertake speculative buildings for sale. Their performance is usually influenced by the lending situations in the country.

Professional consultants

Professional consultants who are regularly engaged by the government and other clients are Architects, the Quantity Surveyors (QS), Geodetic Engineers (GE), Structural Engineers (St.E), Electrical Engineers (EE) and Services Engineers (SE). Geodetic Engineers are often called when it is about roads construction. All these professionals are regulated by their professional institution (Gyadu-Asiedu, 2009).

Contractors

Contractors in Ghana are grouped into eight categories (A, B, C, S, D, K, E and G) according to the type of works they undertake. These are (i) Roads, Airports, and Related Structures (A); (ii) Bridges, Culverts and other Structures (B); (iii) Labour based road works (C); (iv) Steel bridges and structures: construction rehabilitation and maintenance (S); (v) General building works (D); (vi) General civil works (K); (vii) Electrical works (E); and (viii) Plumbing works (G). In each category, they are grouped into 4, 3, 2 and 1 financial classes in increasing order (Vulink, 2004). In addition, Dansoh (2005) notes a combined category of AB for road contractors. According to Dansoh (2005) Class 4 contractors can tender for contracts up to $75,000; class 3 up to $200,000; class 2 up to $500,000. Class 1 takes contracts of all amounts. The research focused on projects undertaken by category D contractors. Categories E and G contractors act as main contractors when the work is of a specialized nature. The industry is dominated by large number of small- and medium-sized firms. This is mainly because such firms are able to register with as little equipment as possible. Mostly, they are sole proprietors, (few cases of partnerships), and are characterized by high attrition rate. This is because they are highly influenced by the boom and slum nature of the industry in Ghana. They are the least organized and because they lack the resources to employ and retain very skilful labour, their performance is usually below expectation and they have often been accused of producing 'shoddy' works. Because there are often more jobs within their financial class than those above their limits, and because they form the largest group, their performance impacts greatly on the performance of the industry. Because of this, the classification by the Ministry has been criticized as being too general and obsolete with the registration criteria, list of contractors and monetary thresholds not regularly updated (Eyiah and Cook, 2003; World Bank, 2003). The two upper classes (D1 and D2) are more organized and hence more stable, taking on both bigger and smaller works. However, these firms (especially the D2 firms) do not always employ the very qualified workers. The Ghanaian-based foreign contractors are able to do this and hence perform better. Vulink (2004) notes that because of the poor performance of Ghanaian local contractors most of the nation's major projects are usually awarded to foreign contractors. Assibey-Mensah (2008) attributes this to the "non-businesslike culture" with which indigenous firms operate in Ghana.

2.3 Wastes in the Construction Industry

This section provides a literature review on waste in construction, moves on to further define waste, talks about construction waste, types of construction waste, materials waste and magnitudes of waste in construction. During the construction process, construction managers have to deal with different factors that can negatively affect the performance of the production process, and producing different type of wastes. Wastes can include mistakes, working out of sequence, redundant activity and movement, delayed or premature inputs and products or services that do not meet customer needs (Construction Industry Board, 1998).

2.3.1 Definition of waste

Waste in construction has been defined in different ways by different studies. According to the new production philosophy, waste should be understood as any inefficiency that results in the use of equipment, materials, labour, or capital in larger quantities than those considered as necessary in the production of a building. Waste includes both the incidence of material losses and the execution of unnecessary work, which generates additional costs but do not add value to the product (Polat and Ballard, 2004). Waste should be defined as any losses produced by activities that generate direct or indirect costs, but do not add any value to the product from the point of view of the client (Alwi *et al.*, 2002; Formoso *et al.*, 1999). According to Polat and Ballard (2004), a simple way to define waste is "that which can be eliminated without reducing customer value". It can be activities, resources, rules, etc. Macomber and Howell (2004), add that, the common sense understanding of waste is anything is not value. More precisely, waste is the expenditure of effort or the using-up of resources without producing value. After categorizing waste to seven types by Ohno (1994), Womack and Jones (1996) defined waste as any activity that absorbs sources and does not have any value adding.

2.3.2 Construction waste

Waste has been considered to be a major problem in the construction industry and in many large cities in the world (Al-Moghany, 2006; Chen *et al.,* 2002; Shen *et al.,* 2002; Teo and Loosemore, 2001; Smallwood, 2000; Wong and Tanner, 1997; Ferguson *et al.*, 1995). According to Formoso *et al.* (1999), waste in the construction industry has been the subject of several research projects around the world in recent years. Some of them have focused on the environmental damage that result from the generation of material waste. On the other hand, there have been a number of studies mostly concerned with the economic aspect of waste in the construction industry. Construction site waste can be described as the non-hazardous by-product resulting from activities during new construction and renovation. It is generated during the construction process because of factors such as site preparation, material use, material damage, material non-use, excess procurement and human error (Mocozoma, 2002). The Environmental Protection Department (EPD) of Hong Kong (2000) defines waste as comprising of unwanted materials generated during construction, including rejected structures and materials, materials which have been over ordered or are surplus to requirements, and materials which have been used and discarded. Waste arises from a number of different activities carried out by the contractor during construction and maintenance and may include: wood from formwork and false work, material and equipment wrappings, unusable or surplus cement/ grouting mixes, damaged/surplus/contaminated construction materials.

2.3.3 Types of construction waste

Waste in construction can be classified into three main types; waste of materials, waste of time and waste of machinery (Al-Moghany, 2006; Ekanayake and Ofori, 2000). However, this research focuses on materials waste.

2.3.3.1 Material waste

Construction material wastes refer to materials from construction sites that are unusable for the purpose of construction and have to be discarded for whatever reason (Yahya and Boussabaine, 2006). According to Ekanayake and Ofori (2000), construction material waste is defined as any material apart from earth materials, which needs to be transported elsewhere from the construction site or used on the site itself other than the intended specific purpose of the project due to damage, excess or non-use or which cannot be used due to non-compliance with the specifications, or which is a by-product of the construction process.

2.3.4 Magnitude of waste in construction

Bossink and Brouwers (1996) conducted a research in The Netherlands that was concerned with the measurement and prevention of construction waste with regard to meeting sustainability requirements stated by Dutch environmental policies. Waste from seven materials was monitored in five house-building projects between April 1993 and June 1994. During the study, all material waste was sorted and weighed. The amount of direct waste by weight ranged between 1 and 10% in weight of the purchased amount of materials. Further, it was concluded that an average 9% (by weight) of the total purchased construction materials end up as site waste in the Netherlands.

A study in Malaysia shows, composition and percentage of material wastes: Soil 27%, wood 5%, brick and blocks 1.16%, metal product 1%, roofing material 0.20%, plastic and packaging materials 0.05%, concrete and aggregate 65.80% (Begum *et al.*, 2006). Jones and greenwood (2003) obtained percentage of waste in ten materials as plaster board 36%, packaging 23%, cardboard 20%, insulation 10%, timber 4%, chipboard 2%, plastic 1%, electric cable 1%, and rubber 1% (Yahya and Boussabaine, 2006).

A study carried out by Rameezdeen and Kulatunga (2004) in Sri Lanka identified the main materials wastages as Sand (25%), Lime (20%), Cement (14%), Bricks (14%), Ceramic Tiles (10%), Timber (10%), Rubble (7%), Steel (7%), Cement Blocks (6%), Paint (5%) and Asbestos Sheets (3%).

Research in Hong Kong indicates that about 5-10% of building materials end up as waste on building sites. There are many contributory factors to this figure, human, mechanical and others (Poon and Jailon, 2004).

In Australia, Forsythe and Marsden (1999) discussed the way in which construction industry clients are responding to the need to improve environmental performance of construction projects in Australia. They proposed a model for analyzing the impact of waste in the cost of a project, including its removal and disposal. This model used waste figures for six building materials that ranged from 2.5 to 22% in weight. These were produced as the result of an empirical study of 15 house-building sites. That study involved the quantification of waste based on the amount of materials effectively delivered on site, according to available documents and also on interviews with representatives of different trades.

Picchi (1993) also reported a relatively small study on material waste, carried out between 1986 and 1987 at three residential building sites, in which the amount of waste removed from the sites were monitored. The percentage of waste was estimated to be between 11 and 17% of the expected weight of the building. This represents a waste of between 0.095 and 0.145 t/m^2.

In the USA, construction activities generate an enormous amount of waste approximately over 29% of overall landfill volumes (Ferguson *et al*., 1995).

According to Formoso *et al.* (2002), one of the first studies on material waste in Brazil was carried out by Pinto (1989). This research involved a single case study, based on data from an 18-storey residential building project that was chosen because all the records of materials supply and use were well kept by the construction company. Both direct and indirect wastes of 10 building materials were estimated. The waste percentages include both direct and indirect waste. The total waste was 18% of the weight of all materials purchased, representing an additional cost of 6%. One of the main contributions of this study was that it pointed out the importance of indirect waste in relation to direct waste. For instance, the amount of indirect waste of mortar was as much as 85% of the designed volume of plaster. This represents not only a waste of materials, but also a significant unnecessary additional load on the building structure.

According to Datta (2000), about 20-25% of materials are wasted on construction sites in Tanzania, Zambia, Zimbabwe and Botswana. Fatta et al., (2003) also stated that in Greece, each 1000m^2 of building activity entail the generation of 50m^3 of waste.

Ayarkwa and Adinyira (n.d.) reports of a wide variation in wastage rates of between 5% and 27% of total materials purchased for construction projects in Ghana.

2.4 Sources of materials waste

Construction waste stems from construction, refurbishment, and repairing work. Many wasteful activities can take place during both design and construction processes, consuming both time and effort without adding value to the client. Generation of the stream of waste is influenced by various factors.

2.4.1 Natural Waste

Natural waste is the wastage that costs more than what is saved if tried to prevent. There is a certain limit up to which, waste of materials can be prevented. Beyond that limit, any action taken to prevent waste will not be viable, as the cost of saving will surpass the value of materials saved. Thus, natural waste is allowed in the tenders. Amount of natural waste is subjective to the cost effectiveness of the approaches used to manage it. The approaches vary from one scenario to another and so do the natural waste. For instance, cost of preventing wastage in a project with a good material controlling policy will be lesser than that of a project, which lacks such a policy. Thus, the acceptable level of natural waste in the former situation will be lesser than the later (Kulatunga *et al.,* 2006; Formoso *et al.*, 2002).

2.4.2 Direct waste

According to Skyoles and Skyoles (1987), waste that can be prevented and which involves the actual loss or removal and replacement of material is called direct waste. Most of the times, the cost of direct waste do not end up in the cost of material, but followed with the cost of removing and disposing. Thus, by preventing direct waste straightforward financial benefits can be obtained.

Direct waste can occur at any stage of the construction process before the delivery of material to the site and after incorporating the materials at the building (Kulatunga *et al.*, 2006; Formoso *et al.*, 2002; Shen *et al.*, 2002). Categories of direct waste can be summarized in Table 2.1.

Table 2.1 Categories of Direct Waste

Category	Reason	Example
Delivery waste	During the transportation of materials to the site, unloading and placing in addition to the initial storage	Bricks, glassing
Cutting and conventional waste	Cutting materials into various sizes and uneconomical shapes	Formwork, tiles
Fixing waste	Dropped, spoiled or discarded materials during fixing	Bricks, roof tiles
Application and residue waste	Hardening of the excess materials in containers and cans	Paint, mortar, plaster
Waste caused by other trades	Damage occurs by succeeding trades	Painted surfaces
Criminal waste	Theft and vandalism	Tiles, cement bags
Management waste	Lack of supervision or incorrect decisions of the management	Throwing away excess material
Waste due to wrong usage	Wrong selection of materials	Rejection of inferior quality marbles, tiles

(Source: Kulatunga *et al.*, 2006 ; Skyoles and Skyoles, 1987)

2.4.3 Indirect waste:

Indirect waste occurs when materials are not physically lost; causing only a monetary loss. For example, waste due to concrete slab thickness larger than that specified by the structural design (Kulatunga *et al.*, 2006; Formoso *et al.*, 2002). Indirect waste arises principally from substitution of materials, waste caused by over allocation, where materials are applied in superior quantity of those indicated or not clearly defined in contract documents, from errors, and waste caused by negligence, where materials are used in addition to the amount required by the contract due to the construction contractor's own negligence. (Shen *et al.*, 2002).

Table 2.2 Categories of Indirect Waste

category	Reason	Example
Substitution waste	Substitution of materials in work, which will incur losses to either contractor or client	Use of facing bricks for common bricks
Production waste	Contractor does not receive any payments for the works he has carried out	
Negligence waste	Site errors because of the condemned work or use of additional material	Over excavation of foundation resulting in the use of additional concrete
Operational waste	Unavailability of proper quantities in the contract documents/ the materials that are left on sites	Formwork

(Source: Kulatunga *et al.*, 2006; Skoyles and Skoyles, 1987)

2.5 Causes of Materials Waste

Many factors contribute to construction waste generation on site. Waste may occur due to one or a combination of many causes.

According to Poon *et al.* (2001), research in Hong Kong indicates there are many contributory factors to the generation of waste; these include both human and mechanical activities. Table 2.3 is a summary of the major causes of materials waste in Hong- Kong.

Table 2. 3 Causes of Construction Site Waste in Hong Kong

	Causes of Building Waste on Site	**Examples**
SITE MANAGEMENT PRACTICES	Lack of a quality management system aimed at waste minimization	lack of waste management plan
	Untidy construction sites	waste materials are not segregated from useful materials
	Poor handling	breakage, damage, losses
	Over-sized foundations and other elements	over design leads to excess excavation and cut-offs
	Inadequate protection to finished work	finished concrete staircases are not protected by boarding
	Limited visibility on site resulting in damage	inadequate lighting in covered storage area
	Poor storage	pallet is not used to protect cement bags from contamination by ground water
	Poor workmanship	poor workmanship of formwork
	Waste generation inherited with traditional construction method	e.g. timber formwork, wet trade
DELIVERY OF PRODUCTS	Over-ordering	over ordering of concrete becomes waste
	Method of packaging	inadequate protection to the materials
	Method of transport	materials drop from forklift
	Inadequate data regarding time and method of delivery	lack of records concerning materials delivery

(Source: Poon *et al.*, 2001)

Bossink and Brouwers (1996), in their study in The Netherlands indicated the main sources and causes of construction waste as shown in Table 2.4.

Table 2. 4 Sources and Causes of Construction Waste in Netherlands

SOURCE	CAUSE
Design	Error in contract documents
Design	Contract documents incomplete at commencement of construction
Design	Changes to design
Design	Choices about specifications of products
Design	Choices of low quality to sizes of used products
Design	Designer is not familiar with possibilities of different products
Design	Lack of influence of contractors and lack of knowledge about construction
Procurement	Ordering error, over ordering, under ordering, and so on
Procurement	Lake of possibilities to order small quantities
Procurement	Use of products that do not fit
Materials handling	Damage during transportation to site/on site
Materials handling	Inappropriate storage leading to damage or deterioration
Materials handling	Unpacked supply
Materials handling	Throwaway packaging
Operation	Error by tradesmen or operatives
Operation	Equipment malfunction
Operation	Inclement weather
Operation	accidents
Operation	Damage caused by subsequent trades
Operation	Use of incorrect material, requiring replacement
Operation	Method to lay the foundation
Operation	Required quantity of product unknown due to imperfect planning
Operation	Information about types and sizes of products that will be used arrived too late on the construction site
Residual	Conversion waste from cutting uneconomical shapes
Residual	Off cuts from cutting material to length
Residual	Over mixing of materials for wet trades due to a lack of knowledge of requirements
Residual	Waste from application process
Residual	Packaging
Other	Criminal waste due to damage or theft
Other	Lack of onsite materials control and waste management plans

(Source: Bossink and Brouwers, 1996)

In Singapore, Ekanayake and Ofori (2000) organized the sources of construction waste under four categories: (1) design; (2) operational; (3) material handling; (4) procurement as shown in Table 2.5.

Table 2. 5 Sources of Construction Waste

Design	Operational	Material handling	Procurement
Lack of attention paid to dimensional coordination of products	Errors by tradesmen or operatives	Damages during transportation	Ordering errors (eg., ordering significantly more or less)
Changes made to the design while construction is in progress	Accidents due to negligence	Inappropriate storage leading to damage or deterioration	Lack of possibilities to order small quantities
Designers inexperience in method and sequence of construction	Damage to work done caused by subsequent trades	Materials supplied in loose form	Purchased products that do not comply with specification
Lack of attention paid to standard sizes available on the market	Use of incorrect material, thus requiring replacement	Use of whatever material close to working place	
Designers unfamiliarity with alternative products	Required quantity unclear due to improper planning	Unfriendly attitudes of project team and operatives	
Complexity of detailing in the drawings	Delays in passing information to the contractor on types and sizes of products to be used		
Errors in contract documents	Equipment malfunctioning		
Incomplete contract documents at commencement of project	Inclement weather		
Selection of low quality products			

(Source: Ekanayake and Ofori, 2000)

According to Alwi *et al.* (2002), the most significant causes of waste during the construction process in a comparative study of Indonesia and Australia construction projects are summarized in Table 2.6.

Table 2. 6 Causes of Construction Waste in Indonesia and Australia

Indonesia	Australia
Design changes	Design changes
Lack of trades' skill	Poor design
Slow in making decisions	Poor quality site documentation
Poor coordination among project participants	Slow drawing revision and distribution
Poor planning and scheduling	Unclear site drawing supplied
Delay of material delivery to site	Unclear specifications
Inappropriate construction methods	Weather

(Source: Alwi *et al.*, 2002)

Upon a study by Arnold (1998) and analysis of some Brazilian building sites by Formoso (2002), the sources of waste were organized into: (1) overproduction; (2) substitution; (3) waiting time; (4) transportation (5) processing; (6)inventories; (7) movement; (8) production of defective products; (9) others (Formoso *et al.*, 1999; 2002; Arnold, 1998).

Table 2.7 Sources of Construction Waste in Brazil

Overproduction	Related to the production of a quantity greater than required or earlier than necessary. This may cause waste of materials, man-hours or equipment usage. It usually produces inventories of unfinished products or even their total loss, in the case of materials that can deteriorate. An example of this kind of waste is the overproduction of mortar that cannot be used on time.
Substitution	Related to the substitution of a material by a more expensive one (with an unnecessary better performance); the execution of simple tasks by an over-qualified worker; or the use of highly sophisticated equipment where a much simpler one would be enough
Waiting time	Related to the idle time caused by lack of synchronization and leveling of material flows, and pace of work by different groups or equipments. One example is the idle time caused by the lack of material or by lack of work place available for a gang.
Transportation	Concerned with the internal movement of materials on site. Excessive handling, the use of inadequate equipment or bad conditions of pathways can cause this kind of waste. It is usually related to poor layout, and the lack of planning of material flows. Its main consequences are: waste of man hours, waste of energy, waste of space on site, and the possibility of material waste during transportation.
Processing	Related to the nature of the processing (conversion) activity, which could only be avoided by changing the construction technology. For instance, a percentage of mortar is usually wasted when a ceiling is being plastered.
Inventories	Related to excessive or unnecessary inventories which lead to material waste (by deterioration, losses due to inadequate stock conditions on site, robbery, vandalism), and monetary losses due to the capital that is tied up. It might be a result of lack of resource planning or uncertainty on the estimation of quantities.
Movement	Concerned with unnecessary or inefficient movements made by workers during their job. This might be caused by inadequate equipment, ineffective work methods, or poor arrangement of the working place.
Production of defective products	It occurs when the final or intermediate product does not fit the quality of specifications. This may lead to rework or to the incorporation of unnecessary materials to the building (indirect waste), such as the excessive thickness of plastering. It can be caused by a wide range of reasons: poor design and specification, lack of planning and control, poor qualification of the team work, lack of integration between design and production, etc.
Others	Waste of any nature different from the previous ones, such as burglary, vandalism, inclement weather, accidents, etc.

(Source: Formoso *et al.,* 2002; Arnold, 1998)

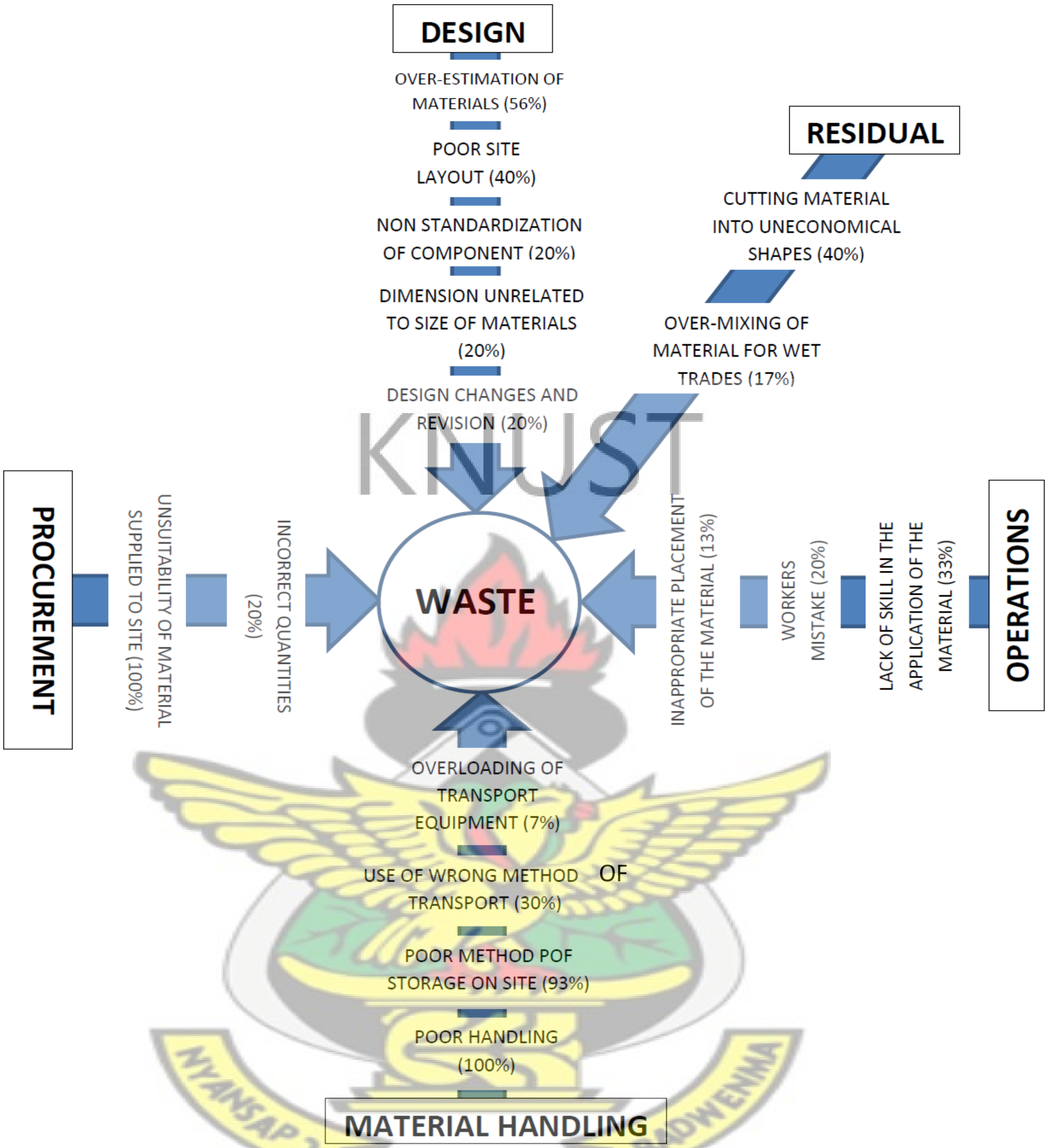
According to Polat and Ballard (2004), the causes of materials waste in the Turkish construction industry are listed in Table 2.8.

Table 2. 8 Main causes of material waste in Turkish construction

Source	Causes of Material Waste	Frequency (%)
Design	Lack of information about types and sizes of materials on design documentations	13
	Design changes and revisions	12
	Error in information about types and sizes of materials on design documentations	10
	Determination of types and dimensions of material without considering waste	3
Procurement	Ordering of materials that do not fulfill project requirements defined on design documents	86
	Over ordering or under ordering due to mistake in quantity surveys	8
	Over ordering or under ordering due to lack of coordination between warehouse and construction crews	4
Material Handling	Damage of materials due to deficient stockpiling and handling of materials	16
Operation	Imperfect planning of construction	61
	Workers' mistakes	32
	Damage caused by subsequent trades	3
Residual	Conversion waste from cutting uneconomical shapes	22
Others	Lack of onsite materials control	23
	Lack of waste management plans	10

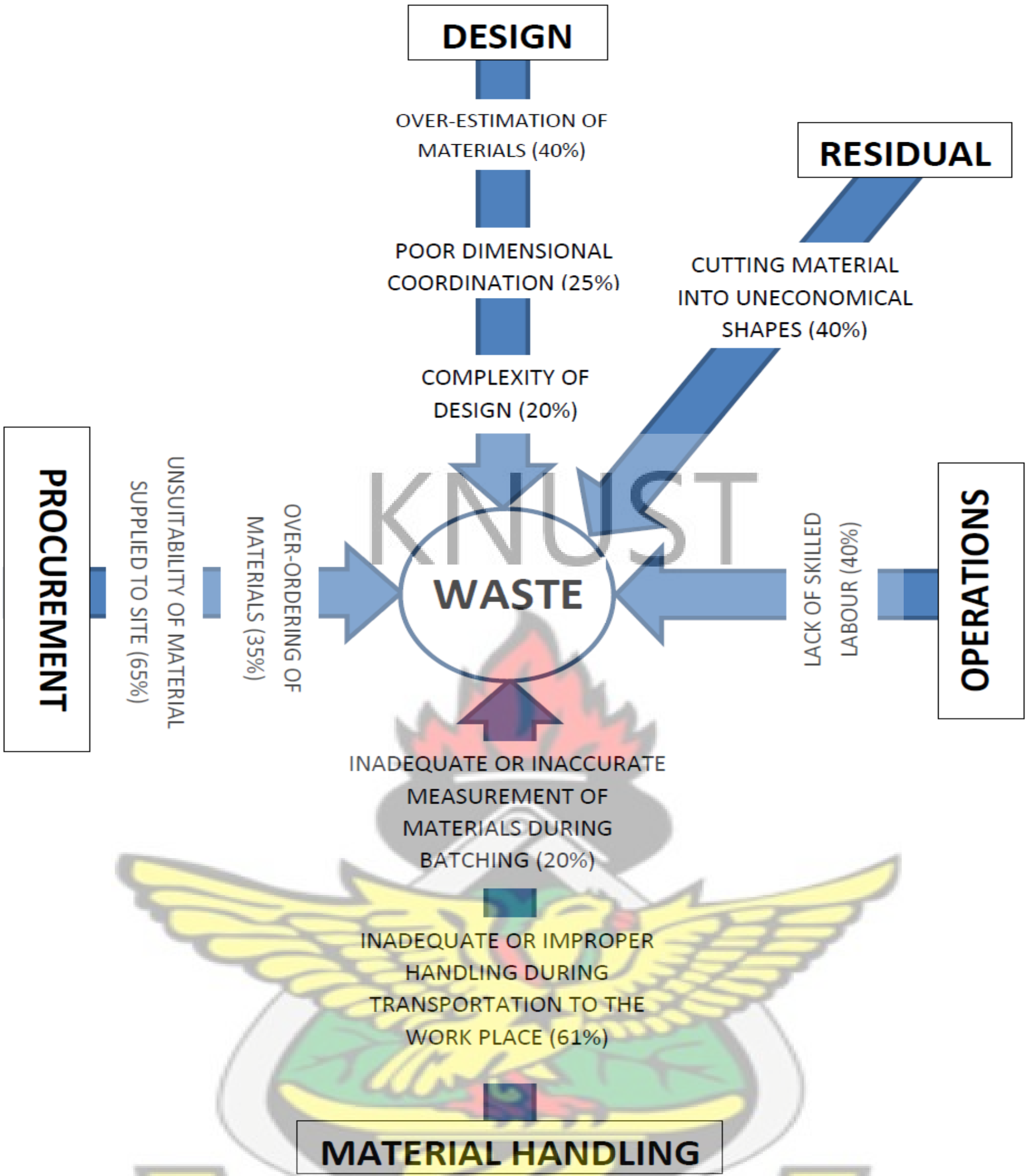
(Source: Polat and Ballard, 2004)

Ayarkwa and Adinyira (n.d), studied the perceptions of contractors and consultants on the major causes of materials wastage on construction sites in Ghana. The results are shown in the Figures 2.1 and 2.2 respectively.



