IMPROVING APPROACHES TO MATERIAL INVENTORY MANAGEMENT IN CONSTRUCTION   INDUSTRY IN THE UK

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ii

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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ABSTRACT

Materials used in construction constitute a major proportion of the total cost of construction projects. An important factor of great concern that adversely affects construction projects is the location and tracking of materials, which normally come in bulk with minimal identification. There is inadequate integration of modern wireless technologies (such as Radio Frequency Identification (RFID), Personal Digital Assistant (PDA) or Just-in-Time (JIT)) into project management systems for easier and faster materials management and tracking and to overcome human error. This research focuses on improving approaches to material inventory managements in the UK construction industry through the formulation of RFID-based materials management tracking process system with projects.

Existing literature review identified many challenges/problems in material inventory management on construction projects, such as supply delays, shortages, price fluctuations, wastage and damage, and insufficient storage space. Six construction projects were selected as exploratory case studies and cross-case analysis was used to investigate approaches to material inventory managements practices: problems, implementation of ICT, and the potential for using emerging wireless technologies and systems (such as RFID and PDA) for materials tracking. Findings showed that there were similar problems of storage constraints and logistics with most of the construction projects. The synthesis of good practices required the implementation of an RFID-facilitated construction management of materials tracking system to make material handling easier, quicker, more efficient and less paperwork. There was also a recommendation to implement Information and Communication Technology (ICT) tools to integrate plant, labour and materials into one system.

The findings from the cases studies and the literature review were used to formulate a process for real-time material tracking using Radio Frequency Identification (RFID) that can improve material inventory management in the UK construction industry. Testing and validation undertaken assisted in formulating a process that can be useful, functional and acceptable for a possible process system's development. Finally, research achievements/contribution to knowledge, limitations were discussed and some suggestions for further research were outlined.

CONTENTS

LIST OF ABBREVIATION

Auto-ID: Automatic Identification

ASCC: American Society of Concrete Contractors

BIM: Building Information Modelling

CC: Consolidation Centre

COME: Construction Materials Exchange

COP: Customer Order Point

CMPS: Construction Materials Planning System

C-TPB-TAM: Combine Theory of Planned Behaviour and Technology Acceptance Model

DoD: Department of Defence

DS: Delivery Status

EAN: European Article Numbering

EPC: Electronic Product Code

ERP: Enterprise Resource Planning

ERP: Electronic Road Pricing

ESCAPE: Expert System Advisor for Concrete Placing

ETO: Engineer-To-Order

GIS: Geographical Information System

GPS: Global Positioning System

ICT: Information and Communication Technology

ID: Identification

IDT: Innovation Diffusion Theory

IEPC: Internet-based Electronic Product Catalogue

IS: Information System

ISARC: International Symposium on Automation and Robotics in Construction

ISO: International Organisation for Standardization

IT: Information Technology

ITC: Information Technology in Construction

JIT: Just-In-Time

LC: Logistics Centre

MEP: Mechanical, Electrical and Plumbing

MHESA: Material Handling Equipment Selection Advisor

MM: Motivational Model

MO: Material Order

MPCU: Model of PC Utilization

NB: Notāre Bene ("note well")

OAN: Japanese Article Numbering

OCR: Optical Character Recognition

OP: Operations Management

OPP: Order Penetration Point

PBC: Perceived Behaviours Control

PC: Personal Computer

PDA: Personal Digital Assistant

PMIS: Project Management Information System

QMS: Quality Management System

RFID: Radio Frequency Identification

RTLS: Real-Time Locating System

SCT:	Social Cognitive Theory
SI:	Storage Information
SN:	Subjective Norms
TAM:	Technology Acceptance Model
TAM2:	Technology Acceptance Model version 2
TAM3:	Technology Acceptance Model version 3
TPB:	Theory of Planned Behaviour
TRA:	Theory of Reasoned Action
TTF:	Task-Technology Fit
UK:	United Kingdom
UPC:	Universal Product Code
US:	Use Status
UTAUT:	Unified Theory of Acceptance and Use of Technology
VCMR:	Virtual Construction Material Router
VMI:	Vendor Managed Inventory
Y2K:