(Source: Ayarkwa and Adinyira, n.d.)

Figure 2.1 Contractors' perception of the main causes of material waste in construction in Ghana



(Source: Ayarkwa and Adinyira, n.d.)

Figure 2.2 Consultants' perception of the main causes of material waste in construction in Ghana

According to Ayarkwa and Adinyira (n.d.), in order to reduce the amount of waste generated in construction, the main causes of waste generation must be identified. The study asked respondents to identify the main causes of material waste in their construction operations. The frequencies of the causes were calculated following a classification proposed by Bossink and Brouwers (1996). The main causes of material waste and their percentage frequencies are presented in Figures 2.1 and 2.2 respectively.

Waste occurs at every stage in the construction life cycle. All contractors and 65% of consultants considered the ordering of unsuitable materials for a project (in terms of quality, type and dimensions) to result in material waste. This situation may arise from wrong information flow, deliberate choice of low quality materials in order to reduce cost, or wrong/ inadequate specification by project consultant. Bossink and Brouwers (1996) and Polat and Ballard (2004), realized that the choice of low quality products and products that do not fit are two main causes of material waste. All contractors and 61% of consultants were of the opinion that poor handling of materials results in material waste. This may occur during transportation to the workplace, within the store, or during application. Poor handling may result from lack of knowledge on proper handling of sensitive material or lack of skill in job performance on the part of site workers. Poor storage method was also considered by 93% of contractors to cause material waste. Poor storage can result in breakage or damage to materials, especially fragile ones like ceramic tiles and glass. Overestimation, over-ordering, and poor site layout were also considered by significant percentages of contractors and consultants to result in material waste. Overestimation leads to over-ordering of materials which will bring more materials than necessary for a job. Improper site layout resulting from improper planning, which affects the flow or sequence of activities on site, creates problems with transportation of materials and movement of site workers, and results in poor handling and resultant damage to materials. Lack of standardization of component dimension, dimensions unrelated to sizes of materials or poor dimensional coordination, which are design issues, may result in cutting, shaping, sawing etc., causing material waste in construction. Most of the causes of construction materials waste identified in their study have been cited in other studies (Garas *et al.,* 2001; Bossink and Brouwers, 1996, Gavilan and Bernold, 1994; Craven *et al.,* 1994; Polat and Ballard, 2004). Twenty percent of contractors indicated that workers' mistakes cause material waste on site. Fourty percent of consultants also think lack of skilled labour cause material waste. In a study of dominant causes of waste generation in Egyptian construction Garas *et al.* (2001) is reported to have found that untrained labourers make mistakes frequently.

The results again showed that the reduction of construction waste is not only a responsibility of the construction company. The client and the designer can make environmentally-friendly choices in the programme of demands and the design. Sources of material waste have been traced to the design, procurement, material handling, operation and residual activities.

2.6 Wastage of key materials on construction sites

A lot of studies have been undertaken concerning the wastage of materials on construction sites. Some of the materials that are wasted on the construction sites include steel reinforcement, concrete, formwork, blocks, cement, mortar, tiles, pipe, aggregate (Poon *et al.* 2004; Shen et al. 2003; Formoso *et al.* 2002; Bossink and Brouwers 1996).

2.6.1 Steel reinforcement

Steel reinforcement bars are common materials used in building (Shen *et al.,* 2002). Controlling the use of steel reinforcement in building sites is relatively difficult because it is cumbersome to handle due to its weight and shape (Formoso *et al.,* 2002). The main causes of wastage of steel are as a result of cutting, damages during storage and rusting (Shen *et al.,* 2002). The reasons of likely waste of steel reinforcement are damage to mesh and bars, loss in mud and excess use of tying wire (Poon *et al.,* 2002).

According to Formoso *et al.* (2002), there are three main reasons that can be pointed out for steel reinforcement waste:

- Short unusable pieces that are produced when bars are cut.
- Some bars may have an excessively large diameter due to fabrication problem and trespassing.
- Structural design that is poor in terms of standardization and detailing, causing waste due to non optimized cutting of bars.

2.6.2 Concrete

There are two types of mixed concrete, concrete ready mixed (premixed concrete) and concrete site-mixed (Formoso *et al.*, 2002). Concrete is the most widely used material both for substructure and superstructure of buildings. The wastage mainly results from the mismatch between the quantity of concrete ordered and that required in the case of ready mixed concrete supply. The contractor may not know the exact quantity because of imperfect planning, leading to over-ordering. Concrete wastes also result from project delays and unnecessary waste handling processes (Shen *et al.*, 2002). In a survey of 22 construction sites in Hong Kong, 80% of the work was made from ready mixed concrete. On average, 3–5% of the material was wasted and most of it was lost through excessive material ordering, broken formwork and redoing due to poor concrete placement quality (Poon *et al.*, 2004). According to Bossink and Brouwers (1996), the building contractor may not know the necessary quantity because of imperfect planning. This leads to over-ordering and overfilling of the means of transport and formwork. If the formwork is overfilled, skimming becomes necessary, i.e., leveling off the concrete poured into the formwork.

2.6.3 Timber formwork

In Hong-Kong, timber for formwork is a major contributor to construction waste accounting for 30% of all wastes identified on construction sites. Timber possesses a number of advantages that makes it a popular construction material. It is relatively inexpensive, light in weight and with a high load bearing capacity. It is also pliable and can be readily cut that it can be shaped for producing any distinct forms of concrete elements. However, its relatively low durability and reusability makes it a material of high wastage. The main causes of wastage are the natural deterioration that results from usage and cutting waste. Both are difficult to avoid (Shen *et al.*, 2002). Another major material used for formwork is timber board. The main causes of wastage are those that result from usage and cutting waste, both of which are difficult to avoid (Shen *et al.*, 2002). A study undertaken on construction sites in Hong-Kong showed that the majority of timber waste was generated from formwork with a smaller quantity resulting from cutting timber for internal finishing and fittings. In the case of formwork, most of the timber materials delivered to site were eventually discarded as waste (100% wastage) after several reuses (Poon *et al.*, 2004).

2.6.4 Cement

Analyzing the waste of cement is relatively complex due to the fact that this material is used as a component of mortar and cast in-place concrete in several different processes, such as brick work, plastering, and floor screed. By contrast this is a relatively expensive material that has high levels of waste in Brazil (Formoso *et al.*, 2002).

2.6.5 Sand, Lime, and Premixed Mortar

In some parts of the world like Brazil, Sand and mortar are usually delivered in trucks, and so there may be additional losses related to the lack of control in the delivery operation and the necessary handling it demands (Formoso *et al.*, 2002). Some companies in Brazil have started using packed ready-to-use mortar mix, which tends to eliminate many of the problems related to delivery control, handling, and transportation. Although not enough data are available, there are indications that such changes have reduced the waste of mortar, in comparison to the traditional method of producing mortar on site (Formoso *et al.*, 2002).

2.6.6 Brick and block

Bricks and blocks are the most common walling materials (Shen *et al.*, 2002). The main cause of brick and block waste is cutting. Unpacked supply may increase wastage of broken damage because of the fragile nature of the materials. Unused bricks left on site may end up in the trash skip ultimately (Shen *et al.*, 2002). In most poorly performing sites, combinations of materials waste causes are related to the waste of bricks and blocks. At several sites, there are problems related to the delivery of materials, such as the lack of control in the amount of bricks or blocks actually delivered and the damage of bricks

2.6.7 Pipes and wires

Keeping track of the causes of waste of electrical pipes, electrical wires, and hydraulic and sewage pipes is a fairly complex task. Both electrical and plumbing services are usually subcontracted, and the materials are sometimes provided by the specialist subcontractor. As this activity tends to be very fragmented on site, such materials are often moved into and out of the site. Another difficulty related to the measurement of waste is the fact that both plumbing and electrical service designs are often poorly detailed, and many changes in the routings of pipes are made during the installation. The most important causes of waste for these materials are short unusable pieces produced when pipes are cut and poor planning in the distribution of materials, which does not encourage cutting optimization (Formoso *et al.,* 2002).

2.7 Materials control on site

Materials control includes those activities that ensure materials availability in the required quantity, at the proper time, considering the minimum feasible cost to satisfy production needs and corporate objectives. Materials control activities include determining materials needs, requisitioning the purchase or fabrication of components based on make or buy economics, record keeping, requisitioning for production and status reporting procedures (Manteau, 2010).

Control of the materials used on site begins at the time the contractor is handed over the site. All materials delivered to site must be compared with the relevant standards. Besides the general waste of materials on site, there is a lot of damage, and this is often due to lack of proper supervision. Responsibility for materials control must begin with the person handling them. Many foremen and supervisors see their main function as that of materials supplier to the group they are responsible for, hence, ignoring materials handling. If a materials controller is appointed to anticipate materials requirement and distribute supplies, trades foremen will have enough time to do their job properly. Site management is ultimately responsible for materials use and handling. However, materials may be kept on site over long or short period of time until they are needed (Johnston, 1981).

- *Materials Control Tasks*

  As a control function, materials control must anticipate usage, use only those materials necessary, determine disposition of materials at any point in time, note deviations and feedback usage and related information to those concerned (Manteau, 2010). The activities of materials control fall into four basic categories (Manteau, 2010);

- Materials Planning: includes the use of production plans to anticipate materials needs on a long term basis. It also includes determination of materials and parts needed to fulfill customer orders or produce for stock with factors such as safety stock, investment and carrying costs taken into consideration and planning for balanced inventory levels.

- Materials Availability: these include
  - ✓ Requisitioning initial purchase and recorder of materials and parts from vendors in economic quantities as needed.
  - ✓ Maintaining accurate and timely records of materials and supplies inventory including all transactions that change the on-hand or available status.
  - ✓ Verifying inventory through periodic physical count to adjust records.
  - ✓ Investigating and reporting discrepancies.

- Materials Movement: to control materials movement, materials control must prepare requisitions to deliver materials to production in line with schedule needs and record movement out of and into stock.

- Materials Feedback: to assure proper feedback, procedures must be established to inform those who are affected when materials problems cause delay or loss of production, late deliveries and excess materials usage. In addition, reports must be made on obsolescence of materials for disposition, and timely inventory data must be issued to note the materials position.

According to Manteau (2010), other control activities are ordinarily performed by other functions.

- Industrial Engineering establishes waste standards for materials.
- Quality Control sets materials quality standards and specifications and inspects incoming materials.
- Receiving and Stores is responsible for maintenance of materials, issuance of materials on a controlled basis to production and processing of materials documents and quarantining of problem materials.
- Production is responsible for the controlled use of materials and feedback of materials waste.
- Purchasing must purchase according to materials control requirements to ensure delivery of materials in the proper quantity and quality and maintain close liaison with vendors to feedback materials problems to and from the vendors.
- Accounting must establish materials costs and disseminate cost reports to concerned functions.

Thus, control of materials is a company-wide responsibility, although materials control in some organizations has assumed many of these tasks. Company policy will dictate the ultimate responsibilities and authorities and maximum efficiency will be achieved when the activities are performed by those who can establish the most effective on-the-spot controls and disciplines that must become part of the everyday tasks of the functions concerned (Manteau, 2010).

2.7.1 Materials storage and handling on site

Materials handling as defined in the context of this study involves the transportation of materials from one designated point to another, as efficiently as possible. According to Badu (2008), materials handling is of importance for the following reasons:

- ✓ Materials flow has to be maintained if output is to be maintained.
- ✓ The health and safety of many members of staff depends a great deal on the type of materials handling system employed, the equipment operated and the level of training among the operators.
- ✓ The cost factor is vital in terms of operational costs, profits and overall cost of production. Handling materials is very expensive in terms of materials handling equipment, time and labour.
- ✓ Materials damage can be very expensive and will undoubtedly reduce the stock-life of many materials.

There are three stages of materials handling (Badu, 2008):

- ✓ Selection of the material from their place of storage
- ✓ Movement of materials from A to B
- ✓ Placement of materials in the required place and position

- *Selecting materials handling system*

Factors to be considered when selecting materials handling system are (Badu, 2008):

- ✓ Location of materials centres
- ✓ Nature and characteristics of the materials
- ✓ Capital and resources available
- ✓ Future needs
- ✓ The total cost of operating system i.e. cost of fuel, maintenance, labour, spares, etc.

- ✓ Compatibility of the existing storage equipment
- ✓ Materials handling equipment available on the market

- *Management of materials handling*

The main problem in materials handling management is ‘double handling’. It refers to situations where materials are being handled more times than is necessary, mainly because of inefficiency (Badu, 2008).

In theory, when materials are delivered to site they are supposed to make only a limited number of journeys. For example

- ✓ Delivery vehicle to place of storage;
- ✓ Selection from place of storage;
- ✓ Delivery to and through the process of production.

However, in practice this seemingly simple flow is not maintained. This increases greatly the real cost of handling (i.e. fuel, plant, labour, etc) with its attendant increase in the risk of accidents and stock damage.

- *Causes of double handling*

According to Badu (2008), the causes of double handling are:

- ✓ Lack of a good stores location system
- ✓ Lack of good communication between stores and production
- ✓ Use of wrong materials handling device (unloading large consignment with small device).
- ✓ Lack of space (unloading in the nearest space as a temporary measure).

- *Methods of materials handling*

Methods of handling materials are either manual or mechanical (Badu, 2008).

Table 2.9 Advantages and Disadvantages of Materials Handling Methods

ADVANTAGES		DISADVANTAGES
MANUAL	MECHANICAL	MECHANICAL
Relatively cheap	Ease of handling extremely heavy loads	High cost of devices
Can be used in confined spaces and older stores the design of which was not based on the use of any devices.	Can be used in almost any environmental condition and employed 24 hours a day.	High running costs in terms of fuel, power, maintenance and service
Efficient in relation to loads that can be handled easily.	Machines have been developed to cope with numerous dangerous materials and situations	Cost of training and employing staff
	They are able to lift certain materials also	Possibility of machine failure which can hold up many operations.

(Source: Badu, 2008)

Material storage can be defined as the provision of adequate space, protection and control of building materials and components held on site during the construction process. Johnston (1981) asserts that improper storage and handling of materials on building projects, which could result to waste, can be caused by inadequate supervision and careless attitudes, together with misplaced incentives. Hence, there is need for proper storage and handling of materials on building projects, as this could be a solution to improper storage and handling of materials.

2.8 Waste Minimization

The Environmental Protection Agency (EPA) of the United States of America views waste minimization as; any method that reduces the volume or toxicity of a waste that requires disposal. In a practical sense, it is any method that reduces the amount of waste. Government regulations, as well as internal cost effectiveness, require that the production and therefore the disposal of all wastes, and particularly hazardous wastes, be kept to a minimum. According to Poon and Jaillon (2002), waste minimization involves any technique, process or activity which avoids, eliminates or reduces waste at its source or allows reuse or recycling of the waste.

The Environmental Protection Agency of UK describes waste minimization as the reduction of waste at source, by understanding and changing processes to reduce and prevent waste (Hoe, 2006). Also known as process or resource efficiency, waste minimization includes the substitution of less environmentally harmful materials in the production process (Hoe, 2006). The waste minimization process involves systematic prevention or reduction of raw material, water and energy consumption and the reuse and recycle of waste on site. It focuses on the term 'Reduce, Reuse, Recycle' with disposal of waste being a last resort. This has financial benefits for businesses by reducing operating costs and minimizing the environmental impact (Hoe, 2006).

Moving towards waste minimization requires that the firm commits itself to increasing the proportion of non-waste leaving activities. Waste minimization is about common sense and a change of attitude, rather than new technologies (Hoe, 2006). The first stage of a whole waste management plan is waste minimization. It is clear that the best option is for waste not to be created at all (Hoe, 2006). Minimization involves surveying the flow of materials into as well as out of a site, and assessing what steps could be employed to reduce the quality and range of material discarded (Hoe, 2006). According to Begum *et al.* (2006), the process of waste minimization consists of two basic operations: source reduction and recycling. Source reduction is most desirable to avoid waste generation, while recycling is useful to conserve resources and to prevent materials from entering the waste stream (Al-Moghany, 2006; Begum *et al.*, 2006). To be specific, waste minimization in industry means practices, including, but not limited to: (1) Product design modifications; (2) Inventory management changes; (3) Operational and maintenance procedure changes; (4) Material changes; (5) Equipment replacement modifications; and (6) Reuse/recycling of waste materials (Hoe, 2006).

Waste minimization, a generic term in the preferred hierarchy of waste management, is often the preferred method of managing waste to achieve the broader environmental objectives of the environmental management system (Hoe, 2006). This system can involve changes to the raw material input, the production process and/or the final product. It can be achieved through simple procedural alterations, or through major changes that may involve or often justify significant capital expenditure (Hoe, 2006).

The benefits of minimizing waste include (Hoe, 2006);

- Reducing demand for landfill space;
- Saving resources and energy;
- Reducing pollution; and
- Increasing the efficiency of production.

2.8.1 Waste Minimization in Construction

The building industry is using a considerable amount of resources, but if the life cycle of the material on site is closely examined, it is generally known that there is a relatively large portion of the materials being wasted because of poor material control on building sites (Hoe, 2006; Poon *et al.*, 2004; Formoso *et al.*, 2002).

According to Coventry *et al.* (2001), the potential for minimizing construction and demolition waste is considerable. Practical waste minimization strategies require a detailed understanding of what causes construction waste (Hoe, 2006). Faniran and Caban (1998) examined waste minimization strategies and the relative significance of construction waste sources using survey. The authors found out that a sizeable proportion of the firms did not have specific policies for minimizing waste. Furthermore, while a majority of firms with specific waste minimization policies made efforts to minimize waste at source such as to avoid generating waste in the first place, this minimization was limited to waste generated by site offices and amenities (Faniran and Caban, 1998). The conclusion for their study was that potential scope exists for improving the effectiveness of waste minimization at source by addressing the sources of all waste generated during the construction phase.

According to Teo and Loosemore (2001), the significant contribution to waste reduction in the construction industry is through people changing their wasteful behavior. Waste is an inevitable by-product of construction activity; its management is a low project priority with an absence of appropriate resource and incentives to support it (Teo and Loosemore, 2001). Their findings complement Lingard *et al.'s* (2000) study which identified the availability of local infrastructure and top management supportiveness as the most critical determinant of waste reduction behavior on projects. Their recommendations to help managers improve operatives' attitudes towards waste include clear communication of waste management policies, provision of necessary waste infrastructure, the cooperation of and promotion of sense of collective responsibility among the workforce. Table 2.10 lists some of the waste minimization measures identified from literature.

Table 2.10 Measures for Materials Waste Minimization

No.	Waste minimization measures
	Purchasing raw materials that are just sufficient
	Using materials before expiry dates
	Use of more efficient construction equipment
	Good coordination between store and construction personnel to avoid over ordering
	Adoption of proper site management techniques
	Training of construction personnel
	Accurate and good specifications of materials to avoid wrong ordering
	Proper storage of materials on site
	Checking materials supplied for right quantities and volumes
	Employment of skilled workmen
	Minimizing design changes
	Change of attitude of workers towards the handling of materials
	Accurate measurement of materials during batching
	Mixing, transporting and placing concrete at the appropriate time
	Access to latest information about types of materials on the market
	Vigilance of supervisors
	Weekly programming of works
	Careful handling of tools and equipment on site
	Good construction management practices
	Adherence to standardized dimensions
	Waste management officer or personnel employed to handle waste issues
	Just in time operations
	Early and prompt scheduling of deliveries
	Encourage re-use of waste materials in projects
	Use of low waste technology
	Recycling of some waste materials on site

(Source: Begum et al., 2006; Shen et al., 2002; Shen and Tam, 2002; Poon et al., 2001; Ho, 2001; Faniran and Caban, 1998; Peng and Scorpio, 1997; Sherman, 1996).

2.8.2 The 3 "R"s of construction waste minimization

The 3 "R"s of construction waste minimization are based on 3 concepts, namely reduction, reuse and recycling. Waste reduction or source reduction, means preventing the creation of the waste in the first place (Begum *et al.*, 2006). This is one of the basic principles of sustainable building (Hoe, 2006). If the contractors aim for zero waste, they not only conserve natural resources and avoid the associated impacts of their extraction and processing but also save money (CIRIA, 1998). Strategies such as designing with standard building material sizes in mind reduce purchasing, handling and disposal costs (Hoe, 2006; Al-Ansary *et al.,* 2004).

Re-use is a form of waste reduction that: (1) extends resource supplies; (2) keeps high-quality-matter resources from being reduced to low-matter-quality waste; and (3) reduces energy and pollution even more than recycling (Begum *et al.*, 2006). According to Ekanayake and Ofori (2000), recycling waste as useful materials is a very important environmental management tool for achieving sustainable development. On the other hand, recycling waste without properly based scientific research and development can result in environmental problems greater than the waste itself. The successful research and development of new building materials or components using waste as raw material, is a complex and multidisciplinary task, including technical, environmental, financial, marketing, legal and social aspects (Hoe, 2006).

2.8.3 Source Reduction

Source reduction is defined as any activity that reduces or eliminates the generation of waste at the source, usually within a process (Begum *et al.,* 2006). It is highest on the construction waste management hierarchy; it has the most positive environmental impact due to the action having a direct result (Hoe, 2006). According to Al- Ansary *et al.* (2004), many design and job site practices can significantly reduce waste and cost of materials on a construction project while requiring only slight modifications of standard procedures. Contractors can apply source reduction on site, by ordering materials in varying lengths to meet construction project conditions, rather than ordering single lengths of materials (Hoe, 2006). Careful coordination of the purchasing of materials can also reduce waste in the construction process (Lim and Ofori, 2004).

2.8.4 Reuse/Salvage of materials

According to Hoe (2006), reuse is to salvage and reprocess materials as much as possible in a construction project. This includes materials removed during demolition, scrap generated on site and used materials or scraps from other jobs. Many of the materials in demolished structures can be removed, cleaned, renovated and used in the same construction project or in other projects (CIRIA, 1998).

When reusing materials, the contractor should ensure that the material is appropriate for the use, of proper quality and is prepared for its reuse. The contractor should also exercise care in installation and removal of materials, and provide warehousing to facilitate their reuse in the future. Excessive fasteners/adhesives can negate intentions to reuse materials. Provision for alterations and remodeling can be made during the initial construction process. Main contractors in controlling subcontractors' usage of materials through separation of waste for reuse would reduce the amount of waste generated (Hoe, 2006).

2.8.5 Recycling

Recycling is commonly defined as a process of separating recyclable materials from non-recyclable materials and supplying them to a hauler or business so they can be processed to make new products (Hoe, 2006; Al-Moghany, 2006). Buying building materials with recycled content helps develop a market for the waste material one recycles from the job site.

2.8.6 Benefits of Construction Waste Minimization

Construction and demolition projects pose unique challenges in the area of waste minimization (Hoe, 2006; Milward, 1995). Since each project is different, generating its own unique combination of wastes, the contractor must be flexible and creative in finding ways to reduce, reuse, or recycle the various types of wastes (Hoe, 2006).

According to Hoe (2006), managing construction and demolition waste can constitute a significant cost to the business. Some wastes require careful and perhaps expensive handling techniques during the construction process. A company can thus benefit in a number of ways from reducing the amount of waste it needs to dispose of. The consideration of waste minimization can generate advantages such as financial and environmental benefits (Al-Moghany, 2006; Poon and Jailon, 2002).

- **Financial benefits**

Waste minimization can provide financial benefits, and in some cases can even save cost and time. The financial benefits can be appreciated over a short term or long-term period. But overall, cost benefits can be appreciated throughout the whole building process by carrying out an analysis of the life cycle costs. Financial benefits include:

- Reduced transportation costs for waste materials (less transportation because of less material wasted). This includes transportation to and from the site and disposal.
- Reduced disposal costs of waste materials.
- Reduced purchase quantity and price of raw materials by waste minimization.
- Reduced purchase price of new materials when considering reuse and recycling (depending on materials).
- Increased returns can be achieved by selling waste materials to be reused and recycled.

Long term benefits through optimizing the building life concept, by avoiding expenses from demolition and construction of new buildings (Al-Moghany, 2006; Poon and Jailon, 2002).

Use of recycled materials has reduced waste storage costs and minimized the dereliction of land (Al-Moghany, 2006; Lnyang, 2003). Sometimes, reuse and recycling may not always be financially viable, hence other considerations should be considered such as environmental benefits (Al-Moghany, 2006).

- **Environmental benefits**

Waste minimization can provide environmental benefits, which are important to be considered due to the alarming situation of materials waste on construction sites (Al-Moghany, 2006; Poon and Jailon, 2002). These environmental benefits are:

- Reduced quantity of waste generated.
- Efficient use of waste generated.
- Reduced environmental effects as a result of disposal, e.g. noise, pollution.

- Reduced transportation of waste to be disposed of (hence less noise, vehicle emission pollution, and energy used).

2.9 LEAN THINKING

Lean thinking is a framework and a production philosophy originating from Japan. It is based on different elements derived from the Toyota Production System (TPS) (Dao and Follestad, 2009; Tezel, 2007). These elements are discussed below.

2.9.1 Lean Production

The term "Lean production" was first coined in the book "*The machine that changed the world*" by Womack *et al.* (1990). This term was used by the International Motor Vehicle Program (IMVP) at Massachusetts Institute of Technology (MIT) to name the Japanese technique of building cars as compared with the traditional Western mass production techniques. Lean production is a form of manufacturing which uses less of everything as compared to mass production. According to Womack and Jones (2003), lean provides a way to do more with less human effort, less equipment less time and less space.

Lean production system is based on the idea that production should only take place when a need arises from a customer. In this respect, Lean production uses a pull system for inventory and production control. In the Lean systems, products are manufactured Just-in-Time to satisfy consumers' needs. Figure 2.3 depicts the Toyota House from the Toyota Production System. This house entails all elements described in the Lean philosophy.

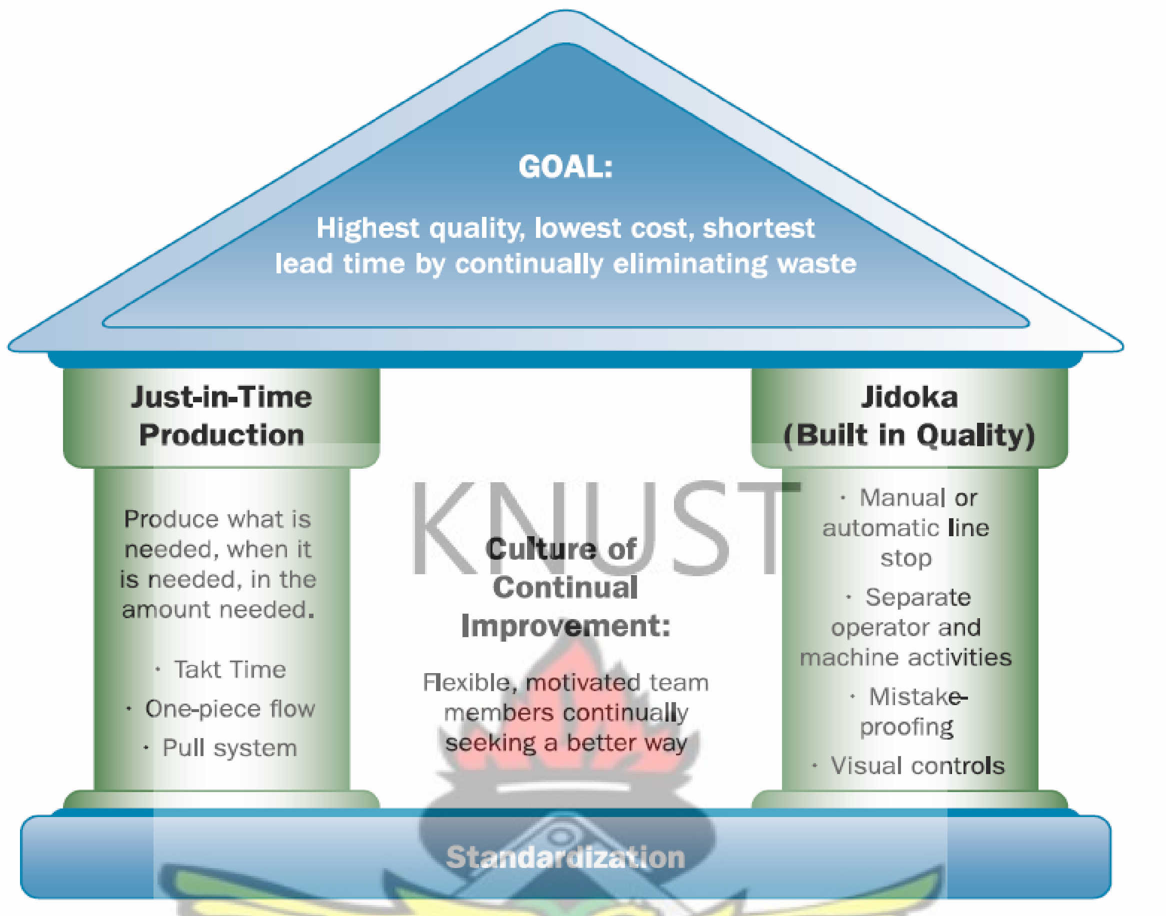


Fig. 2.3 The TPS House (Liker, 2004)

The basic idea behind the house is that every component needs to be in place to keep the house stand steady. The first step in Lean production is to understand what value is and what activities and resources are necessary to create that value. Only what is considered as value for the customer should be taken into consideration. Once this is understood everything else is considered as waste. '*Seven plus one'* different types of waste are discussed in the Lean philosophy.

2.9.2. The Right Lean Wastes

Lean philosophy is a common sense approach that strives for the systematic elimination of waste in the production process. Womack and Jones (2003) define waste as any human activity which absorbs resources but do not create value. Ohno (1988) defines waste into seven categories that are apparent in every manufacturing facility in the world: (1) *overproduction*; (2) *waiting*; (3) *unnecessary transport*; (4) *inappropriate processing*; (5) *unnecessary inventory*; (6) *unnecessary motion*; (7) *defects*. An eighth waste was added by Liker (2004) which is (8) *unused employee creativity*.

- **Overproduction**

This waste is considered as the most serious one as it discourages smooth flow of goods and services and is likely to inhibit quality and productivity. Producing items for which there are no orders generates wastes such as overstaffing, storage and transportation costs. Such overproduction also tends to result in excessive lead and storage times. As a result, defects may not be detected early, products may deteriorate and artificial pressure on work rate may be generated.

- **Waiting**

This waste is concerned with the ineffective use of time. Waiting occur whenever goods are not moving or being processed. In manufacturing, this waste occurs whenever workers are waiting for equipment, plans or instructions on how to proceed. This waste affects both goods and workers, each spending time waiting. The best use of waiting time would for instance be to train workers.

- **Unnecessary transport**

The third waste involves goods being moved around. Carrying work in process (WIP) long distances, creating inefficient transport, or moving materials, parts, or finished goods into or out of storage or between processes. Taken to an extreme, any movement in the factory could be viewed as waste. In addition, double handling and excessive movements are likely to cause damage and deterioration of material.

- **Inappropriate processing**

This waste is about taking unnecessary steps to process the parts. Inappropriate processing can for instance be depicted as using expensive highly advanced equipment where simple tools would be sufficient to do the work. The over complexity generally discourages ownership and encourages the employees to overproduce so that the large investment in the complex machines can be recovered.

- **Unnecessary inventory**

This can be related to material stored on site too far in advance of when it is needed. Unnecessary inventory tends to increase lead time, obsolescence, damaged goods, transportation, storage costs, and delays. The long lead time prevents rapid identification of problems and discourages communication. By achieving flow between the work stations, inventory can be reduced.

- **Unnecessary motion**

Any wasted motion employees have to perform during the course of their work, such as stretching or bending. Taken to an extreme, walking can be considered as waste. Such waste is tiring for the employees and is likely to lead to poor productivity and often, to quality problems.

- **Defects (Rework)**

This is considered as the bottom-line waste because defects are direct costs. Production of defective parts or correction is typically a wasteful spending. Repair or rework, scrap, and inspection mean wasteful handling, time and effort.

- **Unused employee creativity**

This is about losing time, ideas, skills, improvement and learning opportunities by not engaging or listening to employees (Liker 2004; Dimancescu *et al.*, 1997; Hines and Rich, 1997).

2.9.3 Lean Principles

"Lean" is essentially about getting the right things to the right place at the right time, in the right quantity whilst minimizing waste and being open and responsive to change (Kempton, 2006). Lean production has an underlying philosophy that, by eliminating waste, quality can be improved, and production times and costs reduced (Kempton, 2006). In order to reduce waste, a set of key manufacturing principles should be employed (Table 2.11).

Table 2.11 Key Manufacturing Principles Employed to Reduce Waste

Lean Principle	Explanation
Perfect first- time quality	Achieve zero defects, revealing and solving problems at the source
Waste minimization	Eliminating all non-value-adding activities and maximizing the use of resources
Continuous improvement	Reduction of costs, increase quality and productivity
Pull processing	Products pulled from the consumer end, i.e. not pushed from the production end
Flexibility	The production of different mixes and/ or greater diversity of products, without compromising efficiency
Relationships	Building and maintaining long-term relationships with suppliers

(Source: Kempton, 2006)

These five principles of the Lean philosophy have been widely used over the past decades by companies seeking to implement Lean in their production process. Liker (2004) describes a much broader way of implementing Lean through 14 principles of the Toyota way:

- Base your management decisions on a *long term philosophy*, even at the expense of short term financial goals.

- Create *continuous process flow* to bring problems to the surface.
- Use *"Pull" systems* to avoid overproduction.
- *Level out* the workload.
- Build a *culture of stopping the production to fix problems*, to get *quality right* the first time.
- *Standardized tasks* are the foundation for *continuous improvement* and employee empowerment.
- Use *visual control* so no problem is hidden.
- Use only *reliable*, thoroughly tested *technology* that serves your people and processes.
- Grow leaders who thoroughly understand the work, *live the philosophy*, and teach it to others.
- Develop *exceptional people* and teams who follow your company's philosophy.
- *Respect* your extended network of partners and suppliers by challenging them and helping them improve.
- Go and see for yourself to thoroughly *understand the situation*
- Make decisions slowly by *consensus*, thoroughly *considering all options*; *implement decisions rapidly*.
- Become a *learning organization* through relentless reflection and *continuous improvement.*

However, Liker (2004) insists on the fact that the equation might be different depending on the organisation. He insists that Lean philosophy is not about imitating the tools used by Toyota in the particular manufacturing process but about customizing the principles and carefully practicing them to best fit your own organisation. The different tools used in Lean philosophy are discussed in the next section.

2.9.4 Lean Tools

In the framework of International Group of Lean Construction (IGLC), the idea of lean production as basically a theoretical innovation has been at the fore. The idea of understanding of construction as production was introduced by Koskela in 1992. The need for a broader foundation for project management was introduced by Howell and Koskela in (2002). Lean construction is to move beyond the traditional view of project as transformation, to include flow and value generation. The new project theory should include time, variability and customer satisfaction as relevant variables for decision-making. As a result, planning, execution, and control of projects will change. Planning has to include organizing, that is, moving from pure task allocation to structuring a suitable environment for human action. Execution has to be a two-way channel that achieves goals through commitment. Control management must move from auditing to searching for causes and ultimately preventing future problems (Jin, 2007).

According to Koskela (1999), lean construction shares the goals of lean production: elimination of waste, cycle time reduction, and variability reduction. In fact, workflow reliability and labor flow are regarded as key determinants of construction performance (Thomas *et al.*, 2003).

- **Concurrent Engineering**

Concurrent engineering is 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 (Jin, 2007). According to Rolstadas (2005), the engineering process can be modeled by a generalization of Walrasian model which is similar to the earned value (or achieved value) concept in construction. The traditional Walrasian model describes the transformation process by using product and resource data.

The generalization of the Walrasian model includes a time frame and a control system. The time frame ensures that resources are available at specific times and the control system seeks to review synchronization and coordination. Improvements can be accomplished in different ways. Scheduling could be improved by network analysis (CPM and PERT). Other opportunities can be accomplished by overlapping activities, splitting activities, and shrinking transfer time between activities. Algorithms could be implemented to model resource allocation, conditional branching, and stochastic networks within a limited time frame.

According to Kamara (2003), concurrent engineering goes beyond diagrams, charts and algorithms. It demands a multi-disciplinary team effort where information sharing and communication are keys to identify new ideas. Partnering with subcontractors and suppliers can also influence the outcome of concurrent engineering efforts. The relationship with the client should not be overlooked as the client might facilitate concurrent engineering efforts that reduce the project's cost. The success in lean-product-process development relies on the involvement of all participants in the early design (Gil *et al.*, 2000).

- **Last Planner**

According to Ballard (2000), *Last Planner* is a technique that addresses project variability. High-level planning relies upon the completion of tasks. Depending on the complexity of the project, those tasks lead ultimately to assignments that consist of specific physical work. The Last Planner is the person or group accountable for *production unit control,* that is, the completion of individual assignments at the operational level. Traditional practices do not consider a difference between what *should, can, and will* be done. The assumption is that pushing more tasks will result in better results (Jin, 2007). Ballard identified definition, soundness, sequence, size and the learning process, as criteria to determine the quality of assignments. Performance is measured by the execution of the assignments (Ballard, 2000). The Percentage Plan Completed (PPC) that is, the proportion of completed activities with respect to planned activities, measures the work flow reliability. Nonconformance (failures) is the source of information leading to root causes of underlying problems. Actions are taken to prevent those problems and eventually decrease variability.

Last Planner requires *work flow control* that ensures the flow of design, supply and installation through production units. This is done by the *look ahead* schedule, which shapes the sequence and rate of work. It splits the master schedule into packages that detail the method of execution, check capacity, and determine a backlog of ready work. The scope of the look ahead ranges from three to twelve weeks and should be prepared by teamwork. Phases are required in case activities extend beyond the look ahead period. Assignments will always be subject to specific constraints (contract, design, materials, prerequisite work, space, equipment or labor) (Jin, 2007).

- **The Kanban system (or Flow of Materials and Work)**

According to Arbulu *et al.*, (2003), Kanban can be applied to construction. They focused on certain types of materials (consumables, personal protective equipment, hand tools, power tools and consumables for power tools), and the Kanban strategy was based on key components: marketplaces, collection vehicles or ‘milk runs’, supplier Kanbans, satellite stores, and inventory management system. Marketplaces are site warehouses which distribute materials and small tools. Satellite stores are on-site locations that get products from marketplaces. ‘Milk run’ vehicles collect materials from preferred suppliers to the job site. Two kinds of vehicles are included: external collection vehicles and internal delivery vehicles. External milk run vehicles collect materials from suppliers and transport them to marketplaces, and internal milk run vehicles deliver products from marketplaces to satellite stores (Jin, 2007).

Plastic bins are used as Kanban signals to pull materials from suppliers to site on a just-in- time basis; and request forms are used as Kanban signals between satellite stores and marketplaces. The Kanban process starts with open orders so that the site can pull materials from the supplier up to a certain limit. Next, requests arrive at the market place and products are picked up from the store, which is controlled by reorder points. Products are dispatched through internal vehicles, and external vehicles replenish marketplace stocks (Jin, 2007).

- **Quality Management Tools**

The integration of quality tools into lean construction is based on a shift from conformance-based quality to quality at the source (Marosszeky *et al.*, 2002). Quality at the source works with mapping of the activities and defines the *quality shield* (a set of controls required to ensure product conformance). The required control will be translated into checklists to be enforced by the workforce. A *point system* is used to review the execution of planned controls so that workers will follow planned controls rather than quality corrections. A summarized report, by task, is presented as a quality *league* report. The quality league provides positive feedback about the safety of the jobsite, and it seeks to boost ongoing improvement in the quality system (Jin, 2007).

- **Visual inspection**

The mobile nature of work cells in construction does not preclude the application of visual tools for material, work or information flow (Moser and Dos-Santos, 2003). Material identification could speed repetitive operations and reduce the risk of choosing the wrong product. Schedules, milestones, or progress charts could enforce the commitment to the completion of assignments. Communication between decision makers and executers could also be accelerated based on the advantage of information technology (handhelds, mobile devices, and dynamic databases).

2.10 Lean Construction

This section covers the concept of Lean construction from its origin, starting with a brief History on construction and gives the origin of the concept of Lean construction. The Essential features of construction, the Transformation-Flow-Value theory (TFV), Differences between traditional and Lean construction, and Waste in the construction industry are discussed.

2.10.1 History of Lean Construction

The need for shelter to fulfill one of the basic necessities of the human being has made construction very important. The culture of the construction industry and many of its methods have their roots in periods before scientific analysis. However, especially after the Second World War, there have been several attempts to understand construction and its challenges and to develop sustainable solutions and improvement methods. Different initiatives have been taken which include: industrialization, computer integrated construction, and total quality management.

Different operational and tactical techniques such as project planning and control tools, organizational methods, project success factors, and productivity improvement methods have also risen (Dao and Follestad, 2009; Koskela 1992).

Eiji Toyoda and Taiichi Ohno pioneered the concept of lean production at the Toyota Motor Company in Toyota City, Japan around 1950s after the World War II. Lean production quickly became the strength of the Japanese motor-vehicle industry because it was able to eliminate waste: half of the resources, half of the manufacturing space, half of the investment tools, half of the engineering hours, and half of the new product development time than that of mass production (Lehman and Reiser, 2004).

Lean production caused Toyota to gain market share and revitalize the automotive industry. This revitalization and increased market share caused other automobile manufacturers around the world to become interested in Toyota's methods. They wanted to learn their techniques, thus, the International Motor Vehicle Programme (IMVP) at Massachusetts Institute of Technology (MIT) was created in 1985 and the research and learning of the fundamentals of lean production techniques began. Lean principles incorporate teamwork, communication, efficient use of resources, elimination of waste, and stressed the importance of continuous improvement (Lehman and Reiser, 2004).

As the principles of lean were studied, the IMVP team incorporated other value improving principles such as Kaizen (a continuous, incremental improvement process) and Value Engineering (VE) techniques to achieve target costing, Statistical Process Control (SPC), Total Quality Control (TQC), and Computer Aided Design (CAD) were also considered (Lehman and Reiser, 2000).

Lean Construction is to a great extent an adaptation and implementation of the Japanese manufacturing principles within the construction process and in doing this Lean

Construction assumes that construction is a kind of production albeit a special one (Bertelson, 2004).

Even though the guiding principles were not formulated until after nearly ten years of work by Koskela (2000), formulated in more detail in 2001 by Ballard et al., one may easily deduce that from the beginning they were: while delivering the project, maximize the value for the client and minimize the waste (Bertelson, 2004).

Koskela (2000), proposed based on the development of manufacturing theories over more than a hundred years the Transformation-Flow-Value (T-F-V) understanding of construction. Koskela and Howell (2002) suggested that the flow aspect should be given more attention in construction management in lieu of the current overemphasis on the transformation aspect. The production theory for the construction proposed by Koskela and not least the concept of production as a flow showed almost immediately its usefulness by practitioners rethinking the construction management methods (Bertelsen, 2004; Ballard, 2000; Bertelsen and Koskela, 2002).

The concept of flow management was taken further by using the methods introduced by Jim Womack and further developed by the Lean Enterprise Institute (Bertelsen, 2004). Around the same time that Koskela proposed the manufacturing–inspired T-F-V theory, voices were raised that the construction process might be even more complex and that it should be understood in a completely new perspective as well. Gidado (1996) presented a study of project complexity and suggested a numeric method for analyzing the complexity. Radosavljevic and Horner (2002), discussed evidence of complex variability in construction in which they found analogies to the pattern found in complex, dynamic or chaotic–systems, and Howell and Koskela (2000) led a similar discussion at the 8th annual conference of International Group for Lean Construction albeit without much attention from the audience. Inspired by this discussion, Bertelsen (2002) reiterated the idea that construction must be understood as a complex and dynamic system and later presented a broader study of its complexity (Bertelsen, 2003).

2.10.2 Essential Features of Construction

Construction is a fundamentally different kind of production as compared to manufacturing. The construction industry is unique for its production of one-of-a-kind products, on-site production environment and temporary multi-organization for each project (Dao and Follestad, 2009; Groák 1992; Koskela 1992). According to Ballard and Howell (1998), construction's objects possess two characteristics which together uniquely define them: (1) they belong to the category "fixed position manufacturing" in which the product being manufactured eventually becomes too large to be moved through work stations, so the work stations have to move through the product, (2) they are rooted in place which mean they cannot be moved. Also the production process is essentially project based; every project is unique in terms of specifications, delivery methods, administration and participants. Unlike the manufacturing industry where the same workers perform the work continuously, a construction project involves several different companies which have not necessarily worked together before.

Furthermore, projects in the construction industry vary considerably in terms of the kind of sector they serve (for example, shipbuilding, road construction or house building). Construction projects can also be characterized as slow and quick, simple and complex, and certain and uncertain (Ballard and Howell, 1998). Because of these peculiarities; the construction industry is often considered to be different from manufacturing.

2.10.3. The Concepts of Lean Construction

LC is a way to design production systems to minimize waste of materials, time and effort in order to generate the maximum possible amount of value (Koskela *et al.*, 2004; Koskela and Howell, 2002). It is also a holistic design and delivery philosophy with an overarching aim of maximizing value to all stakeholders through systematic, synergistic and continuous improvements in the contractual arrangements, product design and method of selection, the supply chain and the workflow reliability of site operations (Abdelhamid, 2004). At the Design for Manufacture Competition (2005), LC was defined as the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and the pursuit of perfection in the execution of a project. In the opinion of Mossman (2009), lean thinking is lean because it provides a way to do more and more with less and less – less human effort, less equipment, less time and less space – while coming closer and closer to providing customers with exactly what they want.

Lean theory and principles taken together provide the foundation for a new form of project management (Dulaimi and Tanamas, 2001). From roots in production management, LC is a way to design production systems to minimize waste of materials, time and effort in order to generate the maximum possible amount of value (Koskela and Howell, 2002). LC has produced significant improvements particularly on complex, uncertain and quick projects. According to Dulaimi and Tanamas (2001), managing construction under LC is different from typical contemporary practice because it:

- Has a clear set of objectives for the delivery process;
- Is aimed at maximizing performance for the customer at the project level;
- Designs concurrently product and process;

- Applies production control throughout the life of the project.

2.10.4. Lean Construction versus Traditional Construction

Construction is considered to be one of the most change resistant industries in the world. Koskela (1992) claimed that the most general concept seems to be understanding construction as a simple process of transforming an input to an output. This conception is actually shared by both old and newer methods in construction.

The traditional system of construction project focuses more on keeping track of time and cost. Time control is about looking at the progress in the production line, while cost control is primarily concerned with the budget. Cost control tracks if the project is under or over budget. Kim (2002) suggests that in traditional construction, control consists of monitoring against schedule and budget estimates; while in Lean construction control is defined as causing events to conform to plan. Kim (2002) continues to say that traditional construction focuses more on individual activities. In traditional construction, control begins with tracking cost and schedule, and therefore any effort to improve productivity leads to unreliable work flow due to sub-optimization. As a result, project performance is considerably reduced.

In Lean philosophy, the focus is on how one activity affects the next activity, as all activities are part of the whole system. Ballard and Howell (1998) claimed that the goal in Lean construction is to improve the performance of the whole system. They put forward that where current project management manages projects as more or less independent activities, Lean philosophy works first to assure the reliable flow of work between the tasks. In that perspective Koskela (2000) depicts construction as a continuous flow of materials and/or information instead of just conversion activities (from input to output).

According to Koskela (1992), production concepts used in various industries are of three main types:

1. Transformation view – concept of transforming inputs to outputs.

2. Flow view – materials and information flow in a production process.

3. Value generation view – process where the value for customer is created through fulfillment of his/her requirements.

However, construction has for a long time been managed according to the transformation or conversion concept, thus focusing more on transforming an input to an output. Principles related to the flow and value generation concepts were largely neglected resulting in inefficiency. According to Koskela (2000), it is crucial that the peculiarities of construction are understood and taken into consideration in construction management both from the point of view of Transformation-Flow and Value concept. For Koskela (2000), this tripartite view of construction will foster tremendous improvement in construction. Table 2.12 depicts the concept of Transformation Flow and Value. The table describes the nature of construction, its main principles, the methods and practices and its practical contribution from the standpoint of each element of the TFV theory. Table 2.12 is summarized from the practical contribution viewpoint depicted at the bottom of the table. "Taking care to do necessary things" in the Transformation aspect can be linked to effectiveness and "taking care that the unnecessary is done as little as possible" in the Flow aspect can be linked to efficiency. By combining these two aspects, value can be obtained which mean "taking care that customer requirements are met in the best possible manner" (Koskela, 2000). According to Koskela (2000), performance is described in term of attaining value effectively and efficiently, therefore the TFV-theory represents a huge opportunity for the construction industry in its pursuits to achieve successful performance.

Table 2. 12 Transformation/Flow/Value

	Transformation view	Flow view	Value generation
Nature of construction	A series of activities which convert inputs to outputs	The flows of information and resources which release work: composed of conversion, inspection, moving and waiting	A value creating process which defines and meets customer requirements
Main principles	Hierarchical decomposition of activities; control and optimization by activity	Decomposition at joints. Elimination of waste (unnecessary activities), time reduction.	Elimination of value loss, the gap between achieved and possible values.
Methods and practices	Work breakdown structure, critical path method. Planning concerned with timing start and responsibility for activities through contracting or assigning.	Team approach, rapid reduction of uncertainty, shielding, balancing, decoupling. Planning concerned with timing, quality and release of work.	Development and testing of ends against means to determine requirements. Planning concerned with work structure, process and participation.
Practical contribution	Taking care to do necessary things	Taking care that the unnecessary is done as little as possible.	Taking care that customer requirements are met in the best possible manner.

(Source: Ballard, 2000)

The Lean Construction Institute (LCI) seminar (2002B) summarizes in Table 2.13 the major differences between Lean construction and traditional form of project management with respect to control, performance optimization, scheduling viewpoint, production system and process, performance measurement and customer satisfaction.

Table 2. 13 Comparison of Lean and Traditional Construction

Lean Construction	Traditional Construction
Control	
Causing events to conform to plan-steering	Monitoring against schedule and budget projections-tracking
Optimization	
The entire project	A specific activity
Scheduling view point	
• "PULL" work schedule • Based on when its completion is required by a successor activity.	• "PUSH" work schedule • Based on emphasizing required start dates for activities.
Production system	
Flow production system	Conversion production system
Production process	
Effectiveness	Efficiency
Performance measurement	
Percent Plan Complete (PPC)	Work Breakdown Structure (WBS), Critical Path Method (CPM) and Earned Value
Customer satisfaction	
Successor process satisfaction	Owner or final consumer satisfaction
Planning	
Learning	Knowing
Uncertainty	
Internal	External
Coordination	
Keeping a promise	Following orders
Goal of supervision	
Reduce variation and manage flow	Point speed and productivity

(Source: LCI Seminar, 2002)

The most fundamental difference between traditional and Lean construction can be found in scheduling (Kim, 2002). In scheduling, Lean construction uses the "pull" work schedule while traditional construction uses the "push" work schedule. Pull systems schedule work based on demand as opposed to the push systems which schedule work based on system status.

2.10.5 Benefits of lean construction

The LC concept has been introduced in the construction industry in various countries such as Australia, Brazil, Denmark, Ecuador, Finland, Peru, Singapore, United Kingdom, United States of America and Venezuela (Abdullah *et al.*,2009; Johansen and Walter, 2007; Ballard and Howell, 2004), and its application within the industry is reported to have resulted in a lot of benefits. This is so because its approach is different from the normal practices within the construction process as it is based on production management principles. LC also has better results in complex, uncertain and quick projects (Salem *et al*., 2005). The following benefits are claimed for its implementation in the construction industries of many emerging economies (Mossman, 2009; Lehman and Reiser, 2004):

- more satisfied clients,
- productivity gains,
- greater predictability,
- shorter construction periods
- improved design
- reduced cost and less waste.

2.10.6. Measures to bridge the knowledge gap

It is important to carry out extensive planning at the very beginning of any project in order to accomplish lean construction. The design process should include not just the facility design but also the design of the construction process itself (Forbes and Ahmed, 2004). However, it becomes very difficult to apply new principles like lean construction if the knowledge gaps among workers are not dealt with. Some of the measures that could help bridge the knowledge gaps on the concept of lean construction among professionals are presented in Table 2.14.

Table 2.14 Measures to Bridge the Knowledge Gap

	MEASURES TO BRIDGE KNOWLEDGE GAPS
1	Firms should change organizational culture that does not promote lean construction
2	Promotion of the concept to firms, professional bodies and major stakeholders
3	The construction industry should fund workshops and research conferences to promote transfer of knowledge on lean construction
4	Training of employees at all levels on lean construction
5	Engagement of competent and skilled site operatives
6	Working on improving performance when carrying out projects.
7	Construction managers should be committed to changes

(Source: Bashir *et al*, 2010; Kpamma, 2009; Jin, 2008; Johansen, 2007; Kempton, 2006; Salem *et al.*, 2006)

2.10.7. Barriers to the implementation of lean construction

The traditional construction system is mainly project-based and characterized by one-of-a kind set-ups (Hook and Stehn, 2008; Vrijhoef and Koskela, 2005). The capability and efficiency of the construction sector need to be improved to modernize the sector and eventually increase user satisfaction (Alinaitwe, 2009). The various parties in the construction sector have undertaken numerous approaches to assist in establishing methods which are believed to be able to improve and subsequently increase the efficiency and effectiveness of the sector (Alinaitwe, 2009; Mastroianni and Adelhamid, 2003).

The building industry has a large number of specialized areas and disciplines, and many are based on cyclic processes. Proponents of lean construction argue that it is possible to identify the wasteful activities in the processes and make concessions for them, leading to better understanding and improvement in overall performance (Alinaitwe, 2009; Dunlop and Smith, 2004).

LC consists of a series of flow and conversion activities (Alinaitwe, 2009). Conversion activities are those operations performed when adding value to the material or when information is being transformed into a product, and flow represents tasks like inspections, waiting, moving and storing (Alinaitwe, 2009). Harris et al. (2005) also define lean construction as a concept that incorporates several other concepts from the construction management industry such as Total Quality Management (TQM), Last Planner System (LPS), Business Process Re-engineering (BPR), Concurrent Engineering (CE), Product Circles (PCs) and Team and Value Based Management. In the opinion of Alinaitwe (2009), most of these concepts (Figure 2.4) are interrelated and all aim to improve performance while minimizing waste.

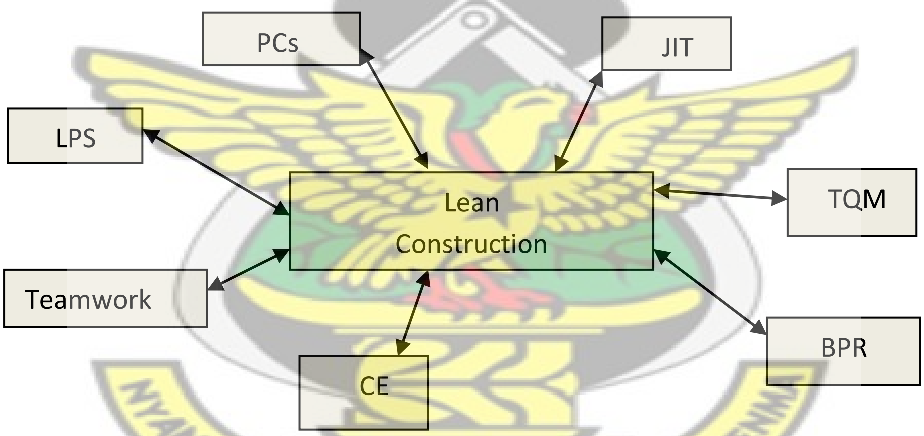


Fig 2.4 Key Concepts of Lean Construction (Alinaitwe, 2009)

As with implementation of other methods or approaches aimed at increasing the performance of the construction sector, the application process of lean principles is sure to encounter various obstacles. Research findings of the Production Management Center (GEPUC) of the Catholic University of Chile, has shown that the application of the LC concept in the industry has faced problems pertaining to time, training, organizational aspects and lack of self-criticism (Alarcon *et al.*, 2008). Furthermore, a major problem with the application of lean construction concept involves aspects of attitude, internal relationships and co-operation. The obstacles within these aspects are related to lack of organizational culture supporting teamwork, lack of group culture, shared vision and shared consensus, inadequate knowledge and skills etc. (Castka *et al*., 2004; Cua *et al.*, 2001; Conte and Gransberg, 2001).

Several researches have been conducted in various countries to investigate factors that could affect the successful implementation of lean construction. A study undertaken by Bashir *et al*. (2010) classified these barriers into six different categories based on a thorough and critical review of international literature relating to the take up of lean practice.

Among the measures to overcome potential barriers to implementation of lean construction identified from literature are:

Table 2.15 Barriers to Implementation of Lean Construction

No.	BARRIERS
1	Lack of interest from clients
2	Waste accepted as inevitable
3	Poorly defined individual responsibilities
4	Lack of training
5	Less involvement of contractors and specialists in design process
6	Delays in decision making
7	Lack of top management support and commitment
8	Poor project definition
9	Delay in materials delivery
10	Lack of equipment
11	Materials scarcity
12	Unsuitable organizational structure
13	Lack of supply chain integration
14	Poor communication
15	Long implementation period
16	Inadequate pre-planning
17	Lack of client and supplier involvement
18	Corruption
19	Poor professional wages
20	Lack of standardization
21	Lack of technical skills
22	High level of illiteracy
23	Lack of awareness programs
24	Difficulty in understanding concepts
25	Inconsistency in government policies
26	Lack of buildable designs
27	Incomplete designs
28	Lack of agreed implementation methodology
29	High dependency of design specifications on in-situ materials and components rather than standardized and industrialized prefabricated components
30	Extensive use of subcontractors
31	Lack of long-term commitment to change and innovation
32	Lack of long-term relationship with suppliers
33	The fragmented nature of the construction industry
34	Lack of holistic implementation
35	Inadequate exposure to requirements for lean implementation
36	Lack of information sharing
37	Lack of social amenities and infrastructure
38	Unsteady price commodities
39	Inflation
40	Uncertainty in supply chain

(Source: Bashir *et al*., 2010; Abdullah *et al*., 2009; Alinaitwe, 2009; Mossman, 2009; Jorgensen and Emmitt, 2008; Olutanji, 2008; Salem *et al*., 2005; Forbes and Ahmed, 2004; Castka *et al*., 2004; Alarcon et al., 2002; Cua *et al*., 2001; Common *et al*., 2000)

2.10.8 Measures to overcome potential barriers to implementation of lean construction

Measures to overcome potential barriers to implementation of lean construction identified from literature are presented in Table 2.16

Table 2.16 Suggested Measures to Overcome Potential Barriers to Implementation of Lean

No.	MEASURES
1	Management should train employees on lean concepts
2	Communication should be improved among players in construction projects
3	Construction should ensure or maintain continuous improvement: thus, reduction of costs, increase quality and productivity
4	Construction managers should be committed to changes
5	Workers should be able to work in teams
6	Proactive measures to prevent defective production should be established by firms
7	Timely delivery of materials to construction sites
8	Firms should understand client needs and expectations and position themselves accordingly
9	Companies should be more client focused
10	Standardized construction elements should be promoted in the industry
11	Firms should be willing to change organizational cultures that do not promote lean construction
12	The opinion of employees should be considered in decision making
13	Government agencies should embark on applicable policies that could provide critical support to make lean methods feasible
14	Management should monitor inflation risks and pricing levels that could provide the stability that organizations need in order to make lean methods feasible
15	Management should deal with uncertainties and fears that cause organizations to conceal information instead of sharing it
16	Partnering should be promoted to maximize team building and development of trust
17	Team members should be empowered in decision-making to make partnerships meaningful

(Source: Bashir *et al*., 2010; Abdullah *et al*., 2009; Alinaitwe, 2009; Mossman, 2009; Jorgensen and Emmitt, 2008; Olutanji, 2008; Salem *et al*., 2005; Forbes and Ahmed, 2004; Castka *et al*., 2004; Alarcon et al., 2002; Cua *et al*., 2001; Common *et al*., 2000)

2.10.9 Conclusion

Construction activities generate avoidable and unavoidable waste. Identifying and categorizing the types and causes of avoidable waste help in its minimization. This chapter reviewed literature on the construction industry in the world and in Ghana, material waste, sources and causes of material waste and waste minimization measures. It further introduces lean thinking, lean production, principles of lean production and concludes with the introduction of lean construction in the construction industry and barriers hindering its implementation.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes the research method adopted in this study. It discusses the design of the survey questionnaire and the selection of sample respondents for the questionnaire survey. The statistical tools for the data analysis are also discussed.

3.2 Research design

Research design is the overall plan for obtaining answers to the questions being studied and for handling some of the difficulties encountered during the research process (Al-Moghany, 2006; Polit and Hungler, 1999). Research design is an action plan for getting from 'here' to 'there' where 'here' may be defined as the initial set of questions to be answered, and 'there' is some set of conclusion (answers) about these questions. Between 'here' and 'there' there are a number of major steps, including the collection and analysis of relevant data (Al-Moghany, 2006; Naoum, 1998). According to Al-Moghany (2006), researchers cannot assume that people think in certain ways without asking them what they think. The design normally specifies which of the various types of research approach will be adopted and how the researcher plans to implement scientific controls to enhance the interpretability of the results (Polit and Hungler, 1999). There are a variety of survey designs that can be used to accommodate different substantive needs and problems if those problems are anticipated in the planning of the survey (Al-Moghany, 2006; Weisberg and Bowen, 1977). The structured questionnaire is probably the most widely used data collection technique for conducting surveys to find out facts, opinions and views (Naoum, 1998). Interviews can be classified according to the degree to which they are structured. In an unstructured or nondirective type of interview the interviewer asks questions as they come to mind. On the other hand, in the structured or directive interview the questions are specified in advance (Dessler, 2000). In a quantitative study, the steps involved in conducting an investigation are fairly standard (Al-Moghany, 2006).

In this study, interviews, structured questionnaire and site visits were used in the gathering of data. The interviews were adapted to collect detailed information about respondents' experiences and impressions about materials wastage and lean construction. It was also used to collect preliminary information to help in structuring the questionnaires. The questionnaire survey was also adapted to get feedback on opinions of respondents' about wastage of building materials and the implementation of lean principles in the Ghanaian construction industry.

The site visits involved observations where the researcher sought to find out how materials were stored and handled and also to provide a compendium on high waste generating building materials used in the construction industry. The researcher spent time (8 months) on building construction sites and observed the flow activities of materials (handling and storage). Only handling and storage were considered because from the questionnaire survey, the project managers attested to the fact that materials storage and handling are the major sources of waste on construction sites. The questionnaire survey revealed that the four high waste generating building materials are timber, concrete, cement/mortar and blocks. Photographs were taken to document how these materials were stored and handled on site.

3.3 Sources of data

The study depended on both primary and secondary data. Primary data was made up of first-hand data collected by the candidate through the use of questionnaires, interviews and site visits (observation). The secondary sources of data were obtained using relevant books, journals, magazines and research papers.

3.3.1. *Sources and causes of materials waste*

Sources and causes of materials waste as well as twenty-six (26) waste minimization measures which have been extensively studied were extracted from the literature (Begum *et al.,* 2006; Shen *et al.,* 2002; Shen and Tam, 2000; Poon *et al.,* 2001; Ho, 2001; Faniran and Caban, 1998; Sherman, 1996). The sources and causes of materials waste gathered from literature were pre-tested through interviews of ten selected construction practitioners to evaluate their applicability to the current study.

3.3.2. Perception of professionals on lean principles

A thorough review of literature was undertaken to extract available lean principles, benefits and possible measures to bridge the knowledge gaps on the concept of LC. The benefits and possible measures to bridge the knowledge gap gathered from literature had been successfully and sufficiently used in similar research in other countries (Bashir *et al.,* 2010; Kpamma, 2009; Jin, 2008; Johansen, 2007; Kempton, 2006; Salem *et al.,* 2006).

3.3.3. *Identifying and prioritizing influential barriers*

To identify and prioritize influential barriers to successful implementation of LC in the Ghanaian construction industry, a thorough review of the literature was conducted. Forty barriers to implementation of lean construction and 17 measures to overcome potential barriers to LC were identified (Bashir *et al*., 2010; Abdullah *et al*., 2009; Alinaitwe, 2009; Mossman, 2009; Jorgensen and Emmitt, 2008; Olatunji, 2008; Salem *et al*., 2005; Forbes and Ahmed, 2004; Castka *et al*., 2004; Alarcon et al., 2002; Cua *et al*., 2001; Common *et al*., 2000). The forty barriers and 17 measures to overcome potential barriers to LC were pre-tested through interviews of ten selected construction practitioners to evaluate their applicability to the current study. This led to the confirmation of 33 barriers and 17 measures to overcome potential barriers which were used in the study.

3.4 Research Instrument

The research data was collected mainly through interviews and questionnaires. Field observations through site visits were also employed to gather data on high waste generating building materials.

3.4.1. *Questionnaire Design*

The questionnaire, which consisted of 6 major sets of closed-ended questions was designed to obtain data on the sources and causes of materials waste and waste minimization measures, the questionnaire further sought to obtain information on the level of knowledge of construction professionals on the concept and benefits of lean construction and barriers to the implementation of lean construction in the Ghanaian building industry. Interviews were also used to obtain more specific information about material waste and lean construction.

Structure of questionnaire

The questions were constructed using the Likert scale. The respondents were asked to rank on a scale of 1-5 factors that cause materials waste on construction sites where 1= ‘Highly unimportant’, 2= ‘Unimportant’, 3= ‘Neutral’, 4= ‘Important’ and 5= ‘Highly important’. For each waste minimization measure, the respondents were asked to score the level of contribution to waste minimization on the Likert scale of 1 to 5 where 1= ‘very low’, 2= ‘low’, 3= ’Medium’, 4= ‘High’ and 5= ‘Very high’. The respondents were further asked to score each measure according to the level of practice in their organization on a scale of 1 to 5 where 1= ‘Not practiced at all’, 2= ‘Not practiced’, 3= ‘Practiced’, 4= ‘Frequently practiced’ and 5= ‘Most frequently practiced’.

Concerning the principles of lean construction, the respondents were asked to indicate their level of agreement to the application of the principles to project delivery in the construction industry on a five- point Likert scale (from 1= ‘highly disagree’ to 5 = ‘highly agree’). For the achievability of customer values, respondents were asked to rank from 1 = ‘highly unachievable’ to 5= ‘highly achievable’. For the benefits of lean construction, the respondents were asked to rank from 1 = ‘highly unbeneficial’ to 5 ‘highly beneficial’ and for measures to bridge the knowledge gap, respondents were asked to rank from 1 ‘highly unimportant’ to 5 ‘highly important’.

On the issues of barriers to the implementation of lean construction, the respondents were asked to score the severity of the 33 potential barriers out of the forty which were pre-tested to the implementation of lean construction on the Likert scale of 1-5 where 1= ‘Not very severe’ and 5= ‘Very severe’. The 17 measures to overcome potential barriers to implementation of LC were also scored on a scale of 1-5, where 1= ‘Highly Unimportant’, 2= ‘Unimportant’, 3= ‘Neutral’, 4= ‘Important’ and 5= ‘highly important.

3.5 Target Population

The target population for the data collection using the questionnaires consisted of consultancy firms (architectural and quantity surveying) and construction organizations. Building construction organizations operating within Ghana register with the Ministry of Water Resource, Works and Housing (MWRWH) in four categories: classes D, K, E and G, based on the nature of work the organizations engage in - building, civil engineering construction, electrical and plumbing works as classified respectively. There are four financial sub-classifications within these categories - Class 1, 2, 3 and 4 - which set the limitations for companies in respect of their asset, plant and labour holdings, and the nature and size of the projects they can undertake. Class 1 has the highest resource base, decreasing through classes 2 and 3, to class 4 having the least resource base (MWRWH, 2011). Project managers of D1 and D2 building construction organizations who are registered with the MWRWH as well as directors of works of architectural and quantity surveying firms fully registered with the Architects Registration Council of Ghana (ARCG) and the Ghana Institution of Surveyors (GhIS) respectively were involved in the study.

3.6 Sampling procedure

The sample size of D1 and D2 construction organizations was determined using the following formula recommended for such studies by Israel (1992).

$$n = \frac{N}{1+N(e)^2}$$

Where n is the sample size, N is the population size and e is the desired level of precision (±5%) at 95% confidence interval.

The MWRWH (2011) records on fully registered construction industries in Ghana indicate that there are 139 registered D1 and 380 registered D2 building construction organizations in the Ashanti and Greater Accra Regions of Ghana. This brings the total population size of D1 and D2 construction organizations to 519.

Therefore N= 519.

$$n = \frac{519}{1+519(0.05)^2} = 226 \text{ building construction organizations}$$

As a result, 226 D1 and D2 building construction organizations were considered. All 114 fully registered architectural firms (ARCG, 2010) and 60 fully registered quantity surveying firms (GhIS, 2010) in Kumasi and Accra making a total of 174 consultancy firms were considered in the study.

The choice of D1/D2 construction organizations was due to lack of reliable information on small scale firms, and also based on the assumption that large and well-established firms have good organizational set up and are more capable of undertaking lean production efforts. A simple random sampling approach was used to select the total number of (226) D1 and D2 firms for the study. In this approach, every unit had an equal chance of selection (Hoe, 2006).

3.7 Procedure for data collection

A sample of 226 D1/D2 construction organizations and 174 consultancy (architectural and quantity surveying firms) in Accra and Kumasi were considered for the administration of the questionnaires. The questionnaires were administered through a face-to-face session.

3.8 Data analysis

The completed questionnaires were edited to ensure completeness, consistency and readability. Once the data had been checked, they were arranged in a format that enabled easy analysis. Quantifiable data from the questionnaires was coded into the software for analysis. Statistical Package for Social Sciences (SPSS 16.0) was selected because it was considered to be user-friendly. The following statistical techniques which are grouped under various headings were then employed to analyze the data collected from the survey.

3.8.1. Sources and causes of material waste

Data for waste sources and causes were analyzed using one sample t-test and mean scores.

The one sample t-test was used to determine whether the level of contribution of the waste sources to materials waste generation were significantly high or not. The test statistics were obtained from the formula

$$t = \frac{\sqrt{n}(X - \mu_x)}{s}$$

where X is the sample mean, μ_x the population mean, S the sample standard deviation, and n the sample size. The causes of waste were also analyzed using the mean score rankings. A mean value of 3.0 is considered as significant for the study.

3.8.1.1 Assessment of wastage of key construction materials

Field observations through site visits were employed to identify key materials that were wasted on some selected Ghanaian building construction sites. The idea of this objective was to provide a compendium on the wastage of these key materials as well as the storage and handling practices on construction sites that resulted in the wastage of these materials. One sample t-test was employed to identify those materials that had high levels of wastage on building construction sites.

3.8.2. Perception of professionals on lean construction

Data obtained from the study were ranked according to their mean scores.

Mean score

The mean is utilized as a measure of central tendency. A high mean relevance rating would mean that the factor under consideration is important (Hoe, 2006). The mean scores were obtained by the following formula

$$\mu = \frac{\sum_{i=1}^{5} i.f_i}{\sum_{i=1}^{5} f_i} \quad \text{(Begum et al., 2006)}$$

Where, *f* is the frequency of score *i* for the factor concerned. In this study, a mean value of 3.0 is considered as significant.

3.8.3. *Barriers to successful implementation of lean construction*

Data obtained from the study were analyzed using mean scores and factor analysis.

3.8.3.1. Factor analysis

Factor analysis is a statistical technique used to identify a relatively small number of factors that explain observed correlations among variables (Marija, 2003). It is primarily used for data reduction or structure detection with the assumptions that the variables are continuous, normally distributed, have a good linear relation between them and have underlying factors responsible for the observed correlation. Factor analysis is used when people have been measured on several continuous variables and it is wished to see whether these variables can be reduced to a smaller set of variables (Chris, 2004). It can also be used to identify any set of variables that correlate well with each other but less well with other items. It can be used to reduce a large number of correlated variables to a more manageable number of independent factors that can then be used in subsequent analysis (Marija, 2003).

A factor is deemed to be significant to the study if it has a mean value of 3.0 or higher. Since all the 33 factors have mean rating 3.0 or higher, they were included in the factor analysis. All the 33 factors had communalities of 1.00, indicating their suitability for the factor analysis. The 33 significant factors were further reduced to common factor patterns. This was done to empirically explain the potential barriers to the implementation of LC in the Ghanaian construction industry. In doing this, principal component analysis with Varimax rotation and Kaizer Normalization was used to determine which factors have empirical significance. Factor retention was by the eigenvalue ≥ 1.0 criterion, suggesting that only factors that account for variances greater than one should be included in the factor extraction.

The principal component analysis where linear combinations of observed variables are formed was the method used to extract the factors.

3.8.4. *Materials waste minimization*

The study adopted the weighted average and coefficient of variation criteria to identify the level of contribution of some waste minimization measures to waste reduction and the level of practice of such measures among construction professionals in Ghana.

3.8.4.1. *Average significant score*

The study used the weighted average model (Begum *et al.*, 2006) to examine the relative levels of significant contribution of the waste minimization measures as perceived by the construction professionals:

The weighted average model is given by

$$ASS_i = \frac{\sum_{i=1}^{5} X_j N_{ij}}{N}$$

where;

ASS_i = is the average significant score of the waste minimization measure i,

X_j = the waste minimization score assigned (on a Likert scale of 1 to 5),

N_{ij} = the number of respondents who assigned the score X_j for the measure i,

N = the total number of respondents.

3.8.4.2. *Coefficient of variation*

The coefficient of variation, measured as minimization index value (MIV), was calculated using the following model (Begum *et al.*, 2006):

$$MIV_i = \frac{ASS_i + ASS_i}{\delta i}$$

where;

Where MIV_i = the coefficient of variation of the waste minimization measure i,

ASS_i = the average significant score of the waste minimization measure i,

δi = the standard deviation of the average significance score for the measure i.

Although the ASS is a weighted average measure and could be used to rank all the waste minimization measures, it does not consider the degree of variation between individual responses. Since a smaller variation between individual responses give better quality to the weighted average value, when two factors carry the same or very close weighted values, the factor carrying the smaller variation is given a higher ranking. Thus, the effective assessment of ranking attributes should consider both the weighted average and the coefficient of variation measured by the minimization index value (Begum et al. 2006).

3.8.5 Conclusion

The research methodology used in this study was discussed as above. A description of how the questionnaire was administered and the various sections in the questionnaire were highlighted. Subsequently, the statistical tools for data analysis were discussed. With this background, statistical results obtained from the data are discussed in chapter four.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter reports and discusses the survey findings. After the questionnaire survey was carried out, statistical analyses were undertaken on the responses using various methods described in the research methodology.

4.2 Respondents' profile

Table 4.1 Summary of Respondents' Profile

RESPONDENTS' CHARACTERISTICS	CONSTRUCTION ORGANIZATIONS PROJECT MANAGERS		CONSULTANCY FIRMS DIRECTORS OF WORKS	
	Frequency	**Percentage**	**Frequency**	**Percentage**
Education				
Bachelors	94	50	87	70
HND	38	20	25	20
Masters/Postgraduate Diploma	56	30	12	10
Total	**188**	**100**	**124**	**100**
Major Clients				
Public sector	13	7	19	15
Private sector	66	35	31	25
Both public and private	109	58	74	60
Total	**188**	**100**	**124**	**100**

The average years of experience of the firms surveyed in the construction market are between 10 and 20 years (Table 4.1). This implies that all the firms have significant experience in the building industry to ensure reliability and accuracy of data. With regards to the average number of permanent and temporary employees in the firms, none of the firms contacted was willing to disclose the records. The main reason given was that those records were confidential to them. The respondents, however, indicated that they had enough employees and could recruit additional employees when necessary. Senior architects and quantity surveyors of Architectural and quantity surveying firms who answered the questionnaires constituted 58% and 42% respectively (Table 4.1). For the construction organizations, project managers were interviewed. Fifty percent of the project managers and 70% of the senior consultants of consultancy firms hold bachelors' degree, and 20% of the project managers and 20% of the senior consultants of consultancy firms hold Higher National Diploma (HND) certificates (Table 4.1). The study further showed that 10% of the senior consultants of consultancy firms and 30% of the project managers hold Master's/Postgraduate diploma degree. The results also showed that majority of the firms (58% of construction organizations and 60% of consultancy) had both public and private sector clients (Table 4.1). Seven percent of construction organizations and 15% of consultancy firms had public sector clients and 35% of construction organizations and 25% of consultancy firms also had private sector clients, an indication of how well they are doing in the construction sector (Table 4.1).

4.3 SOURCES OF WASTE

There are many factors which contribute to construction materials waste generation on site. Waste may occur due to one or combination of many causes (Ekanayake and ofori, 2000). Previous works organized the sources of waste under six categories: design, procurement, handling of materials, operation, residual related and others (Ekanayake and Ofori, 2000; Bossink and Brouwers, 1996; Gavilan and Bernold, 1994).

4.3.1. Level of contribution of the waste sources to the generation of waste

When the responses of the professionals (consultants and project managers) on the level of contribution of waste sources to the generation of waste were compared, the results showed significant difference at 5% significance level.

The major sources of waste according to senior consultants (architects and quantity surveyors) of the consultancy firms interviewed include ‘design and documentation’, ‘procurement’ and ‘materials storage and handling’ (Table 4.2). Mean scores of all the waste sources evaluated except ‘operational factors’ are significantly greater than the neutral score of 3.00 (*p= 0.05*) when the t-test was applied. Thus, the senior consultants (architects and quantity surveyors) agree that ‘design and documentation factors’, ‘procurement factors’ and ‘materials storage and handling factors’ have significantly high contribution to the generation of waste on construction sites.

Table 4.2 Level of Contribution of Waste Sources- Views of Senior Consultants

WASTE SOURCE	MEAN SCORES OF WASTE SOURCES	STANDARD DEVIATION	t-value	Sig	RANKING
Design and documentation	4.452	0.667	24.237	0.000	1
Procurement	4.202	0.786	17.027	0.000	2
Materials storage and handling	3.919	1.008	10.147	0.000	3
Operational	2.968	0.919	-0.391	0.697	4

Table 4.3 Level of Contribution of Waste Sources- Views of Project Managers

WASTE SOURCE	MEAN SCORES OF WASTE SOURCES	STANDARD DEVIATION	t- value	Sig	RANKING
Materials storage and handling	4.777	0.613	39.392	0.000	1
Operational	4.761	0.632	38.563	0.000	2
Design and documentation	3.426	0.863	5.665	0.000	3
Procurement	3.356	1.262	4.622	0.000	4

Table 4.2 shows that the mean scores of all the waste sources evaluated are significantly greater than the neutral score of 3.00 (*p=0.05*) when the t-test was applied. Thus, according to the project managers ‘materials storage and handling’, ‘operational factors’, ‘design and documentation factors’ and ‘procurement factors’ all contribute to the generation of waste on construction sites. The results show that both directors of works and project managers have different opinions on the sources of materials waste on

construction sites. Whereas the consultants identified design and documentation as the major source of waste (Table 4.2), the project managers identified materials storage and handling as the major source of waste of materials on construction sites (Table 4.3). The consultants further consider operational activities to have nothing to do with the wastage of materials at all (Table 4.2).

4.4 Causes of materials waste on site

For the purpose of the study, the four waste sources were further broken down into causes of wastage on construction sites.

4.4.1. Design and documentation

Respondents were asked to score which factors are considered to be major causes of waste arising from design and documentation. When the responses of the professionals (consultants and project managers) on the causes of waste arising from design and documentation were compared, the results showed no significant difference at 5% significance level. Hence, all the data were pooled together (Table 4.4).

Table 4.4 shows that the mean scores of all the 15 causes of waste evaluated are greater than the neutral value of 3.0 for the respondents (project managers and consultants). This means that all the fifteen factors are considered as causes of waste arising from design and documentation. The results further show that 'last minute client requirement (resulting in rework)', 'poor communication leading to mistakes and errors', 'selection of low quality products', 'designer's inexperience in method and sequence of construction' and 'poor/ wrong specifications' are the first five major causes of waste as a result of design and documentation. Other causes of waste include 'lack of knowledge about construction techniques during design activities', 'lack of attention paid to dimensional coordination of products', 'lack of information in the drawings', 'poor site layout', 'lack of attention paid to standard sizes available on the market', 'complexity of detailing in the drawings', 'variations in the design while construction is in progress', 'designer's unfamiliarity with alternative products', 'incomplete contract documents at commencement of project' and 'overlapping of design and construction'.

Table 4.4 Causes of Design and Documentation Waste (Consultants and Project Managers)

DESIGN AND DOCUMENTATION WASTE	MEAN SCORES OF WASTE CAUSES	STANDARD DEVIATION	Ranking
Last minute client requirement (resulting in rework)	4.95	0.214	1
Poor communication leading to mistakes and errors	4.88	0.324	2
Selection of low quality products	4.84	0.370	3
Designer's inexperience in method and sequence of construction	4.69	0.464	4
Poor/ wrong specifications	4.14	0.950	5
Lack of knowledge about construction techniques during design activities	4.07	0.867	6
Lack of attention paid to dimensional coordination of products	4.02	0.861	7
Lack of information in the drawings	4.02	0.871	8
Poor site layout	3.81	0.938	9
Lack of attention paid to standard sizes available on the market	3.71	1.064	10
Complexity of detailing in the drawings	3.68	1.002	11
Variations in the design while construction is in progress	3.61	1.005	12
Designer's unfamiliarity with alternative products	3.83	1.080	13
Incomplete contract documents at commencement of project	3.58	0.939	14
Overlapping of design and construction	3.51	0.992	15

The above results in Table 4.4 agree with literature which list the causes of waste resulting from design and documentation to include 'selection of low quality materials', 'designer's inexperience in method and sequence of construction', 'lack of information in the drawings', 'lack of attention paid to dimensional co-ordination of products', 'complexity of detailing in drawings', 'designer's unfamiliarity with alternative products' and 'incomplete contract documents at commencement of project' (Osmani *et al.*, 2008; Wang *et al.*, 2008; Al-Moghany, 2006; Polat and Ballard, 2004; Alwi *et al.*, 2002; Garas *et al.*, 2001; Ekanayake and Ofori, 2000; Faniran and Caban, 1998; Enshassi, 1996; Bossink and Brouwers, 1996; Gavilan and Bernold, 1994; Craven *et al.*, 1994).

4.4.2. Operational factors

Respondents were asked to score the major causes of wastes arising from operational activities on construction sites. When the responses of the professionals (consultants and project managers) on the causes of waste arising from operational activities were compared, the results showed no significant difference at 5% significance level. Hence, all the data were pooled together (Table 4.5).

Table 4.5 below shows that the mean scores of all the 17 factors evaluated are greater than the neutral value of 3.0 for all the respondents (project managers and consultants).
The results in Table 4.5 above reveal that all the seventeen factors are causes of waste resulting from operational activities on construction sites. The results further revealed that 'errors by tradesmen or operatives', 'use of incorrect material that requires replacement', 'required quantity unclear due to improper planning', 'delays in passing of information to the contractor on types and sizes of products to be used' and 'poor interaction between various specialists' are considered as the first five major causes of waste that result from operational activities on construction sites. Other equally important causes of operational waste from the analysis are 'unfriendly attitudes of project team and operatives', 'choice of wrong construction method', 'damage to work done caused by subsequent trades', 'inappropriate placement of the material', 'accidents due to negligence', 'equipment malfunctioning', 'inclement weather', 'poor technology of equipment', 'effects of political and social conditions', 'shortage of tools and equipment required', 'frequent breakdown of equipment' and 'difficulties in obtaining work permits'.

Table 4.5 Causes of Operational Waste (Project Managers and Consultants)

OPERATIONAL FACTORS	MEAN SCORES OF WASTE CAUSES	STANDARD DEVIATION	RANKING
Errors by tradesmen or operatives	4.971	0.168	1
Use of incorrect materials that require replacement	4.926	0.296	2
Required quantity unclear due to improper planning	4.760	0.471	3
Delays in passing of information to the contractor on types and sizes of products to be used	4.295	0.592	4
Poor interaction between various specialists	4.253	0.792	5
Unfriendly attitudes of project team and labors	4.202	0.786	6
Choice of wrong construction method	4.087	0.732	7
Damage to work done caused by subsequent trades	3.994	0.680	8
Inappropriate placement of the material	3.919	1.008	9
Accidents due to negligence	3.426	0.863	10
Equipment malfunctioning	3.420	1.076	11
Inclement weather	3.397	1.228	12
Poor technology of equipment	3.391	0.949	13
Effects of political and social conditions	3.365	1.043	14
Shortage of tools and equipment required	3.285	0.952	15
Frequent breakdown of equipment	3.237	1.152	16
Difficulties in obtaining work permits	3.103	1.271	17

The above results in Table 4.5 confirm that in literature which lists 'errors by tradespersons or laborers', 'damage to work done caused by subsequent trades', 'delays in passing of information to the contractor on types and sizes of products to be used', 'required quantity unclear due to improper planning' 'accidents due to negligence', 'use of incorrect material that requires replacement' and 'frequent breakdown of equipment' as the major causes of waste as a result of operational activities on construction sites (Al-Moghany, 2006; Polat and Ballard, 2004; Garas *et al.*, 2001; Ekanayake and Ofori, 2000; Bossink and Brouwers, 1996; Gavilan and Bernold, 1994; Craven *et al.*, 1994).

4.4.3. Procurement factors

Wastes arising from procurement factors on construction sites were evaluated by respondents. When the responses of the professionals (consultants and project managers) on the causes of waste arising from procurement activities were compared, the results showed no significant difference at 5% significance level. Hence, all the data were pooled together (Table 4.6).

Table 4.6 shows that the mean scores of all the 5 factors evaluated are greater than the neutral value of 3.0 for all the respondents (project managers and consultants).

Table 4.6. Causes of Waste Arising from of Procurement (Project Managers and Consultants)

PROCUREMENT WASTE	MEAN SCORES OF WASTE CAUSES	STANDARD DEVIATION	RANKING
Purchased products that do not comply with specification	4.218	0.824	1
Unsuitability of materials supplied to site	4.096	1.231	2
Substitution of a material by a more expensive one	3.939	1.001	3
Ordering errors	3.606	1.140	4
Changes in material prices	3.574	1.330	5

From the results in Table 4.6 above, 'purchasing products that do not comply with specification', 'unsuitability of materials supplied to site', 'substitution of a material by a more expensive one', 'ordering errors' and 'changes in material prices' are the major causes of waste as a result of procurement.

The results confirm earlier findings in literature which list 'purchased products that do not comply with specification', 'unsuitability of materials supplied to site', 'substitution of a material by a more expensive one' and 'ordering errors' as the major causes of waste resulting from procurement activities (Al-Moghany, 2006; Polat and Ballard, 2004; Formoso *et al.*, 2002; Ekanayake and Ofori, 2000; Bossink and Brouwers, 1996).

4.4.4. Materials storage and handling

The respondents were asked to evaluate causes of materials waste arising from materials storage and handling. When the responses of the professionals (consultants and project managers) on the causes of waste arising from materials storage and handling activities were compared, the results showed no significant difference at 5% significance level. Hence, all the data were pooled together (Table 4.7).

The mean scores of all the 14 factors evaluated are greater than the neutral value of 3.0 for all the respondents (project managers and consultants) as shown in Table 4.7

Table 4.7 Causes of Waste Arising from Materials Storage and Handling

MATERIALS STORAGE AND HANDLING WASTE	MEAN SCORES OF WASTE CAUSES	STANDARD DEVIATION	RANKING
Lack of onsite materials control	4.256	0.793	1
Damage to materials on site during transportation	4.250	0.607	2
Poor handling of materials	4.218	0.654	3
Waste resulting from cutting uneconomical shapes	4.180	0.814	4
Using excessive quantities of materials than required	4.128	0.659	5
Overproduction/ production of a quantity greater or required than necessary	4.051	0.906	6
Theft	4.026	0.921	7
Poor method of storage on site	3.878	0.971	8
Manufacturing defects	3.801	0.889	9
Unnecessary inventories on site leading to waste	3.782	0.895	10
Use of whatever material close to working place	3.744	1.069	11
Insufficient instructions about handling	3.718	0.994	12
Use of wrong method of transport	3.717	0.941	13
Overloading of transport equipment	3.385	1.192	14

It can be seen from the results in Table 4.7 that ‘lack of onsite materials control’, ‘damage to materials on site during transportation’, ‘poor handling of materials’, ‘waste resulting from cutting uneconomical shapes' and 'using excessive quantities of materials than required' are the major causes of waste arising from materials storage and handling. The results further revealed that 'overproduction/ production of a quantity greater or required than necessary', 'theft', 'poor method of storage on site', 'manufacturing defects,' 'unnecessary inventories on site leading to waste', 'use of whatever material close to working place', 'insufficient instructions about handling', 'use of wrong method of transport' and 'overloading of transport equipment' are other important causes of materials waste arising from storage and handling.

The results confirm findings in literature in which 'damage to materials on site during transportation', 'overproduction/ production of a quantity greater or required than necessary', 'using excessive quantities of materials than required', 'poor method of storage on site', 'use of whatever material close to working place', 'theft', 'manufacturing defects', 'unnecessary inventories on site leading to waste' were listed as the causes of waste arising from materials storage and handling (Al-Moghany, 2006; Alwi *et al.*, 2002; Formoso *et al.*, 2002; Ekanayake and Ofori, 2000; Garas *et al.*, 2001; Bossink and Brouwers, 1996; Enshassi, 1996).

4.5 Assessment of wastage of key construction materials

The results revealed that the four key materials which are wasted most on construction sites are 'timber', 'cement/mortar', 'concrete' and 'blocks' (Table 4.7). Mean scores of all the key materials evaluated are significantly greater than the neutral score of 3.00 ($p= 0.05$) when the t-test was applied. Thus, the respondents agree that 'timber', 'cement/mortar', 'concrete', 'blocks', 'steel', 'quarry chippings', 'paint', 'sand', 'tiles' and 'pipes' all contribute to the generation of waste on construction sites.

Table 4.8 Level of Contribution of Key Construction Materials to Wastage on Construction Sites

Material	**Mean**	**Standard deviation**	**T-value**	**Sig**	**Ranking**
Timber	4.289	0.860	26.462	0.000	1
Cement/mortar	4.205	0.902	23.607	0.000	2
concrete	3.888	0.880	17.812	0.000	3
Blocks	3.843	1.087	13.701	0.000	4
Steel	3.721	0.940	13.553	0.000	5
Quarry chippings/coarse aggregate	3.612	0.860	12.572	0.000	6
Paint	3.561	0.854	11.601	0.000	7
Sand	3.471	1.054	7.893	0.000	8
Tiles	3.337	0.760	7.821	0.000	9
Pipes	3.093	1.031	1.593	0.112	10

This result confirms findings in literature which list concrete, cement/mortar, timber, blocks and steel as the major materials wasted on construction sites (Wang *et al.*, 2008; Shen *et al.*, 2002; Formoso *et al.*, 2002; Garas *et al.*, 2001; Ayarkwa and Adinyira, n.d.).

COMPENDIUM ON WASTAGE OF KEY CONSTRUCTION MATERIALS AND RECOMMENDED WAYS OF WASTE MINIMIZATION

4.6 Introduction

This section looks at the manufacturing, control and storage and handling of the key construction materials identified as constituting to high wastage on site.

4.6.1 Wastage of Key Materials on Building Construction Sites

Timber

a) Dismantled formwork boards

b) Dismantled formwork left on site

c) Timber pieces left to decay on site

d) Pieces on timber left on site to decay

Fig. 4.1 Timber members that have been wasted on construction sites

Shown in Figure 4.1 (a), (b), (c) and (d) are pieces of timber that have been wasted on construction sites.

Cement/ Mortar

a) A bag of cement left unused on site

b) Abandoned bags of cement

c) Abandoned bags of cement on site

d) Abandoned bags of cement on site

e) Mortar mixed with water

Fig. 4.2 Wasted cement/mortar on construction site

Presented in figure 4.2 (a), (b), (c), (d) are bags of cement that have been abandoned on site to go waste. Figure 4.2 (e) shows mortar in a container mixed with rain water.

Concrete

Fig. 4.3 Wastage of aggregates on building construction sites

Shown in Figure 4.3 (a), (b) and (d) are fine aggregates that have been wasted on site. Figure 4.3 (c) and (e) shows coarse aggregates scattered on site.

Blocks

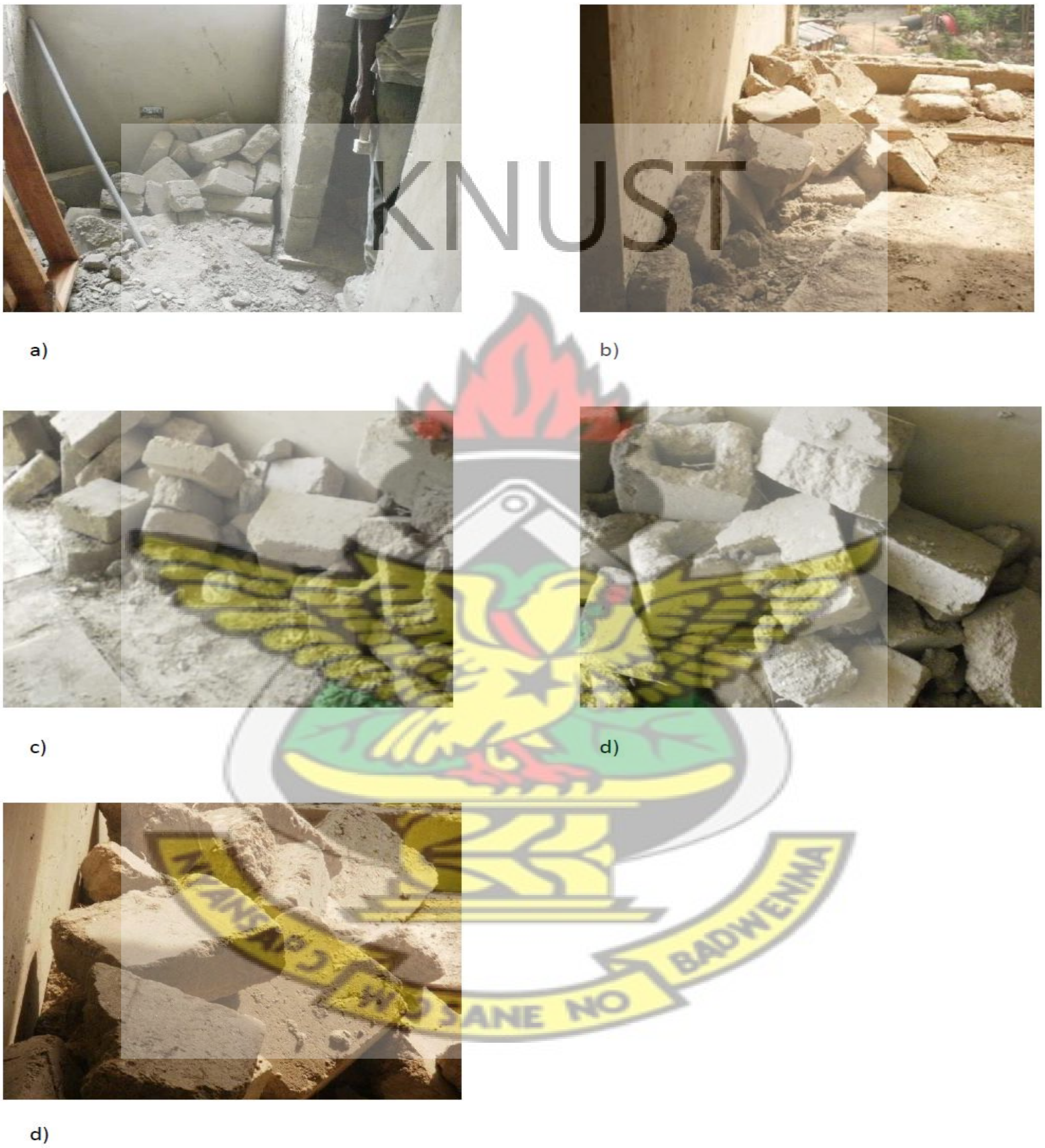


Figure 4.4 Wasted blocks on building construction sites

4.6.2 Wastage of key materials arising out of manufacturing, storage and handling on building construction sites

4.6.2.1 Blocks

Blocks are most commonly used as walling materials on building construction sites.

- ***Storage and handling of blocks on construction sites***

a) Broken pieces of blocks due to handling

b) Loss of physical appearance of blocks

c) Loss of physical appearance due to poor storage

d) Poor storage of blocks

e) Broken pieces of blocks due to transportation

f) Wrong arrangement of blocks

Fig. 4.5 Poor storage and handling of blocks on construction site

Figure 4.5 shows some of the ways in which blocks are wrongly stored on site. During the time of the visit to the site, blocks in plate 'f' were scattered on the site close to the concrete mixer. This wrong storage could lead to breakages, especially if the mixer is to be used and workers are going up and down. At times some quantities of blocks are wasted as a result of wrong methods of handling on construction sites. Figures 4.5 (a) and (e) depict typical instances where some quantities of blocks have been wasted as a result of unloading and transportation operations. These problems were very severe on most of the sites that were visited. Figure 4.5 (b) and (c) show quantity of blocks that have been left in the open for several months resulting in loss of physical appearance. This could affect the quality and could become extremely dangerous to use in building.

Recommended ways of storing and handling blocks on construction sites to avoid wastage

To avoid wasting a lot of blocks on construction sites, it is advisable to take into consideration its storage and handling operations on site.

- The blocks should be stacked on pallets or on level grounds
- It should be stored in a container or a covered place
- It should not be stored in a walk way where people will always step on it. For instance in Figure 4.5 (f).

a) Blocks arranged on site

b) Correct arrangement of blocks on site

c) Blocks properly packed on site

d) Blocks packed on site

Fig. 4.6 Recommended ways of storing blocks on site

4.6.2.2 Handling and storage of Concrete making materials on site

Coarse and fine aggregates and cement should be properly stored, batched, and handled to maintain the quality of the resulting concrete.

Fig. 4.7 Batching of concrete making materials

Fig 4.7 (a), (b), (c) and (d) show the batching of aggregates (coarse and fine) and cement. Fig 4.7 (e) and (f) show the outcome of the batched materials after mixing which is the concrete being poured into the wheelbarrow. Figure 4.7 (c) and (d) show quantities of wasted aggregates arising from batching. Figure 4.7 (e) and (f) show clearly that there is the tendency of some concrete being poured away as the workers try to fill the wheelbarrow.

- ***Wastage arising from batching and measurement of concrete making materials that lead to materials wastage***

The batching and measurement of concrete making materials (coarse and fine aggregates and cement) most of the times lead to wastage of these materials on construction sites. Some of the wastages from batching involve (Iowa State University, 2004):

- Aggregate segregation
- Varying moisture content
- Addition of too much water, resulting in reduced concrete strength and increased shrinkage

- ***Recommended ways of batching concrete making materials***

To avoid wasting the aggregates (coarse and fine), proper equipment should be used. Instances of proper batching of concrete making materials are shown in Figures 4.8 (a), (b), (c) and (d) respectively.

To assist in minimizing the wastage of concrete making materials resulting from batching, it is recommended that the following procedures be adhered to (Iowa State University, 2004):

- Use separate aggregate bins for each size of coarse aggregate. Bins should be capable of shutting off material with precision.
- Use controls to monitor aggregate quantities during hopper charging.
- Use standard test weights for checking scale accuracy.
- Maintain mixer blades. Watch for wear and coating.
- Do not load mixer above rated capacity.
- Operate mixer at manufacturer-recommended speed.

- Mix all concrete thoroughly until it is uniform in appearance, with all ingredients evenly distributed.
- Take samples from different portions of a batch to ensure that the whole batch has the same air content, slump, unit weight, and aggregate proportions

a) Proper end loader operation

b) Proper pouring of cement

c) Proper batching of fine aggrgeate

d) Batched materials in concrete mixer

Fig 4.8 Recommended ways of batching concrete making materials

- **Wastage arising from mixing and transportation of concrete on site**

Thorough mixing is essential for the production of uniform quality concrete. Therefore, equipment and methods should be capable of effectively mixing concrete materials containing the largest specified aggregate to produce uniform mixtures of the lowest slump practical for the work.

- Stationary mixed concrete is often used where large volumes of concrete need to be placed in a short period of time. Common problems associated with the stationary mixing of concrete are (Iowa State University, 2004):
  - ✓ Short mixing times resulting in non-uniform mixtures, poor distribution of air voids, poor strength gain, and early stiffening problems.
  - ✓ Insufficient monitoring of aggregate moistures
  - ✓ Lumps or segregation resulting in non-uniform mixture

- **Recommended procedures to follow to prevent wasting concrete during mixing**

Stationary mixing is the mixing of concrete at a nearby or on-site concrete batch plant. To avoid wasting concrete during the mixing the following procedures are recommended.

- Set and lock the mixer timing device to the recommended mixing time if possible.
- Measure the mixing period from the time all cement and aggregates are in the mixer drum.
- Add supplementary cementitious materials after the cement.
- Add all of the water before one-fourth of the mixing time has elapsed.
- When two or more admixtures are used in the same batch of concrete, introduce them separately to avoid any interaction that might compromise the effectiveness of the admixtures.
- Introduce admixtures in the same sequence in the charging cycle.
- Complete the addition of admixtures not later than one minute after adding water to the cement or prior to the start of the last three-fourths of the mixing cycle, whichever occurs first (Iowa State University, 2004).

Transportation

The method used to transport concrete depends on which one is the lowest in cost and easiest for the job size. Some ways to transport concrete include: a concrete truck, a concrete pump, a crane and bucket, a chute, a conveyor or a hoist. On small jobs a wheelbarrow is the easiest way to transport concrete. Always transport concrete as little as possible to reduce problems of segregation and wastage.

a) A concrete mixer in action

b) A mason ready to transport concrete with a wheelbarrow

c) Transportation of concrete to destination

d) Transported concrete ready to be cast

Fig 4.9 Mixing and transportation of concrete

- ***Problems with the transportation of concrete with wheelbarrow or hoist***

With these modes of transport, there is the probability of wasting concrete especially with the wheelbarrow resulting from overloading. Figure 4.9 (c) shows a hoist with timber supports. Where these supports are not firmly fixed to the ground a large volume of concrete could be lost due to failure.

- ***Recommended methods of transporting concrete to avoid wastage***

- Concrete should be transported from the mixer to the place of casting as rapidly as possible by methods which will prevent the segregation or loss of any of the ingredients and maintaining the required workability.
- During hot or cold weather, concrete should be transported in deep containers, other suitable methods to reduce the loss of water by evaporation in hot weather and heat loss in cold weather may also be adopted (Iowa State University, 2004).

Storage and handling of concrete making materials

The storage of concrete making materials on construction sites is a major problem. Some of these materials are not stored appropriately resulting in the severe wastage of materials on site. This section presents photographs of how key materials are wasted on construction sites as a result of storage and recommends appropriate ways of storing these materials to reduce their levels of wastage on construction sites.

- **Wastage of aggregates through storage and handling**

According to Oziegbe (1991), aggregate that are not properly stored will limit the strength of the concrete work on a building project, it could also affect the durability and structural performance of the building. Aggregates should be stored where it will not have direct contact with the lateritic soil, which may reduce the quality of the concrete or cause void on the surface of the concrete.

Common problems in storing aggregates

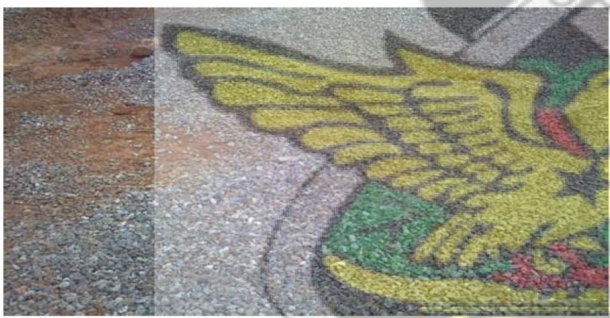
- Segregation of aggregate (example: large particles of aggregate roll down the side of a tall cone pile)
- Degradation of aggregate (example: end loaders or trucks on pile crush the aggregate)
- Contamination of materials by deleterious substances (example: trucks track clay and mud onto aggregate)
- Inconsistent or undesirable moisture content (example: materials are not wetted or allowed to drain properly)
- Frozen lumps of aggregates due to lack of precautions in cold weather (Iowa State University, 2004).

a) Quantity of sand stored near refuse damp

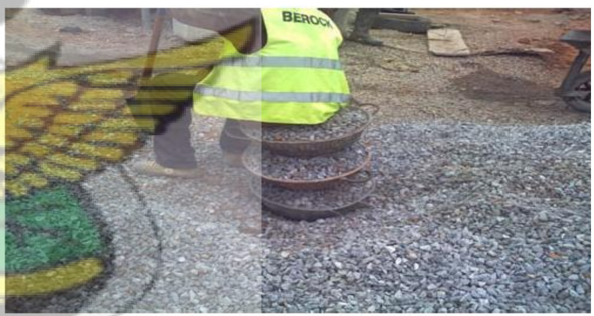
b) Quantity of sand left unused

c) Poor storage of chippings

d) Poor storage of sand



e) Stored chippings left scattered on site



f) Mason sitting on batched chippings

Fig 4.10 Poor storage of aggregates on site

According to Al-Moghany (2006) and Enshassi (1996), inadequate stacking and insufficient storage site is one of the principal reasons for wastge of building materials on site. The pictures presented in Figure 4.10 show how coarse aggregates (coarse and fine) are stored and handled on site. Figure 4.10 (e) shows chippings that have been scattered on site. These chippings have a high tendency of being mixed with the lateritic soil when workers try to fetch it, resulting in neglecting them, hence, wastage occurs.

As at the time of the visit to the site, this pile of chipping in figure 4.10 (c) had been abandoned in the bush. This depicts poor storage as it will be very difficult to fetch it during the time of usage. Since the whole area is bushy, transporting it to the mixing area will become very difficult especially on sites where wheelbarrow is the major means of transport.

The aggregates (coarse and fine) on this site were poorly stored (Fig 4.10 d). Figure 4.10 (d) shows how muddy the area is. Since these aggregates have been stored on the bare ground, there is the likelihood of the loader to fetch some mud in addition to the aggregates. This will reduce the quality of the concrete or cause void on the surface of the concrete. Furthermore, not all the aggregates could be fetched, hence, it will result in some quantities being wasted.

Research has shown that wrong handling of aggregates is a major problem on construction sites. This is clearly seen in Figure 4.10 (f) where a tradesman is sitting on batched aggregate ready to be transported to the mixer. This situation could lead to the head pan turning over and scattering the aggregates, resulting in wastage.

Figures 4.10 (a) and (b) show how sand is stored on most of the construction sites. In Figure 4.10 (d), the sand has been stored on a muddy ground. Most of this sand will mix with the mud and result in wastage. Aside that, there is the likelihood for majority of the sand to be washed away once there is rainfall since it is stored on a sloppy ground.

Recommended ways of storing and handling aggregates to minimize wastage

a) Well built and well maintained aggregate stockpile (http://www.pccentre.iastate.edu

b) Well built aggregate stockpile

c) Unused quantity of coarse aggregate neglected but stored properly

d) Well built aggregate stockpile

Fig 4.11 Recommended ways of storing aggregates on site

To minimize the wastage of aggregates through storage and handling, the following recommendations should be adhered to.

- Store aggregates in separate bunkers when many gradations and types of aggregate are required in small quantities for relatively low-production operations.
- Otherwise, store aggregate in open stockpiles.

Stockpiling aggregate

- ***Locating stockpiles***

➢ Locate stockpiles where they will not be driven on. Driving on stockpiled aggregate segregates and degrades the aggregate, affecting its performance.

➢ Separate stockpiles from each other. If there is not enough space between them to keep them separate, use a separating wall (Iowa State University, 2004).

- ***Preparing stockpile base***

➢ Make sure the stockpile base is firm and uniform because it supports the pile and prevents soil from being scooped in with the aggregate.

➢ Provide adequate base of a differing aggregate type to prevent pumping mud into the bottom of the aggregate pile (Iowa State University, 2004).

- ***Building stockpiles***

➢ Determine the equipment to be used and personnel responsible before delivering aggregate to the plant site.

➢ Do not pile aggregate in a high cone shape because it will segregate.

➢ Do not make the stockpile higher than the lift of the end-loader's bucket.

➢ Build the pile outward, not upward (Iowa State University, 2004).

- ***Maintaining stockpiles***

➢ Do not drive on stockpiles; this may breakdown the aggregates and segregate the particle sizes.

➢ Keep the area clean and discard contaminated materials.

➢ When removing aggregate from a pile with a front-end loader, attempt to get a portion of each layer in each load.

- ➢ Work the aggregate stockpile to maintain uniform moisture and gradation.
- ➢ Do not allow stockpile to get so low that the loader digs into soil base.
- ➢ Avoid careless dumping of material into the wrong stockpile (Iowa State University, 2004).

- ***Managing stockpile moisture***

- ➢ Keep the aggregate moisture content at or above the saturated surface dry condition, especially for absorptive aggregates used during hot weather.
- ➢ Note differences in aggregate moisture throughout the stockpile since the moisture condition of aggregate affects the workability of concrete. The moisture content of successive batches should not vary by more than 0.5%.
- ➢ If aggregate moisture varies through the day, measure moisture content more frequently.
- ➢ Regularly mix aggregate from different areas of the pile for each batch so that the overall aggregate moisture level is consistent from batch to batch (Iowa State University, 2004).

- ***Wastage of cement through storage and handling***

The effective storage of cement on building projects reduces wastes, project delay and helps to keep the quality of cement in good shape before usage (Oziegbe, 1991). Analyzing the waste of cement is relatively complex due to the fact that this material is used as a component of mortar and cast-in-place concrete in several different processes, such as brickwork, plastering and floor screed (Al-Moghany, 2006; Formoso *et al.*, 2002). According to Oziegbe (1991), the effects of poor storage of cement and handling results in cracks and spilling of concrete, which the damage usually starts at the edges and corners of concrete, reduction in quality of concrete and caking of cement.

a) Bags of cement left unused

b) Improper way of handling cement

c) Quantity of cement left unused

d) Mortar wasted as a result of plastering

Fig 4.12 Ways in which cement is wasted on site

Figure 4.12 (a) and (c) show quantities of cement that have been left on site. The quantity in Fig 4.12 (c) was left in the rains and as such has been destroyed. Figure 4.12 (b) shows wrong way of pouring cement for concrete by a mason. The effect could be to lose a lot of the cement if the head pan turns over. In Fig 4.12 (d) masons are plastering walls with, mortar. It can be seen how some of the mortar are scattered on the ground.

- ***Recommended ways of storing cement to minimize wastage***

Portland cement that is kept dry retains its quality indefinitely. Portland cement stored in contact with moisture sets more slowly and has less strength than dry Portland cement. A warehouse or shed used to store cement should be as air-dry as possible. All cracks and openings should be closed. Cement bags should not be stored on damp floors. Bags should be stacked close together to reduce air circulation, but they should not be stacked against outside walls. Bags to be stored for long periods should be covered with tarpaulins or other waterproof covering.

On smaller jobs where no shed is available, bags should be placed on raised wooden platforms. Waterproof coverings should be placed over the pile and extend over the edges of the platform to prevent rain from reaching the cement and the platform. Rain-soaked platforms may damage the bottom bags of cement.

Cement stored for long periods may develop what is called “warehouse pack”. This can usually be corrected by rolling the bags on the floor. At the time of use, cement should be free flowing and free of lumps. If the lumps do not break up easily, the cement should be tested before use in important work.

Standard strength tests or loss on ignition tests should be made whenever the quality of the cement is doubtful. Bulk cement is usually stored in waterproof bins. Ordinarily, it does not remain in storage very long but it can be stored for a relatively long time without deterioration.

Fig 4.13 Recommended ways of storing cement on site

Wastage of timber arising from storage and handling

Timber possess a number of advantages, it is relatively inexpensive compared to other materials, light in weight and easy to handle. However, its relatively low durable and reusable nature makes it a material of high wastage.

Fig 4.14 Poorly stored timber on site

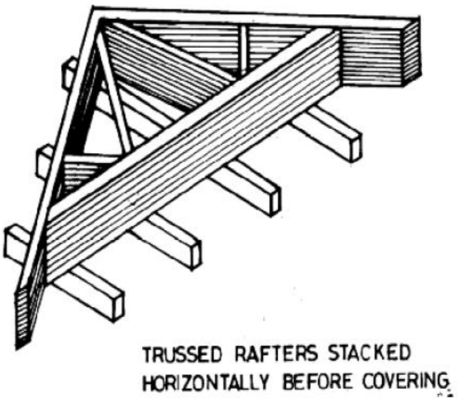
Figure 4.14 (a), (b), (c) and (d) show timber that has been poorly stored on site. Bad handling and poorly organized storage of timber and wood-based products are major causes of wastage on building sites. Being reasonably durable and resilient, timber can withstand considerable abuse without damage, but lack of care before and during construction can affect wood products adversely. In addition to the strength of timber, texture, grain, colour and shape can be important features of a finished structure. Proper storage and handling can ensure that the quality of these features is maintained.

Recommended ways of storing timber

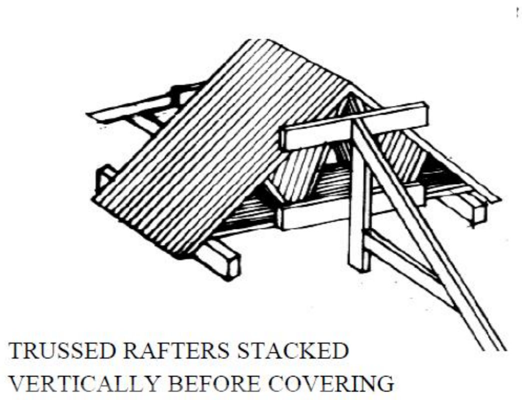
If timber is properly stored on site, shrinkage problems can be reduced. Even when it gets wet during construction, carefully stored timber of the right moisture content will shrink less than badly stored timber of too high moisture content. Remember that a new building is not as a rule a good place to store timber, even for a few days. The inside condition will be too damp until all concrete, mortar and plaster have had time to dry thoroughly unless, of course, the building is of timber-framed construction in which case there should have been no necessity to use wet trades at all. A shed or garage will often serve for storing timber, but it must be clean, dry and ventilated. Windowless lockup garages are not ideal.

Carcassing Timber (Figure 4.15 (e))

- Spread a fine granular material such as sand or ashes on a well-drained space in the open and stack the timber on bearers to keep it off the ground.
- Bearers should be arranged as shown in the illustration (Fig 4.15 (e)) so that the timber will lie flat otherwise warping can result.
- The stack must be covered as shown below to keep off the rain, but in such a way as to allow free circulation of air and ability to dry, thereby overcoming condensation problems under the covering.
- The covering is also essential to provide protection against direct sunlight.



a)



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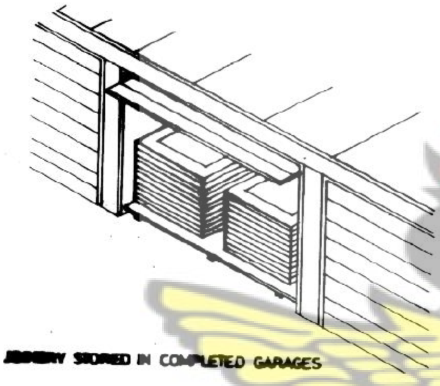

c)

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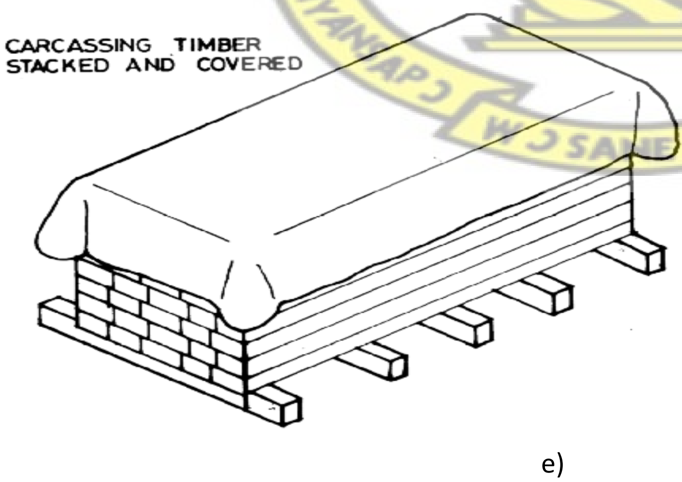

e)

Fig 4.15 Storing timber correctly

Structural Components

- Structural components such as trussed rafters, timber frame components, ply-box beams etc. should be properly stored on site.

- They should be stored above ground on leveled bearers, and generally be laid horizontally or vertically as shown in Figure 4.15 (a) and (b).

- Structural components should be tarpaulined to protect them from rain and sun.
- Care should also be taken to ensure a good circulation of air around the components.

- Where trusses are laid flat, bearers should be placed as shown in Figure 4.15 (a) and (b) to give level support at close centres, sufficient to prevent long term deformation of all truss members.

Joinery (Figure 4.15 c)

- A similar method to structural components should be used for external joinery, with support being chosen carefully to avoid warping or twisting due to unnatural loading.

- Internal joinery and flooring should be kept in a 'drystore' appropriately heated, to maintain correct moisture content.

- A lean-to store may be constructed for this purpose but on most sites early completion of garages forms an excellent storage facility.

- However, do not rest components directly on fresh concrete and be sure to close pile and fully wrap.
- Ensure that the store is ventilated.

- Kitchen units and fitments, and other factory finished components may be treated in a manner similar to that for internal joinery and flooring.
- Additionally, however, particular care is necessary to avoid damage, and especially with completed units.

4.7 Waste Minimization Measures

A structured questionnaire survey was conducted to identify measures which were considered best in minimizing materials wastage and to provide empirical evidence on levels of significant contribution of waste minimization measures to waste reduction, and levels of practice of same measures using weighted average and coefficient of variation criteria.

4.7.1 Ranking of waste minimization measures by respondents

Table 4.9 shows that the mean scores of all the 26 waste minimization measures evaluated are greater than the neutral value of 3.0 for the respondents (project managers and senior consultants). All 26 measures are considered as important for minimizing wastage of materials on site. The results further show that 'purchasing raw materials that are just sufficient (WMM 24)', 'using materials before expiry dates (WMM 25)', 'good coordination between store and construction personnel to avoid over ordering (WMM 4)', 'use of more efficient construction equipment (WMM 5)' and 'adoption of proper site management techniques (WMM 21)' are the five most important measures which can minimize the wastage of materials on construction sites. Other equally important measures are shown in Table 4.9. The least but important measures identified by the respondents include 'encouraging re-use of waste materials in projects (WMM16)', 'use of low waste technology (WMM 12)' and 'recycling of some waste materials on site (WMM 1)'.

Table 4.9 Ranking of Waste Minimization Measures

Waste minimization measures (WMM)	Mean scores of measures	Standard deviation	Ranking
Purchasing raw materials that are just sufficient (WMM 24)	4.96	0.286	1
Using materials before expiry dates (WMM 25)	4.88	0.461	2
Good coordination between store and construction personnel to avoid over ordering (WMM 4)	4.46	0.689	3
Use of more efficient construction equipment (WMM 5)	4.42	0.605	4
Adoption of proper site management techniques (WMM 21)	4.37	0.727	5
Training of construction personnel (WMM3)	4.36	0.797	6
Proper storage of materials on site (WMM 7)	4.35	0.82	7
Checking materials supplied for right quantities and volumes (WMM 13	4.32	0.817	8
Good construction management practices (WMM 2)	4.24	1.098	9
Employment of skilled workmen (WMM 14)	4.22	0.813	10
Mixing, transporting and placing concrete at the appropriate time (WMM 19)	4.21	0.978	11
Adherence to standardized dimensions (WMM 10)	4.18	1.103	12
Accurate and good specifications of materials to avoid wrong ordering (WMM 26)	4.17	0.765	13
Accurate measurement of materials during batching (WMM 15)	4.16	0.942	14
Minimizing design changes (WMM 23)	4.15	0.876	15
Vigilance of supervisors (WMM 6)	4.13	0.982	16
Change of attitude of workers towards the handling of materials (WMM 11)	4.12	0.893	17
Weekly programming of works (WMM 18)	4.10	0.896	18
Access to latest information about types of materials on the market (WMM 22)	4.07	0.948	19
Careful handling of tools and equipment on site (WMM 17)	4.07	1.032	20
Waste management officer or personnel employed to handle waste issues (WMM20)	4.01	1.068	21
Early and prompt scheduling of deliveries (WMM 9)	4.01	1.203	22
Just in time operations (WMM 8)	3.99	1.187	23
Encourage re-use of waste materials in projects (16)	3.76	1.197	24
Use of low waste technology (WMM 12)	3.73	1.339	25
Recycling of some waste materials on site (WMM 1)	2.65	1.524	26

The results obtained confirm that in literature in which 'purchasing raw materials that are just sufficient', 'using materials before expiry date', 'training of construction personnel' and 'using of more efficient construction equipment' among others are considered as measures that minimize the wastage of materials on construction sites (Begum *et al.,* 2006; Shen *et al.*, 2002; Shen and Tam, 2002; Poon *et al.*, 2001; Ho, 2001; Faniran and Caban, 1998; Sherman, 1996).

4.7.2 Empirical *evidence of the levels of contribution of the waste* ***minimization measures***

Table 4.10 shows a summary of average significant scores (ASS), minimization index values (MIVs) and rankings of the levels of significance contribution of the minimization measures on the basis of MIV. The waste minimization measure 24 (WMM 24) is ranked the first measure that most significantly contributes to waste minimization, indicating that 'purchasing raw materials that are just sufficient for a project' very highly contributes to waste minimization. WMM 1 is ranked the 26th, indicating that 'recycling of some waste materials on site' has the least significant contribution to waste minimization. The other measures evaluated have ASS ranging between 4.88 and 3.73. Thus, apart from 'recycling of some waste materials on site' (WMM 1), 'using of low waste technology' (WMM 12) and 'encouraging re-use of waste materials in projects' (WMM 16), all the other measures evaluated by the construction professionals have medium to high contribution to waste minimization in Ghana.

Table 4.10 Summary of Average Significant Scores, Minimization Index Values and their Rankings

Waste minimization measures (WMM)	**Average significant score (ASS)**	**Standard deviation (δ)**	**Minimization index value (MIV)**	**Rank of minimization index value (RMIV)**
Purchasing raw materials that are just sufficient (WMM 24)	4.96	0.286	34.685	1
Using materials before expiry dates (WMM 25)	4.88	0.461	21.171	2
Use of more efficient construction equipment (WMM 5)	4.42	0.605	14.612	3
Good coordination between store and construction personnel to avoid over ordering (WMM 4)	4.46	0.689	12.946	4
Adoption of proper site management techniques (WMM 21)	4.37	0.727	12.022	5
Training of construction personnel (WMM3)	4.36	0.797	10.941	6
Accurate and good specifications of materials to avoid wrong ordering (WMM 26)	4.17	0.765	10.910	7
Proper storage of materials on site (WMM 7)	4.35	0.82	10.610	8
Checking materials supplied for right quantities and volumes (WMM 13	4.32	0.817	10.575	9
Employment of skilled workmen (WMM 14)	4.22	0.813	10.380	10
Minimizing design changes (WMM 23)	4.15	0.876	9.475	11
Change of attitude of workers towards the handling of materials (WMM 11)	4.12	0.893	9.227	12
Accurate measurement of materials during batching (WMM 15)	4.16	0.942	8.832	13
Mixing, transporting and placing concrete at the appropriate time (WMM 19)	4.21	0.978	8.609	14
Access to latest information about types of materials on the market (WMM 22)	4.07	0.948	8.586	15
Vigilance of supervisors (WMM 6)	4.13	0.982	8.411	16
Weekly programming of works (WMM 18)	4.10	0.896	8.384	17
Careful handling of tools and equipment on site (WMM 17)	4.07	1.032	7.888	18
Good construction management practices (WMM 2)	4.24	1.098	7.723	19
Adherence to standardized dimensions (WMM 10)	4.18	1.103	7.579	20
Waste management officer or personnel employed to handle waste issues (WMM20)	4.01	1.068	7.509	21
Just in time operations (WMM 8)	3.99	1.187	6.723	22
Early and prompt scheduling of deliveries (WMM 9)	4.01	1.203	6.667	23
Encourage re-use of waste materials in projects (16)	3.76	1.197	6.282	24
Use of low waste technology (WMM 12)	3.73	1.339	5.571	25
Recycling of some waste materials on site (WMM 1)	2.65	1.524	3.478	26

The ranking profile (Fig. 4.16) shows empirical evidence of the levels of significant contribution of the various measures to waste minimization in the implementation of waste management.

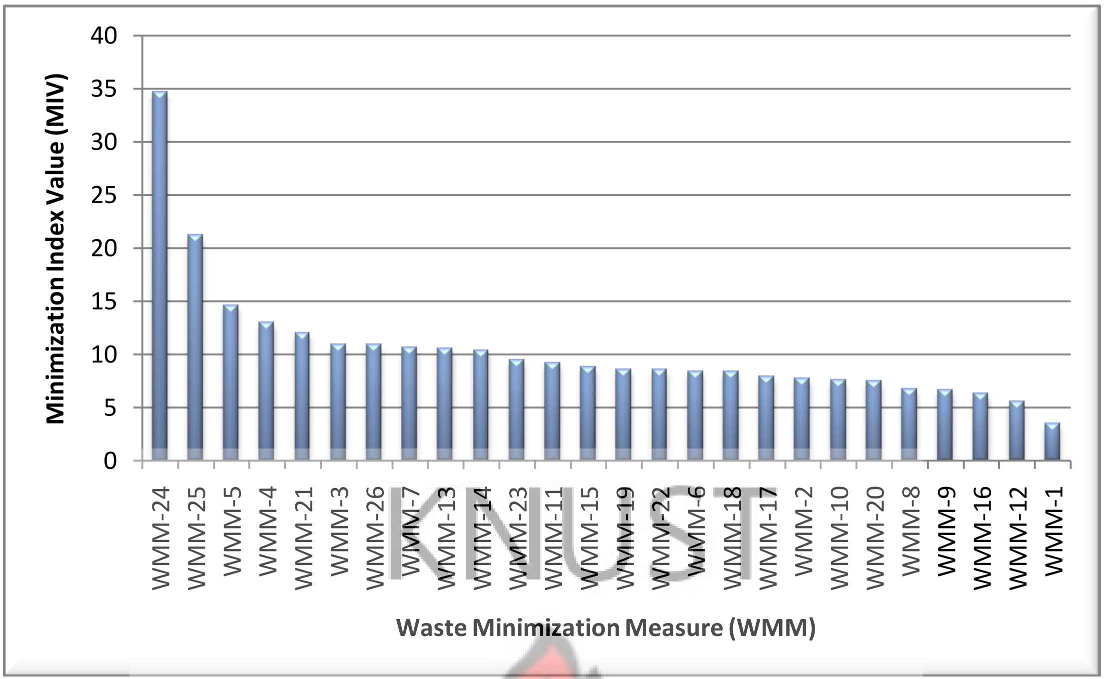

Fig. 4.16 Ranking profile of the levels of significant contribution of waste minimization measures

4.7.3 *Empirical evidence of the levels of practice of the waste minimization measures*

Table 4.11 gives a summary of average practiced scores (APS), practiced index values (PIVs) and rankings of the level of practice of the various measures on the basis of PIVs. WMM-25 is ranked the first measure highly practiced by the respondents to minimize waste indicating that 'using materials before expiry dates' is most frequently practiced to minimize waste in Ghana. WMM-1 is ranked the 26th, indicating that 'recycling of some waste materials on site' is the least practiced measure to minimize waste in Ghana. The other measures evaluated have APS ranging between 4.10 and 3.64. Thus, apart from 'recycling of some waste materials on site' (WMM 1), 'using of low waste technology'(WMM 12) and 'encouraging re-use of waste materials in projects' (WMM 16), all the other measures evaluated by the construction professionals are either practiced or frequently practiced to minimize waste in Ghana. The ranking profile (Fig. 4.17) shows empirical evidence of the levels of practice of the various measures to minimize waste in construction projects.

Table 4.11 Level of practice of waste minimization measures among professionals

Waste minimization measures (WMM)	Average Practiced score (APS)	Standard deviation (δ)	Practiced index value (PIV)	Rank of Practiced index value (PIV)
Using materials before expiry dates (WMM 25)	4.83	0.575	16.800	1
Use of more efficient construction equipment (WMM 5)	4.18	0.693	12.063	2
Purchasing raw materials that are just sufficient (WMM 24)	4.68	0.821	11.400	3
Adoption of proper site management techniques (WMM 21)	3.92	0.848	9.245	4
Good coordination between store and construction personnel to avoid over ordering (WMM 4)	4.09	0.834	9.808	5
Minimizing design changes (WMM 23)	4.10	0.896	9.152	6
Training of construction personnel (WMM 3)	4.07	0.913	8.916	7
Proper storage of materials on site (WMM 7)	4.02	0.905	8.884	8
Employment of skilled workmen (WMM 14)	3.99	0.900	8.867	9
Accurate and good specifications of materials to avoid wrong ordering (WMM 26)	3.71	0.905	8.200	10
Checking materials supplied for right quantities and volumes (WMM 13)	3.95	0.989	7.988	11
Change of attitudes of workers towards the handling of materials (WMM 11)	3.83	0.978	7.832	12
Vigilance of supervisors (WMM 6)	3.95	1.030	7.670	13
Access to latest information about types of materials on the market (WMM 22)	3.83	1.025	7.473	14
Accurate measurement of materials during batching (WMM 15)	3.88	1.071	7.246	15
Weekly programming of works (WMM 18)	3.64	1.017	7.158	16
Good construction management practices (WMM 2)	3.96	1.113	7.116	17
Mixing, transporting and placing concrete at the appropriate time (WMM 19)	3.88	1.092	7.106	18
Adherence to standardized dimensions (WMM 10)	3.97	1.131	7.020	19
Waste management officer or personnel employed to handle waste issues (WMM 20)	3.73	1.134	6.578	20
Early and prompt scheduling of deliveries (WMM9)	3.76	1.169	6.433	21
Just in time operations (WMM 8)	3.67	*1.143*	6.422	22
Careful handling of tools and equipment on site (WMM 17)	3.69	1.154	6.395	23
Encourage re-use of waste materials in projects (WMM16)	3.42	1.203	5.686	24
Use of low waste technology (WMM 12)	3.53	1.312	5.381	25
Recycling of some waste materials on site (WMM 1)	2.55	1.422	3.586	26

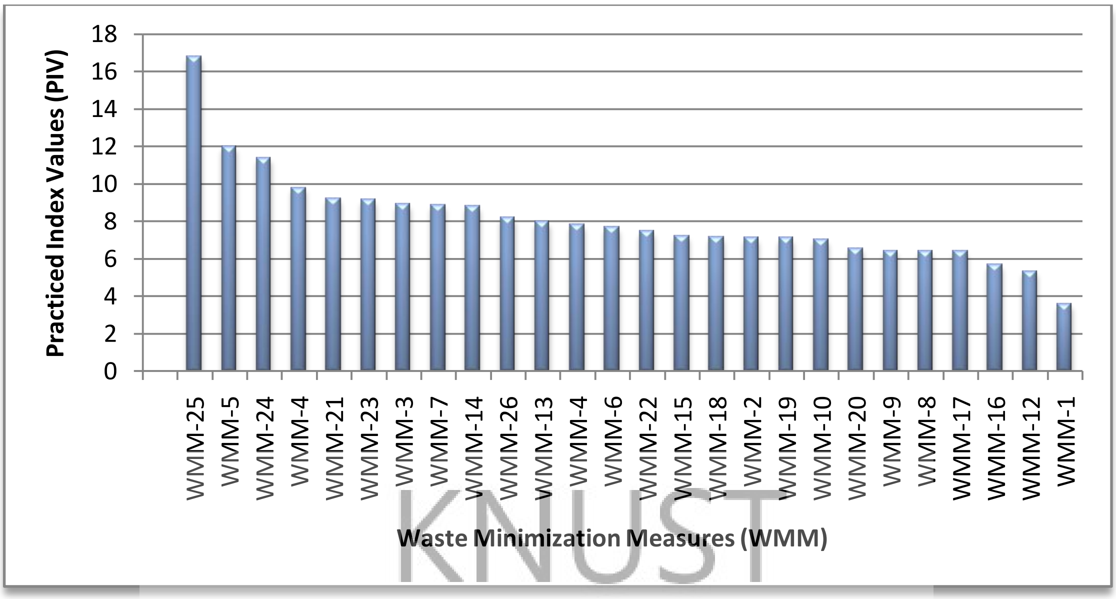

Fig. 4.17 Ranking profile of the levels of practice of waste minimization measures

The empirical evidence presented in Tables 4.10 and 4.11and Figures 4.16 and 4.17 shows that the ranking of the various waste minimization measures by the weighted average criteria (i.e. the ASS and the APS) give the same results as that by the coefficient of variation criteria (i.e. the MIV and the PIV). Thus, both criteria are effective for assessing the relative levels of significance contribution and relative levels of practice of the various measures in the implementing of construction waste management.

The study has shown that the measures that are highly practiced by construction organizations (i.e. 'purchasing raw materials that are just sufficient' (WMM 25), 'using materials before expiry dates' (WMM 24) and 'use of more efficient construction equipment' (WMM 5), are those that directly result in cost savings to the organization, and the least practiced measures (i.e. 'encouraging re-use of waste materials in projects' (WMM 16), 'using of low waste technology' (WMM 12) and 'recycling of some waste materials on sites' (WMM 1)) are those that require investment or further processing of materials to obtain value. Thus, the results show little awareness among construction professionals on the importance of waste minimization. This corroborates with the findings of Teo and Loosemore (2001) and Lingard *et al.* (2000) on waste minimization in Australia. In Australia, waste management was reported as a low project priority amongst construction workers. Waste sorting and recycling although widely publicized by government bodies in Australia, were still not used on most sites at the time. Applying environmentally friendly technology on site and using low waste technology are considered less attractive environmental management measure to construction organizations in Ghana, confirming findings of Begum et al. (2006) and Shen and Tam (2002). Such measures were seen as adding to their production cost hence defeating their perceived views of waste minimization as a cost saving technique.

4.8 Extent of practice of lean thinking in the Ghanaian construction industry

4.8.1. Familiarity with the concept of lean construction

Table 4.12 Summary of Respondents' Familiarity with Lean Construction

FAMILIARITY WITH LEAN CONCEPTS	CONSTRUCTION ORGANIZATIONS PROJECT MANAGERS		CONSULTANCY FIRMS SENIOR CONSULTANTS	
	FREQUENCY	PERCENTAGE	FREQUENCY	PERCENTAGE
Just Aware	141	75	74	60
Have Adopted	9	5	8	6
Not Aware	38	20	42	34
TOTAL	**188**	**100**	**124**	**100**

On the level of awareness of LC, 80% of the project managers and 66% of the senior consultants indicated that they were either just aware of the lean principles or had adopted them in their construction projects (Table 4.12). Only 20% of the project managers and 34% of the senior consultants were not aware of the lean principles (Table 4.12). For the project managers and senior consultants just aware of LC, they either became aware through interaction with their colleagues in other firms or heard about it in school, but they have not gone beyond thinking of introducing it. For the project managers and senior consultants with experience on lean construction, the study showed that only few lean principles such as ‘just in time’ and ‘use of prefabricated components’ had actually been adopted in their construction projects. The project managers and senior consultants just aware of Lean construction admitted that although lean principles are not applied in their activities, they are considering its application in the future. This result gives hope about future implementation of lean principles in the Ghanaian construction industry. The results indicate a good level of awareness, but a low level of familiarity and application of lean concepts in the Ghanaian construction industry.

The above results compare with findings from the literature regarding the initial level of familiarity and application of lean concepts in the UK, The Netherlands and in Germany. In the UK survey, Common et al. (2000) found a distinct lack of understanding and application of the fundamental techniques required for a lean culture to exist. In the case of the Netherlands, Johansen and Walter (2007) concluded that the lean concept appeared to be largely unknown although some issues associated with it had some low penetration in the industry. This shows that the future is bright as respondents’ show good level of awareness of lean principles, hence, will become easier for its implementation.

4.8.2. Application of lean principles to project execution

Respondents (project managers and senior consultants) were asked to score on a Likert scale of 1 to 5 which of 10 basic principles of lean construction they agreed or disagreed with and which they think should be considered when carrying out projects.

The results (Tables 4.13 and 4.14) show that mean scores of all the 10 principles evaluated are greater than the mean value of 3.0 for both the consultants and the contractors. This indicates that the respondents agree with all the ten basic principles of lean construction, and that the principles should be considered during project execution. The results further show that the respondents consider ‘establishing continuous improvement’, ‘delivering what the client wants’, ‘constantly seeking better ways to do things’ and ‘minimizing waste’ as the first four important lean principles to be considered in project execution. Other important principles include ‘building and maintaining long term relationships with suppliers’ and ‘avoiding defects in the works done’. The opinions of the respondents were in agreement with findings from the literature which lists basic principles of lean construction to include ‘delivering what the client wants’, ‘establishing continuous improvement’, and ‘doing the right things the first time’ (Kempton, 2006; Mathew Hunter Associates, 2005; Salem and Zimmer, 2005; Dulaimi and Tanamas, 2001).

Table 4.13. Principles Applied in Carrying Out Projects – Opinions of Consultants

PRINCIPLE	**MEAN SCORE**	**STANDARD DEVIATION**	**RANKING**
Establishing continuous improvement	4.46	0.703	1
Delivering what the client wants	4.44	0.615	2
Constantly seeking better ways to do things	4.35	0.735	3
Waste minimization	4.25	0.717	4
Building and maintaining long term relationships with suppliers	4.21	0.768	5
Avoiding defects in the works done	4.15	0.985	6
Doing the right things at the first time	4.14	0.679	7
Involving the whole project team from the design right through to construction	4.10	1.039	8
Increasing output value through systematic consideration of customer requirements	3.91	0.786	9
Increasing output flexibility	3.58	1.045	10

Table 4.14 Principles Applied in Carrying Out Projects – Opinions of Project Managers

PRINCIPLE	MEAN SCORE	STANDARD DEVIATION	RANKING
Establishing continuous improvement	4.16	0.780	1
Delivering what the client wants	4.07	1.000	2
Involving the whole project team through the design to construction	4.05	0.885	3
Waste minimization	3.92	0.889	4
Constantly seeking better ways to do things	3.90	1.067	5
Avoiding defects in the works done	3.89	1.044	6
Increasing output value through systematic consideration of customer requirements	3.88	0.779	7
Doing the right things at the first time	3.71	1.072	8
Building and maintaining long-term relationships with suppliers	3.68	1.273	9
Increasing output flexibility	3.57	1.029	10

4.8.3 Transferability of lean principles to construction

On transferability of lean principles to the construction industry, all the project managers and the senior consultants admitted that it would be possible to transfer the principles of lean construction to the construction industry. This positive indication should motivate the industry to increase efforts aimed at the successful implementation of LC, as construction environment becomes increasingly demanding, and processing of modern-day projects almost certainly determined by increasing technological and financial pressure (Johansen and Walter, 2007). Transferability of lean principles to the construction industry can help change current practices such as the generation of excessive waste and sub-standard products.

4.8.4 Achievability of customer values

All the respondents were of the opinion that customer values are very important and highly achievable in their firms. The respondents' evaluation of the level of achievability of various customer values is presented in Tables 4.15 and 4.16.

Mean scores of customer values evaluated are all greater than the neutral value of 3.0, indicating that in the opinion of the respondents, these customer values are all significantly important and achievable within activities of consultancy and construction organizations. Whereas the consultants consider 'minimizing waste' as the most important and achievable customer value, the project managers consider 'keeping everything simple right from design to construction'. Other customer values such as 'perfect first time', 'continuous improvement' and 'increasing output flexibility' are considered significantly important and achievable by both the project managers and the consultants.

Table 4.15 Achievability of Customer Values – Perception of Project Managers

VALUES	MEAN SCORE	STANDARD DEVIATION	RANKING
Keeping everything simple, right from design to completion	4.01	0.801	1
Continuous improvement; reduction of costs, increase quality and productivity	3.88	0.694	2
Minimizing waste; eliminating all non-value adding activities and maximizing the use of resources	3.73	0.787	3
Increasing output flexibility including the production of different mixes and or greater diversity of products, without compromising efficiency	3.68	0.771	4
Perfect first time quality; achieving zero defects, revealing and solving problems at the source	3.67	0.659	5

Table 4.16 Achievability of Customer Values – Perception of Consultants

VALUES	MEAN SCORE	STANDARD DEVIATION	RANKING
Minimizing waste; eliminating all non-value adding activities and maximizing the use of resources	4.10	0.663	1
Continuous improvement; reduction of costs, increase quality and productivity	3.95	0.656	2
Perfect first time quality; achieving zero defects, revealing and solving problems at the source	3.80	0.802	3
Keeping everything simple, right from design to completion	3.79	0.898	4
Increasing output flexibility including the production of different mixes and or greater diversity of products, without compromising efficiency	3.68	0.945	5

4.8.5 Benefits of lean construction

The respondents were asked to evaluate nine benefits gathered from the literature and confirmed through interviews. Mean scores and rankings of the benefits are presented in Tables 4.17 and 4.18 for consultants and contractors respectively.

The consultants perceive that the first three most important benefits expected from the application of lean construction are 'improvement of project delivery methods', 'promotion of continuous improvement in project delivery methods through lessons learned' and 'delivery of products or services that enable clients to better accomplish their goals'. To the contractors, 'delivery of products or services on time and within budgets', 'promotion of continuous improvement in project delivery methods through lessons learned' and 'delivery of products or services that enable clients to better accomplish their goals' are the first three most important benefits likely to be achieved from the application of lean principles. Other benefits (Tables 4.17 and 4.18) also considered beneficial in the opinion of the project managers and consultants are included in Tables 4.17 and 4.18.

The findings from this study confirm those from the literature. Mossman (2009) and Lehman and Reiser (2004) reported of benefits from LC as 'more satisfied clients', 'productivity gains', 'greater predictability', and 'shorter construction periods'.

Table 4.17 Benefits of Lean Construction- Perception of Consultants

BENEFITS	MEAN SCORE	STANDARD DEVIATION	RANKING
Improvement of project delivery methods	4.31	0.616	1
Promotion of continuous improvement in project delivery methods through lessons learned	4.29	0.784	2
Delivery of products or services that enable clients to better accomplish their goals	4.20	0.662	3
Delivery of products or services on time and within budget	4.15	0.807	4
Minimization of risk and maximization of opportunities	4.14	0.654	5
Well-informed business decisions at all project levels	4.13	0.733	6
Delivery of custom product, instantly, without waste.	4.12	0.832	7
Injection of reliability, accountability, certainty, and honesty into the project environment	4.08	0.717	8
Minimization of direct costs through effective project delivery management	4.06	0.641	9

Table 4.18 Benefits of Lean Construction- Perception of Project Mannagers

BENEFITS	MEAN SCORE	STANDARD DEVIATION	RANKING
Delivery of products or services on time and within budget	4.43	0.612	1
Promotion of continuous improvement in project delivery methods through lessons learned	4.27	0.673	2
Delivery of products or services that enable customers to better accomplish their goals	4.23	0.502	3
Minimization of direct costs through effective project delivery management	4.20	0.740	4
Well-informed business decisions at all project levels	4.14	0.808	5
Improvement of project delivery methods	4.12	0.834	6
Minimization of risk and maximization of opportunities	4.07	0.734	7
Injection of reliability, accountability, certainty, and honesty into the project environment	4.03	0.734	8
Delivery of custom product, instantly, without waste.	4.01	0.767	9

4.8.6 Measures to bridge the knowledge gap

On measures which would bridge the knowledge gap on lean construction, mean scores of 7 measures investigated and their rankings are presented in Tables 4.19 and 4.20 for consultants and project managers respectively.

Mean scores of all the measures to bridge the knowledge gap are greater than the neutral value of 3.0, indicating that they are all important for bridging the knowledge gap on lean construction. From the evaluation of the consultants, the first three most important measures to bridge the knowledge gap are 'firms should change organizational culture that does not promote lean construction', 'promotion of the concept of lean construction to firms, professional bodies and major stakeholders' and 'the construction industry should fund workshops and research conferences to promote transfer of knowledge on lean construction'. To the contractors, however, 'training of employees at all levels on lean construction', 'engagement of competent and skilled site operatives' and 'promotion of the concept to companies, professional bodies and major stakeholders' are the first three most important measures. The other measures considered important are also ranked in Tables 4.19 and 4.20.

Table 4.19 Measures to Bridge Knowledge Gaps- Perception of Consultants

MEASURES	MEAN SCORE	STANDARD DEVIATION	RANKING
Firms should change organizational culture that does not promote lean construction	4.479	0.542	1
Promotion of the concept to firms, professional bodies and major stakeholders	4.442	0.596	2
The construction industry should fund workshops and research conferences to promote transfer of knowledge on lean construction	4.383	0.639	3
Training of employees at all levels on lean construction	4.356	0.721	4
Engagement of competent and skilled site operatives	4.330	0.535	5
Working on improving performance when carrying out projects.	4.297	0.758	6
Construction managers should be committed to changes	3.888	0.726	7

Table 4.20 Measures to Bridge Knowledge Gaps- Perception of Project Managers

MEASURES	MEAN SCORE	STANDARD DEVIATION	RANKING
Training of employees at all levels on lean construction	4.413	0.583	1
Engagement of competent and skilled site operatives	4.347	0.820	2
Promotion of the concept to firms, professional bodies and major stakeholders	4.262	0.706	3
The construction industry should fund workshops and research conferences to promote transfer of knowledge on lean construction	4.222	0.656	4
Working on improving performance when carrying out projects	4.183	0.720	5
Construction managers should be committed to changes	4.095	0.824	6
Firms should change organizational culture that does not promote lean construction	4.079	0.699	7

4.8.7 Barriers to implementation of LC

The barriers to implementation of Lean Construction identified from literature and confirmed by industry practitioners were ranked according to their mean scores and standard deviations. The results presented in Table 4.21 show that the five strongest barriers to implementation of LC in Ghana are ‘fragmented nature of the industry’, ‘extensive use of subcontractors’, ‘lack of long term relationship with suppliers’, ‘delays in decision making’ and ‘waste accepted as inevitable’, in that order. The weakest barriers include ‘inefficient use of quality standards’, ‘lack of supply chain integration’ and ‘poor project definition’ among others.

Effect of the fragmented nature of the construction industry on the implementation of lean construction has been well documented in the literature (Bashir *et al.*, 2010; Mossman, 2009; Frodel and Josephson, 2009; Abdullah *et al.*, 2009; Bender and Septelka, 2002). The traditional construction process is characterized 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 success of lean construction is highly dependent on having a cohesive team working towards congruent goals and objectives (Abdullah *et al.*, 2009).

Extensive use of subcontractors as a barrier to the implementation of LC in Ghana confirms results from literature (Bashir *et al.*, 2010; Abdullah *et al.*, 2009; Forbes and Ahmed, 2004). Sub-contractors are mainly responsible for specialists’ works and contractors typically hire sub-contractors who do not have direct contracts with the client. Most sub-contractors work with inadequate resources and have low expertise, thereby often compromising quality (Forbes and Ahmed, 2004). Poor supervision of sub-contractors may result in lack of solution to critical problems involved in LC. Extensive use of sub-contractors who often lack technical expertise constitute a serious barrier to lean construction.

Table 4.21 Ranking of Barriers to Implementation of Lean Construction in Ghana

Barriers	**Mean**	**Standard Deviation**	**Rank**
Fragmented nature of the industry	4.650	0.741	1
Extensive use of subcontractors	4.580	0.670	2
Lack of long term relationship with suppliers	4.550	0.729	3
Delays in decision making	4.540	0.707	4
Waste accepted as inevitable	4.430	0.786	5
Inconsistency in government policies	4.370	0.835	6
Materials scarcity	4.300	0.817	7
Lack of long term commitment to change and innovation	4.290	0.837	8
Delays in materials delivery	4.240	0.805	9
Long implementation period	4.220	0.794	10
Less involvement of contractors and specialists in design process	4.220	0.836	11
Lack of technical skills	4.080	0.867	12
corruption	4.060	0.964	13
Lack of client and supplier involvement	4.050	0.784	14
Poor communication	4.040	0.791	15
Lack of management support and commitment	4.040	0.855	16
Inadequate pre-planning	4.000	0.866	17
Incomplete designs	3.990	0.833	18
Lack of agreed implementation methodology	3.980	0.754	19
High dependency of design specifications on in-situ components and materials	3.970	0.825	20
Lack of buildable designs	3.970	0.837	21
Difficulty in understanding lean concepts	3.970	1.025	22
Unsuitable organizational structure	3.960	0.783	23
Poor professional wages	3.950	0.893	24
Poorly defined individual responsibilities	3.930	0.797	25
Lack of standardization	3.930	0.883	26
Lack of technical skills	3.910	0.872	27
Lack of training	3.910	0.934	28
Lack of equipment	3.900	0.849	29
Lack of interests from clients	3.890	0.878	30
Poor project definition	3.880	0.734	31
Lack of supply chain integration	3.880	0. 907	32
Inefficient use of quality standards eg. ISO 9000	3.800	0.826	33

There are several effects that result from lack of long term relationship with suppliers on the implementation of lean construction (Bashir *et al.*, 2010; Mossman, 2009; Frodel and Josephson, 2009; Abdullah *et al.*, 2009; Bender and Septelka, 2002). Contractors who purchase materials and services up to 70-80% of their turnover should realize that the suppliers' are part of the delivery (Frodel and Josephson, 2009). They should prioritize the value created by the suppliers in order to increase their competitiveness. The lack of long term relationships of construction companies with their suppliers has also been attributed to the fragmented nature of the construction industry (Frodel and Josephson, 2009).

Many construction organizations suffer from delays. Delay means slowing down the work without stopping it entirely. Delays give rise to disruption of work and loss of productivity, late completion of project which can lead to abandonment of the work by the contractor or termination of contract by the client. It is important that management keeps track of the progress of the project to reduce possible delay

4.8.7.1 Factor Analysis of Barriers to Implementation of Lean Construction

Table 4.22 presents the results of the factor analysis carried out on the potential barriers to implementation of LC.

Table 4.22. Component Matrix After Varimax Rotation

		Components					
No	Barriers	1	2	3	4	5	6
1	Lack of interests from clients		0.676				
2	Inefficient use of quality standards eg. ISO 9000	0.646					
3	Poorly defined individual responsibilities		0.669				
4	Lack of training						
5	Less involvement of contractors and specialists in design process		0.549				
6	Lack of management support and commitment						
7	Poor project definition			0.514			
8	Delays in materials delivery	0.532					
9	Lack of equipment			0.644			
10	Materials scarcity	0.591					
11	Lack of agreed implementation methodology			0.548			
12	Lack of supply chain integration						
13	Poor communication						0.612
14	Long implementation period	0.676					
15	Inadequate pre-planning						
16	Lack of client and supplier involvement						
17	corruption					0.709	
18	Poor professional wages					0.755	
19	Unsuitable organizational structure			0.502			
20	Lack of technical skills						
21	High level of illiteracy						
22	Waste accepted as inevitable	0.717					
23	Difficulty in understanding lean concepts						0.804
24	Inconsistency in government policies	0.724					
25	Lack of buildable designs				0.699		
26	Incomplete designs				0.661		
27	Lack of standardization				0.625		
28	High dependency of design specifications on in-situ components and materials	0.658					
29	Extensive use of subcontractors	0.690					
30	Lack of long term commitment to change and innovation	0.579					
31	Lack of long term relationship with suppliers	0.610					
32	Fragmented nature of the industry		0.525				
33	Delays in decision making	0.520					
	Eigenvalues	**9.020**	1.405	**0.988**	**0.866**	**0.834**	**0.708**
	Percentage of variance explained	**39.381**	6.136	**4.314**	3.782	**3.643**	**3.090**
	Cumulative percentage of variance explained	39.381	**45.516**	**49.830**	**53.612**	**57.254**	**60.345**

Note:

Valid N (listwise)= 312
Extraction method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalisation
KMO value= 0.925

Bartlett's Test of Sphericity Significance level= 0.000
Insignificant factor loadings (i.e. < 0.5) are blanked

Table 4.23 Total Variance Explained

component	initial Eigen-values			Extraction sums of squared loadings			Rotation Sums of Squared Loadings		
	Total	% variance	cumulative %	Total	% variance	cumulative %	Total	% variance	cumulative %
1	9.020	39.381	39.381	9.020	39.381	39.381	4.013	17.520	17.520
2	1.405	6.136	45.516	1.405	6.136	45.516	2.651	11.575	29.093
3	0.988	4.314	49.830	0.988	4.314	49.830	2.380	10.390	39.484
4	0.866	3.782	53.612	0.866	3.782	53.612	1.866	8.146	47.630
5	0.834	3.643	57.254	0.834	3.643	57.254	1.580	6.898	54.528
6	0.708	3.090	60.345	0.708	3.090	60.345	1.322	5.817	60.345
7	0.667	2.912	63.218						
8	0.652	2.847	66.104						
9	0.610	2.700	68.803						
10	0.588	2.586	71.372						
11	0.546	2.385	73.757						
12	0.530	2.314	76.071						
13	0.472	2.059	78.130						
14	0.452	1.974	80.103						
15	0.393	1.716	81.820						
16	0.369	1.611	83.431						
17	0.366	1.599	85.030						
18	0.431	1.491	86.520						
19	0.334	1.459	87.979						
20	0.291	1.273	89.252						
21	0.284	1.242	90.493						
22	0.279	1.218	91.711						
23	0.242	1.058	92.769						
24	0.237	1.033	93.802						
25	0.213	0.931	94.733						
26	0.208	0.906	95.639						
27	0.178	0.778	96.417						
28	0.164	0.717	97.134						
29	0.153	0.666	97.801						
30	0.146	0.636	98.436						
31	0.133	0.582	99.019						
32	0.114	0.485	99.515						
33	0.111	0.556	100.000						

Extraction method: Principal Component Analysis

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A factor is deemed to be significant to the study if it has a mean value of 3.0 or higher. Since all the 33 factors have mean rating 3.0 or higher, they were included in the factor analysis. All the 33 factors had communalities of 1.00, indicating their suitability for the factor analysis. The 33 significant factors were further reduced to common factor patterns. This was done to empirically explain the potential barriers to the implementation of LC in the Ghanaian construction industry. In doing this, principal component analysis with Varimax rotation and Kaizer Normalization was used to determine which factors have empirical significance. Factor retention was by the eigenvalue ≥ 1.0 criterion, suggesting that only factors that account for variances greater than one should be included in the factor extraction.

The principal component analysis (Table 4.22), where linear combinations of observed variables are formed, was the method used to extract the factors. The first principal component is the combination that accounts for the largest amount of variance and the second principal component accounts for the next largest amount of variance and is uncorrelated with the first. From Table 4.22, component 1 has total variance of 9.020, which accounts for 39.381% of the total variance of the 33 factors. Component 2 has total variance of 1.405 accounting for 6.136% of the total variance of the 33 factors, component 3 has a total variance of 0.988 accounting for 4.314% of the total variance of the 33 factors, component 4 has a total variance of 0.866 accounting for 3.782% of the total variance of 33 factors, component 5 has a total variance of 0.834 accounting for 3.643% of the total variance of 33 factors and component 6 has a total variance of 0.708 accounting for 3.090% of the total variance of 33 factors. These six components constitute 60.345% of the total variance of the 33 factors.

From the 33 factors identified from the literature as potential barriers to implementation of LC, and then confirmed through meetings with practitioners, factor analysis enabled 26 of them to be placed under six components as follows:

Component 1: delays in materials delivery, inefficient use of quality standards, long implementation period, waste accepted as inevitable, inconsistency in government policies, high dependency of design specifications on in-situ components and materials, extensive use of subcontractors, lack of long term commitment to change and innovation, lack of long term relationship with suppliers, delays in decision making and materials scarcity.

Component 2: fragmented nature of the construction industry, lack of interest from clients, poorly defined individual responsibilities and less involvement of contractors and specialists in design process.

Component 3: poor project definition, lack of equipment, lack of agreed implementation methodology and unsuitable organizational structures.

Component 4: lack of buildable designs, incomplete designs and lack of standardization

Component 5: poor professional wages and corruption

Component 6: difficulty in understanding lean concepts and poor communication.

Based on the examination of inherent relationships among the factors under each component, the following interpretations were made to explain the underlining phenomenon linking the factors.

Component 1: Lack of proper planning and control

Inefficient planning and control has adverse effects on the successful implementation of LC (Bashir *et al.*, 2010; Alinaitwe, 2009; Olatunji, 2008). This component identified delays in materials delivery, inefficient use of quality standards, long implementation period, waste accepted as inevitable, inconsistency in government policies, high dependency of design specifications on in-situ components and materials, extensive use of subcontractors, lack of long term commitment to change and innovation, lack of long term relationship with suppliers, delays in decision making and materials scarcity as major barriers to the implementation of lean construction. Despite the significant economic contribution made by the construction sector in various countries, it faces numerous problems relating to improper planning and control.

Component 2: Lack of teamwork

Teamwork has a major influence on the implementation of LC (Bashir *et al.,* 2010; Mossman, 2009; Frodel and Josephson, 2009; Abdullah *et al.,* 2009; Bender and Septelka, 2002). This component identified the fragmented nature of the industry, lack of interest from clients, poorly defined individual responsibilities and less involvement of contractors and specialists in design process. Teamwork can be defined as "cooperative effort by the members of a group or team to achieve a common goal" (Bender and Septelka, 2002). It is common knowledge that various parties in the construction industry work as a team (Abdullah *et al.*, 2009). These team members share the common goal of completing the project to the satisfaction of the client, but because of conflicting and competing interest, a project may suffer from lack of teamwork (Bender and Septelka, 2002). These separate interests are due to the fragmented nature of the construction industry. If these parties are incapable of co-operating among themselves, the implementation of LC will definitely be negatively affected as it needs commitment and a strong co-operative network involving all parties concerned. The success of LC is highly dependent on having a cohesive team working towards congruent goals and objectives.

Component 3: Poor project management

Good project management has positive impact on LC (Alinaitwe, 2009; Alarcon *et al.*, 2008; Common *et al.*, 2000; Forbes and Ahmed, 2004). This component identified poor project definition, lack of equipment, lack of agreed implementation methodology and unsuitable organizational structures as barriers to implementation of LC. The management of every organization has a major role to play in achieving successful implementation of innovative strategies (Bashir *et al.*, 2010; Salem *et al.*, 2005). The success of lean practice lies in the commitment of management in developing and implementing an effective plan and adequately providing the required resources and support to manage changes arising from the implementation (Bashir *et al.*, 2010). Without the support of management, the professionals involved in construction may face numerous difficulties in adapting the LC concept (Abdullah *et al.*, 2009).

Component 4: Lack of technical capabilities

Literature has been well documented on the effect of technical capabilities on the success of LC (Ballard and Howell, 2004; Koskela *et al.*, 2004; Alinaitwe, 2009; Bashir *et al.*, 2010). This component identified lack of buildable designs, incomplete designs and lack of standardization as the major barriers to the implementation of lean construction. These barriers are considered technical because they have a direct impact on the success of application of lean construction principles and tools such as reliability, simplicity, flexibility and benchmarking (Bashir *et al.*, 2010). Design over-sights and over adherence to standard design solutions can lead to buildability problems or constrain innovation that might offer more cost-effective solutions. Both of these would hold back the industry's desires to develop "leaner" approaches to construction (CIRIA, 1998). The designer is paid to produce a design expressed in the form of specifications and drawings. The contractor is expected to use these as a means of communication, and produce the completed facility. This communication often does not work as well as it should (Forbes and Ahmed, 2004). The problem might be due to the fact that the design lacks buildability and so cannot be interpreted.

Component 5: Lack of professional motivation

There have been several reports on the way professional motivation has contributed to the successful implementation of lean construction (Bashir *et al.,* 2010; Mossman, 2009; Olatunji, 2008; Common *et al.,* 2000). Innovative strategies like LC require some funds for its adequate implementation. Adequate funding is needed to motivate workers, provide relevant equipment and employ lean specialists to guide both employers and employees in implementing the concept. Financially related issues are among the most common barriers to lean practice across different organizations in various countries. However, the nature of this barrier varies across countries. This component identified poor professional wages and corruption as the major barriers to implementation of LC. Corruption which includes bribery, extortion and fraud may damage the implementation of LC by resulting in the cutting of corners, overpricing of projects, using of inferior materials and poor workmanship.

Component 6: Poor communication between parties

The impact of good communication between parties on the success of LC implementation has been reported in the literature (Bashir *et al.*, 2010; Abdullah *et al.,* 2009). This component identified lack of communication and difficulty in understanding lean concepts as the major barriers to implementation of LC. Since LC evolved from the manufacturing industry, it is vital that the parties involved in the construction industry have a full knowledge of the lean manufacturing concept before its implementation. Without this prior comprehension, it is feared that concerned parties will not be able to fully understand the concept of LC. The construction industry is made up of different parties with different opinions (clients, consultants and contractors) who have to come and work together as a team in order to ensure the successful completion of the project. There is therefore the need to establish and improve communication among all parties. In the process of implementing lean principles, poor communication between respective parties will lead to disruption and ineffective delivery and co-ordination process (Abdullah *et al.*, 2009).

4.8.8 Measures to overcome potential barriers to implementation of LC

The respondents were asked to evaluate the 17 measures that are considered to have the potential to overcome barriers to implementation of LC. Table 4.24 presents mean scores, standard deviations and rankings of the 17 measures.

All the 17 measures have mean ratings of 3.0 or higher and therefore considered significant (Table 4.24). The results show that the five most significant measures to overcome potential barriers to implementation of LC in the Ghanaian construction industry are 'management should train employees on lean concepts', 'communication should be improved among players in construction projects', 'construction should ensure or maintain continuous improvement: thus, reducing costs, increasing quality and productivity', 'construction managers should be committed to changes', and 'workers should be able to work in teams'. The findings of this study confirm that in the literature (Bashir *et al.*, 2010). Steps to overcome barriers to implementation of LC in the UK include taking full advantage of staff training on LC at all levels, engaging skilled site operatives, and promoting the LC concept to companies, professional bodies and major stakeholders. The UK construction industry also engaged in funding workshops and research that generate more literature to guide LC implementation (Abdullah *et al.*, 2009).

Table 4.24 Ranked Measures to Overcome Potential Barriers to Implementation of Lean Construction

Measures	Mean score	Standard deviation	Ranking
Management should train employees on lean concepts	4.417	0.594	1
Communication should be improved among players in construction projects	4.365	0.774	2
Construction should ensure or maintain continuous improvement: thus, reduction of costs, increase quality and productivity	4.346	0.658	3
Construction managers should be committed to changes	4.234	0.661	4
Workers should be able to work in teams	4.218	0.788	5
Proactive measures to prevent defective production should be established by firms	4.141	0.680	6
Timely delivery of materials to construction sites	4.134	0.688	7
Firms should understand client needs and expectations and position themselves accordingly	4.131	0.630	8
Companies should be more client focused	4.106	0.878	9
Standardized construction elements should be promoted in the industry	4.080	0.816	10
Firms should be willing to change organizational cultures that do not promote lean construction	4.071	0.807	11
The opinion of employees should be considered in decision making	4.068	0.801	12
Government agencies should embark on applicable policies that could provide critical support to make lean methods feasible	4.067	0.924	13
Management should monitor inflation risks and pricing levels that could provide the stability that organizations need in order to make lean methods feasible	4.061	0.837	14
Management should deal with uncertainties and fears that cause organizations to conceal information instead of sharing it	4.060	0.893	15
Partnering should be promoted to maximize team building and development of trust	4.051	0.923	16
Team members should be empowered in decision-making to make partnerships meaningful	3.923	0.986	17

4.9 A PROPOSED FRAMEWORK FOR MINIMIZING MATERIALS WASTAGE ON CONSTRUCTION SITES

A popular misconception is that lean is used for only manufacturing. In fact lean principles apply in every business and process. Lean is not a tactic or a cost reduction exercise, but a way of thinking and acting for an entire organization. Businesses in all industries and services are using lean principles as the way they think and do things. Many organizations choose not to use the word lean, but to label what they do as their own system. This is to drive home the point that lean is not a program or short term cost reduction exercise, but the way the company operates. The word transformation or lean transformation is often used to characterize a company moving from an old way of thinking to lean thinking (Womack and Jones, 2003).

The framework proposed emphasizes how lean principles could be applied to minimize materials wastage on construction sites. The objectives of the framework are to help managers to:

- Better understand the major challenges (barriers) that could hinder the implementation of lean principles during the construction stage of a project. It suggests that before management decide to implement lean principles in their projects, these barriers are likely to be encountered.
- Identify what could be done to tackle these challenges (what to do),
- Identify how to address these challenges (how to do it) and
- Realize the possible outcome (results), which is minimizing materials wastage.

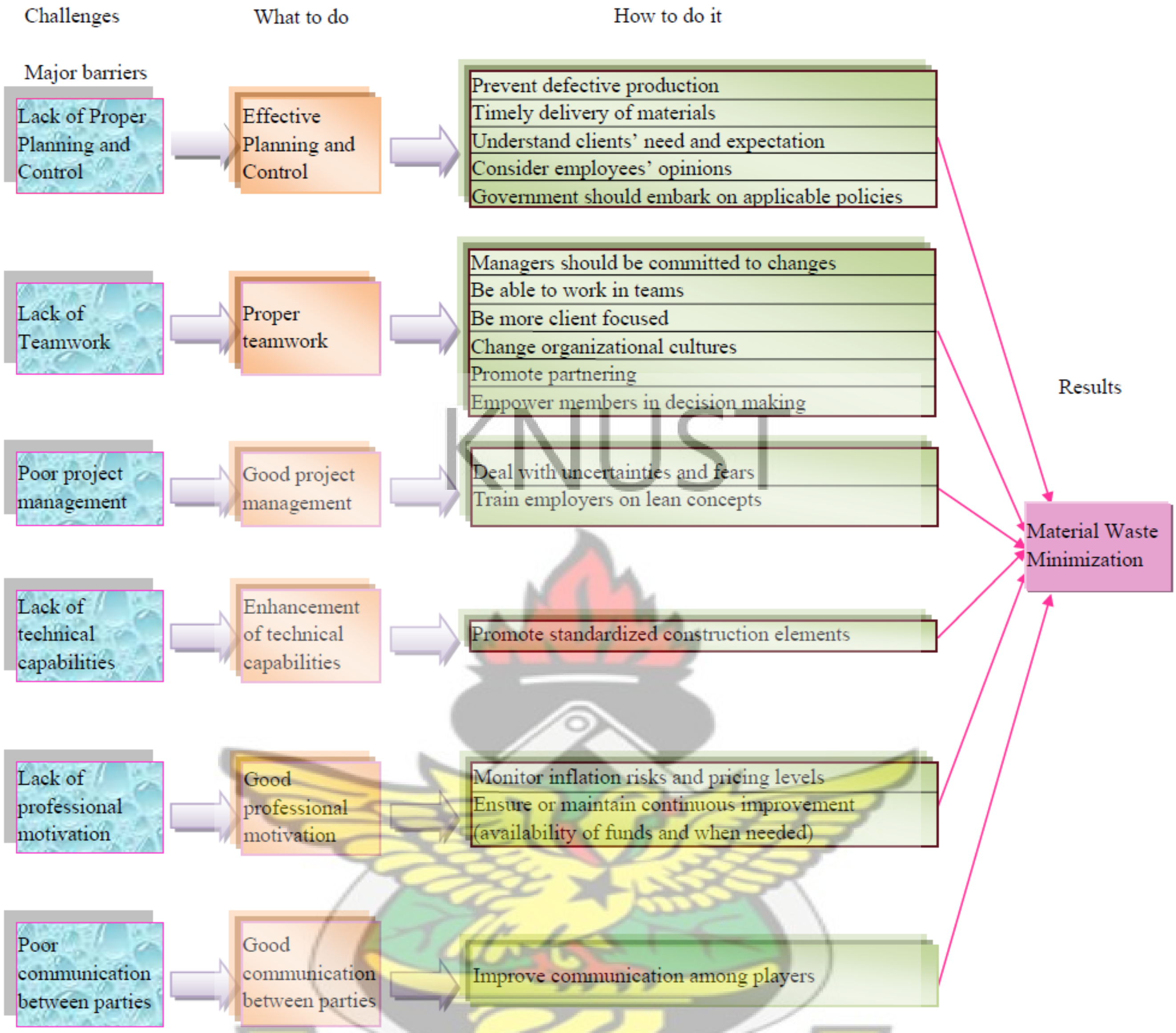

Fig 4.18 A framework for minimizing materials waste

Based on the 33 barriers identified in literature and from which factor analysis enabled 26 of them to be grouped under 6 components (lack of proper planning and control, lack of team work, poor project management, lack of technical capabilities, lack of professional motivation and poor communication between parties), several ways of addressing these problems were proposed accordingly. From the proposed framework illustrated in Figure 19, six (6) lean construction strategies, namely; Effective planning and control, Proper teamwork, Good project management, Enhancement of technical capabilities, Good professional motivation and Good communication between parties, are presented to address the barriers. These six strategies correspond to the components extracted by factor analysis. The measures suggested to overcome potential barriers were grouped under the various strategies based on their suitability.

P1: Effective planning and control

The traditional construction planning and control system has been criticized in terms of insufficiency of its underlying theories and ineffectiveness of its techniques (Sriprasert and Dawood, 2002). A successful project requires careful planning, organization and control throughout the project to achieve the correct result for the client. For the contractor, good planning, organization and control are essential in order to achieve a timely and satisfactory outcome for the client, and to ensure a financial profit.

If lean principles are to be effectively implemented, it is important for management to plan and control activities on construction sites. This encompass 'establishing proactive measures to prevent defective production', 'timely delivery of materials to construction sites', 'understanding of clients' needs and expectations', 'considering the opinions of employees in decision making' and 'embarking on applicable policies that could provide critical support to make lean methods feasible by government agencies'.

P2: Proper teamwork

Teamwork means workers working as a group to achieve a common goal. Teamwork, if carried out effectively, results in motivated workers, improved job satisfaction, reduced overall work time, and can improve the quality of work (Griffin *et al.*, 2001). To ensure the successful implementation of lean principles there should be an effective teamwork between all parties. To ensure proper teamwork on construction sites, managers should be committed to change, workers should be able to work in teams, companies should be more client focused, firms should be willing to change organizational cultures that do not promote lean construction, partnering to maximize team building and team members should be empowered in decision-making to make partnerships meaningful.

Parties to a contract busily discussing issues on site. Such team work is always sure to provide a good end result. The various parties to a contract need each other for the project to be successfully executed.

Fig. 4.19 Parties to a contract busily discussing issues on site.

P3: Good project management

Strengthening the influence of the various employees on their own work (empowerment) is often discussed as a management strategy for the management of complex products and processes, many actors, fragmented processes and tasks, etc. which is precisely what characterize the construction sector (Dainty *et al.*, 2002). Managing a construction project depends on how parties in a construction project interpret the construction process. Lean strategies such as training of employees on lean concepts and dealing with uncertainties and fears that cause organizations to conceal information instead of sharing it should be employed to enhance the implementation of lean principles.

Strengthening the influence of the various employees on their own work (empowerment) is often discussed as a management strategy

Fig. 4.20 Project manager issuing instructions to workers

P4: Enhancement of technical capabilities

The enhancement of technical capabilities is very important in order to effectively implement the principles of lean on construction sites. To ensure that technical capabilities are enhanced, Orr (2005) suggests that managers should understand and use standards to define normal and abnormal conditions and develop clear, user friendly, visual controls at all levels to help monitor and improve standards. The lack of standardization can be viewed as one of the reasons for the inefficiency of the construction sector (Santos *et al.*, 2002). Womack and Jones (1996) suggested that standardization of processes can be a means of reducing costs and saving time. Santos *et al.* (2002) also suggested that standardization should be viewed as an approach aimed at waste reduction by the critical disentanglement of processes to reduce their variability. There is also the need for managers to maintain personal discipline, direct and coach others to keep within standards and procedures and always react to off standard and off target situations with immediate investigation. It is also important that managers do not allow short cuts and tackle reasons why a standard is overlooked or neglected. Also, standardized construction elements should be promoted to reduce the amount of materials wasted on construction sites.

P5: Good professional motivation

Fig. 4.21 Good professional motivation to employees

The financial capabilities of companies are one of the critical factors for successful implementation of Lean. Financial resources are needed for employee training programs, external consultants, etc. Sometimes even production of firms may be interrupted as a result of the employees' training in the new techniques. Managers would rather refuse unnecessary loss of resources especially if they do not anticipate immediate returns. To help deal with these financial problems, management should ensure that construction maintains continuous improvement, thus reduction of costs and increase quality and productivity. Management should monitor inflation risks and pricing levels that could provide the stability that organization need in order to make lean methods feasible.

P6: Good communication between parties

Communication refers to the exchange of information between workers during the period of work (Weick and Browning, 1986). In an organization, communication is carried out in several ways including verbal and signs. Authority, control and motivation are the functioning of an organization. Workers communication needs to be effective for coordinate efforts, leading to improvement in quality of the works. Communication quality which has characteristics of being timely, accurate and useful and complete enhances productivity and quality of work (Byrne *et al.*, 2006). Communication should be improved among players to enhance the successful implementation of lean strategies.

4.10 Value of Proposed Framework

Despite the fact that the variables in the framework have not been operationalized, it provides a platform for construction professionals to understand major challenges that could hinder the implementation of lean construction and suggest ways to address these problems. This will ensure the smooth implementation of Lean Principles during the construction stage of projects for efficient minimization of materials waste.

4.11 Conclusion

This chapter presented results from the quantitative analysis and the site observations. Results have been presented on the sources and causes of materials wastes and waste minimization measures. A compendium on wastage of key construction materials and recommended ways of waste minimization is also provided. Results were presented on respondents perceptions of the concept of lean construction and barriers to implementation of lean construction. Finally a framework which has the potential of minimizing materials wastage at the construction stage of a project using lean principles is proposed.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Conclusion:

A summary of the findings established from the analysis of the data have been related to the objectives of the study in this section.

5.1 Sources and causes of materials waste on construction sites

The study has identified the main sources and causes of materials waste in the Ghanaian construction industry from the perspective of construction practitioners. The level of contribution of the waste sources to the generation of waste saw differences between the perceptions of the respondents (project managers and senior consultants). The senior consultants of consultancy firms (architectural and quantity surveying) agree that 'design and documentation factors', 'procurement factors' and 'material handling factors' have significantly high contribution to the generation of waste on construction sites. Operational factors were however, not of significance to the senior consultants since they believed these problems could easily be dealt with if proper management actions are put in place. The project managers considered 'materials handling', 'operational factors', 'design and documentation factors' and 'procurement factors' as having high significant contribution to the generation of waste on construction sites. The results showed that whereas the senior consultants identified design and documentation as the major source of waste, the project managers identified materials handling as the major source of waste.

5.1.1 Design and documentation

All the fifteen factors evaluated were considered as major causes of design and documentation waste on construction sites. The results further showed that 'last minute client requirement (resulting in rework)', 'poor communication leading to mistakes and errors', 'selection of low quality products', 'designer's inexperience in method and sequence of construction’ and ‘poor/ wrong specifications’ are the first five major causes of waste resulting from design and documentation. Other causes of waste include ‘lack of knowledge about construction techniques during design activities’, ‘lack of attention paid to dimensional coordination of products’, ‘lack of information in the drawings’, ‘poor site layout’, ‘lack of attention paid to standard sizes available on the market’, ‘complexity of detailing in the drawings’, ‘variations in the design while construction is in progress’, ‘designer's unfamiliarity with alternative products’, ‘incomplete contract documents at commencement of project’ and ‘overlapping of design and construction’.

5.1.2 Operational factors

The results from the survey revealed that the respondents consider all the seventeen factors as causes of waste arising out of operational activities on construction sites. The results further revealed that ‘errors by tradesmen or task operatives’, ‘use of incorrect material, thus requiring replacement’, ‘required quantity unclear due to improper planning’, ‘delays in passing of information to the contractor on types and sizes of products to be used’ and ‘poor interaction between various specialists’ were the first five major causes of waste that arise out of operational activities on construction sites. Other equally important causes of operational waste are ‘unfriendly attitudes of project team and task operatives’, ‘choice of wrong construction method’, ‘damage to work done caused by subsequent trades’, ‘inappropriate placement of the material’, ‘accidents due to negligence’, ‘equipment malfunctioning’, ‘inclement weather’, ‘poor technology of equipment’, ‘effects of political and social conditions’, ‘shortage of tools and equipment required’, ‘frequent breakdown of equipment’ and ‘difficulties in obtaining work permits’.

5.1.3 Procurement factors

The findings revealed that 'purchasing products that do not comply with specification', 'unsuitability of materials supplied to site', 'substitution of a material by a more expensive one', 'ordering errors' and 'changes in material prices' are the major causes of waste arising out of procurement activities.

5.1.4 Materials storage and handling

It was established from the survey that 'lack of onsite materials control', 'damage to materials on site during transportation', 'poor handling of materials', 'waste resulting from cutting uneconomical shapes' and 'using excessive quantities of materials than required' are the major causes of waste arising from materials storage and handling. The results further revealed that 'overproduction/ production of a quantity greater or required than necessary', 'theft', 'poor method of storage on site', 'manufacturing defects,' 'unnecessary inventories on site leading to waste', 'use of whatever material close to working place', 'insufficient instructions about handling', 'use of wrong method of transport' and 'overloading of transport equipment' are other important causes of materials waste arising from storage and handling.

5.2 Wastage of key construction materials

Timber, cement/mortar, concrete, blocks, steel, quarry chippings/ coarse aggregates, paint, sand and tiles are the key materials wasted on construction sites. The results showed that all the materials with the exception of pipes have high levels of contribution toward the generation of waste on construction sites.

5.3 Ranking of waste minimization measures

The respondents considered all the 26 measures as important for minimizing wastage of materials on site. The results further showed that ‘purchasing raw materials that are just sufficient (WMM 24)’, ‘using materials before expiry dates (WMM 25)’, ‘good coordination between store and construction personnel to avoid over ordering (WMM 4)’, ‘use of more efficient construction equipment (WMM 5)’ and ‘adoption of proper site management techniques (WMM 21) are the five most important measures which can minimize the wastage of materials on construction sites. The least but important measures identified by the respondents include ‘encouraging re-use of waste materials in projects (WMM16)’, ‘use of low waste technology (WMM 12)’ and ‘recycling of some waste materials on site (WMM 1)’.

5.4 Level of contribution and level of practice of waste minimization measures

The study has provided empirical evidence on the levels of contribution and the levels of practice of waste minimization measures in the Ghanaian construction industry. It has shown that purchasing raw materials that are just sufficient, using materials before expiry dates and use of more efficient construction equipment are perceived as the three measures that most significantly contribute to waste minimization and also the most practiced waste minimization measures. Encouraging re-use of waste materials in projects, using low waste technology and recycling of some waste materials on sites are, however, perceived as the least significant factors that contribute to waste minimization and the least practiced measures simply because such measures are seen as adding to their production cost instead of reducing cost.

5.5 Perspectives for the implementation of lean construction

Analysis of the results obtained from the structured questionnaire survey showed the existence of some level of awareness among professionals in the Ghanaian construction industry on the concept of lean construction. Principles adopted by construction organizations in their activities such as 'delivering what the client wants', 'establishing continuous improvement', 'constantly seeking better ways to do things', 'waste minimization' and 'avoiding defects in works done' are observed to be generally consistent with lean construction practice. Majority of the construction professionals surveyed are receptive to lean principles implementation in the construction industry, and are also of the opinion that the transfer of lean construction principles into the construction industry would bring a lot of benefits including 'improvement of project delivery methods' and 'delivery of products or services that enable clients to better accomplish their goals'.

5.6 Barriers to successful implementation of lean construction

From 33 factors identified by the Ghanaian building construction organizations and consultancy firms as potential barriers to the implementation of LC, factor analysis enabled 26 of them to be placed under six components: 1) lack of proper planning and control comprising delays in materials delivery, inefficient use of quality standards, long implementation period, waste accepted as inevitable, inconsistency in government policies, high dependency of design specifications on in-situ components and materials, extensive use of subcontractors, lack of long term commitment to change and innovation, lack of long term relationship with suppliers, delays in decision making and materials scarcity; 2) Lack of teamwork comprising the fragmented nature of the industry, lack of interest from clients, poorly defined individual responsibilities and less involvement of contractors and specialists in design process; 3) Poor project management comprising poor project definition, lack of equipment, lack of agreed implementation methodology and unsuitable organizational structures; 4) Lack of technical capabilities comprising lack of buildable designs, incomplete designs and lack of standardization; 5) Lack of professional motivation comprising poor professional wages and corruption; 6) Poor communication between parties comprising difficulty in understanding lean concepts and poor communication.

5.7. Measures to overcome potential barriers to implementation of LC

The results revealed that the five most significant measures to overcome potential barriers to implementation of LC in the Ghanaian construction industry are 'management should train employees on lean concepts', 'communication should be improved among players in construction projects', 'construction should ensure or maintain continuous improvement: thus, reducing costs, increasing quality and productivity', 'construction managers should be committed to changes', and 'the ability of workers to work in teams'.

5.8 Recommendations

The following recommendations have been made to enhance the application of lean principles to minimize materials wastage on construction sites in Ghana.

- Proper site and waste management techniques, and preparation of accurate specification for materials are recommended measures to adopt in the quest to minimize materials waste in construction.
- In order to assist the construction industry to minimize wastage of materials, it is recommended that government should enact laws and establish policies that engender positive attitudes towards waste minimization at all levels in a construction project. Also the construction industry in Ghana should collaborate

with relevant government agencies to develop appropriate guidelines for preparing waste management plans for the construction industry. Furthermore, the construction industry should adopt low waste and environmentally friendly technologies on site, and government should provide incentives to the construction industry to encourage the reduction, recycling and re-use of construction waste. Finally, construction organizations should also provide waste reduction training to site staff to raise their environmental awareness and improve working procedures to reduce waste generation in construction projects.

- In order to bridge the knowledge gap on the application of LC, it is suggested among others that construction firms should change organizational culture that does not promote lean construction and also promote the concept of lean construction through workshops and conferences.
- Construction managers should among others be committed to changes, understand client needs and expectations, and maintain continuous improvement (i.e. reduction of costs, increase quality and productivity. Government agencies on their part should embark on applicable policies that could provide critical support to make lean methods feasible. The identified barriers and measures to overcome potential barriers to implementation of LC should provide an enabling environment for construction practitioners to successfully implement lean construction and improve construction quality and efficiency for the benefit of the client.

5.9 Limitation

- The study should have covered all categories of building contractors but due to lack of reliable information on small scale construction organizations, only large firms in the highest financial classes were covered.

- Structural Engineering Firms were excluded from the survey because of lack of precise data on these firms in Ghana.

5.10 Recommendation for future studies

- Further research is suggested on the perceptions of construction clients of the lean construction philosophy.
- Culture and Waste Management in the Ghanaian Construction Industry.
- Sustainability, Resource Efficiency and Waste Elimination in the Ghanaian Construction Industry.

5.11 Practical Implication

- The results will enable building organizations to improve construction quality and efficiency through the implementation of the measures suggested to remove potential barriers to the implementation of lean construction.
- Minimizing materials waste would improve project performance and enhance value for individual customers, and have a positive impact on the national economy.

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APPENDIX 1

QUESTIONNAIRE FOR CONSTRUCTION ORGANIZATIONS AND CONSULTANCY FIRMS

COMPANY PROFILE

1. Company name:……………………………………………………….
2. Year of establishment:………………………………………………..
3. Profession

   Architect [ ]   Building Contractor [ ]   Project manager [ ]

   Quantity Surveyor [ ]   Site supervisor [ ]

   Other, please specify…………………………………

4. Level of education

   HND [ ]   Bachelors Degree [ ]   Masters Degree [ ]

   Doctorate degree [ ]   other, please specify,

5. Level of experience in years

   0-5 [ ]   5-10 [ ]   10-15 [ ]   15-20 [ ]   > 20 [ ]

6. Who are your major clients?

   Public organizations [ ]

   Private individuals and organizations [ ]

   Both public and private figures [ ]

   Others, please specify…………………………………………………………………..

7. Geographical operational locations

   International [ ]

   Local [ ]

   Both local and international [ ]

1. SOURCES AND CAUSES OF WASTE

a) Below are possible sources of construction waste. Rank on a scale of 1-5 which of these waste sources contributes highly to the generation of waste on site.

1	2	3	4	5
Not a waste cause	Insignificant waste cause	Neutral	Significant waste cause	Major waste cause

WASTE CAUSE	1	2	3	4	5
Design and documentation					
Operational					
Materials storage and handling					
Procurement					

b) Below are possible sources and causes of construction waste. Rank on a scale of 1-5 which of these activities is a major contributor of waste generation.

1	2	3	4	5
Not a waste cause	Insignificant waste cause	Neutral	Significant waste cause	Major waste cause

DESIGN AND DOCUMENTATION	1	2	3	4	5
Lack of attention paid to dimensional coordination of products					
Variations in the design while construction is in progress					
Designer's inexperience in method and sequence of construction					
Lack of attention paid to standard sizes available on the market					
Designer's unfamiliarity with alternative products					
Complexity of detailing in the drawings					
Lack of information in the drawings					
Poor/ wrong specifications					
Incomplete contract documents at commencement of project					
Selection of low quality products					
Last minute client requirement (resulting in rework)					
Poor communication leading to mistakes and errors					
Overlapping of design and construction					

Lack of knowledge about construction techniques during design activities					
Poor site layout					
OPERATIONAL	1	2	3	4	5
Errors by tradesmen or operatives					
Accidents due to negligence					
Damage to work done caused by subsequent trades					
Use of incorrect material, thus requiring replacement					
Required quantity unclear due to improper planning					
Delays in passing of information to the contractor on types and sizes of products to be used					
Equipment malfunctioning					
Inclement weather					
Inappropriate placement of the material					
Poor interaction between various specialists					
Choice of wrong construction method					
Unfriendly attitudes of project team and labors					
Effects of political and social conditions					
Difficulties in obtaining work permits					
Frequent breakdown of equipment					
Poor technology of equipment					
Shortage of tools and equipment required					
MATERIALS STORAGE AND HANDLING					
Overloading of transport equipment					
Use of wrong method of transport					
Poor method of storage on site					
Poor handling					
Use of whatever material close to working place					
Theft					
Damage to materials on site					
Waste resulting from cutting uneconomical shapes					
Unnecessary inventories on site leading to waste					
Overproduction/ production of a quantity greater required or earlier than necessary					
Manufacturing defects					
Lack of onsite materials control					
Using excessive quantities of materials than required					
Insufficient instructions about handling					
PROCUREMENT					

Ordering errors (eg., ordering significantly more or less)					
Purchased products that do not comply with specification					
Unsuitability of materials supplied to site					
Substitution of a material by a more expensive one (with an unnecessary better performance)					
Changes in material prices					

c) Below are some selected materials which are wasted on construction sites. Rank on a scale of 1-5 which of these materials is severely wasted on site.

1	2	3	4	5
Not severe	Less severe	Quite severe	severe	Very severe

MATERIAL	1	2	3	4	5
Concrete					
Steel					
Timber					
Cement/mortar					
Sand					
Quarry chipping/ coarse aggregate					
Blocks					
Tiles					
Paint					
Pipes					

d) Below are possible measures that contribute to the minimization of material wastes. Rank on a scale of 1-5

1	2	3	4	5
Very low contribution	Low contribution	Medium contribution	High contribution	Very high contribution

MEASURES	1	2	3	4	5
Recycling of some waste materials on site					
Good construction management practices					
Training of construction personnel					
Good coordination between store and construction personnel to avoid over-ordering					
Use of more efficient construction equipment					
Vigilance of supervisors					
Proper storage of materials on site					
Just in time operations					
Early and prompt scheduling of deliveries					
Adherence to standardized dimensions					

Change of attitude of workers towards the handling of materials					
Regular education and training of personnel on how to handle					
Checking materials supplied for right qualities and volumes					
Employment of skilled workmen					
Accurate measurement of materials during batching					
Accurate and good specifications of materials to avoid wrong ordering					
Encourage re-use of waste materials in projects					
Careful handling of tools and equipment on site					
Weekly programming of works					
Mixing, transporting and placing concrete at the appropriate time					
Waste management officer or personnel employed to handle waste issues					
Adoption of proper site management techniques					
Access to latest information about types of materials on the market					
Minimizing design changes					
Purchasing raw materials that are just sufficient					
Using materials before expiry dates					

e) Rank on a scale of 1-5 the level of practice of these waste minimization measures in your firms

1	2	3	4	5
Not practiced at all	Not practiced	Practiced	Frequently practiced	Most frequently practiced

MEASURES	1	2	3	4	5
Recycling of some waste materials on site					
Good construction management practices					
Training of construction personnel					
Good coordination between store and construction personnel to avoid over-ordering					
Use of more efficient construction equipment					
Vigilance of supervisors					
Proper storage of materials on site					
Just in time operations					
Early and prompt scheduling of deliveries					
Adherence to standardized dimensions					
Change of attitude of workers towards the handling of materials					
Regular education and training of personnel on how to handle					
Checking materials supplied for right qualities and volumes					

Employment of skilled workmen					
Accurate measurement of materials during batching					
Accurate and good specifications of materials to avoid wrong ordering					
Encourage re-use of waste materials in projects					
Careful handling of tools and equipment on site					
Weekly programming of works					
Mixing, transporting and placing concrete at the appropriate time					
Waste management officer or personnel employed to handle waste issues					
Adoption of proper site management techniques					
Access to latest information about types of materials on the market					
Minimizing design changes					
Purchasing raw materials that are just sufficient					
Using materials before expiry dates					

2. KNOWLEDGE ON LEAN CONCEPTS

LEAN CONCEPT

- A way to do more and more with less and less- less human effort, less equipment, less materials, less time and less space
- To get the right things to the right place at the right time, the first time.
- Balanced use of people, materials and resources

A. How familiar are you with the concept of lean construction?

Not aware of it at all	Just aware of it	Have been involved in its application	Other, please specify

B. Below are lists of principles applied in carrying out projects. Rank on a Likert scale of 1-5 your level of agreement to the application of these principles to the design and construction stages of your activities.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	2	3	4	5

PRINCIPLE	1	2	3	4	5
Delivering what the client wants					
Establishing continuous improvement: thus, reduction of costs, increase in quality and productivity					
Doing the right things at the first time: thus achieve zero defects, revealing and solving problems at the source					
Avoiding defects in the works done that can result in for example, waste, unnecessary rework, loss of customers and corporate reputation					
Involving the whole project team through the design to construction					
Constantly seeking better ways to do things					
Increasing output value through systematic consideration of customer requirements					
Increasing output flexibility: thus the production of different mixes and/ or greater diversity of products, without compromising efficiency					
Waste minimization: thus, eliminating all non-value adding activities and maximizing the use of all resources					
Building and maintaining long-term relationships with suppliers					

C. Lean construction has been successfully adopted in the manufacturing/ production processes. How do you consider the transferability of lean principles to construction? Rank on a scale of 1-5

1	2	3	4	5
Not good	Quite good	Neutral	Good	Very good

D. To what extent do you think lean principles are already used within your company? Rank on a scale of 1-5

Highly unused	Unused	Neutral	Used	Highly used
1	2	3	4	5

E. How do you rank the achievability of customer values in your operations?

1	2	3	4	5
Highly unachievable	Unachievable	Neutral	Achievable	Highly achievable

F. To your knowledge in construction, rank on a scale of 1-5 how you believe the following customer values can best be achieved in your operations.

1	2	3	4	5
Highly unachievable	Unachievable	Neutral	Achievable	Highly achievable

VALUES	1	2	3	4	5
Perfect first-time quality: achieving zero defects, revealing and solving problems at the source					
Continuous improvement: reduction of costs, increase quality and productivity					
Waste minimization: eliminating all non-value adding activities and maximizing the use of resources					
Keeping everything simple, right from design through to completion					
Increasing output flexibility: thus, the production of different mixes and or greater diversity of products, without compromising efficiency.					

3. BENEFITS OF LEAN CONSTRUCTION

Below are lists of possible benefits of the implementation of lean concepts in the construction industry. Rank these benefits on a scale of 1-5.

Highly unbeneficial	Unbeneficial	Neutral	Beneficial	Highly beneficial
1	2	3	4	5

BENEFITS	**1**	**2**	**3**	**4**	**5**
Deliver products or services that enable customers to better accomplish their goals					
Deliver products or services on time and within budget					
minimize direct costs through effective project delivery management					
make well-informed business decisions at all project levels					
Deliver a custom product, instantly, without waste.					
Minimize risk and maximize opportunity					
Inject reliability, accountability, certainty, and honesty into the project environment					
Reduce system noise					
Improve project delivery methods					
Promote continuous improvement in project delivery methods through lessons learned					

4. Measures to Bridge knowledge gaps

Below are lists of possible measures to bridge the knowledge gaps on the concept of lean construction in the construction industry. Rank these measures on a scale of 1-5.

Highly unimportant	Unimportant	Neutral	Important	Highly important
1	2	3	4	5

MEASURES	1	2	3	4	5
Training of employees at all levels on lean construction					
Engagement of competent and skilled site operatives					
Promotion of the concept to firms, professional bodies and major stakeholders					
The construction industry should fund workshops and research conferences to promote transfer of knowledge on lean construction					
Working on improving performance when carrying out projects					
Construction managers should be committed to changes					
Firms should change organizational culture that does not promote lean construction					

5. BARRIERS TO THE IMPLEMENTATION OF LEAN CONSTRUCTION CONCEPTS

Below are lists of factors acting as barriers to the implementation of lean construction concepts. Rank them on a scale of 1-5 according to their level of severity.

1	2	3	4	5
Not influential	Less influential	Quite influential	Influential	Very influential

BARRIERS	1	2	3	4	5
Lack of interest from clients					
Waste accepted as inevitable					
Poorly defined individual responsibilities					
Lack of training					
Less involvement of contractors and specialists in design process					
Delays in decision making					
Lack of top management support and commitment					
Poor project definition					
Delay in materials delivery					
Lack of equipment					
Materials scarcity					
Unsuitable organizational structure					
Lack of supply chain integration					
Poor communication					
Long implementation period					
Inadequate pre-planning					
Lack of client and supplier involvement					
Corruption					
Poor professional wages					
Lack of standardization					
Lack of technical skills					
High level of illiteracy					
Lack of awareness programs					
Difficulty in understanding concepts					
Inconsistency in government policies					
Lack of buildable designs					
Incomplete designs					
Lack of agreed implementation methodology					
High dependency of design specifications on in-situ materials and components rather than standardized and industrialized prefabricated components					
Extensive use of subcontractors					
Lack of long-term commitment to change and innovation					
Lack of long-term relationship with suppliers					
The fragmented nature of the construction industry					

6. MEASURES TO OVERCOME BARRIERS TO THE IMPLEMENTATION OF LEAN CONCEPTS

Below are measures for **overcoming barriers to the implementation of lean concepts.** Rank the measures on a scale of 1-5 as follows.

Highly unimportant	Unimportant	Neutral	Important	Highly important
1	2	3	4	5

Measures	1	2	3	4	5
Management should train employees on lean concepts					
Communication should be improved among players in construction projects					
Construction should ensure or maintain continuous improvement: thus, reduction of costs, increase quality and productivity					
Construction managers should be committed to changes					
Workers should be able to work in teams					
Proactive measures to prevent defective production should be established by firms					
Timely delivery of materials to construction sites					
Firms should understand client needs and expectations and position themselves accordingly					
Companies should be more client focused					
Standardized construction elements should be promoted in the industry					
Firms should be willing to change organizational cultures that do not promote lean construction					
The opinion of employees should be considered in decision making					
Government agencies should embark on applicable policies that could provide critical support to make lean methods feasible					
Management should monitor inflation risks and pricing levels that could provide the stability that organizations need in order to make lean methods feasible					
Management should deal with uncertainties and fears that cause organizations to conceal information instead of sharing it					
Partnering should be promoted to maximize team building and development of trust					
Team members should be empowered in decision-making to make these partnerships meaningful					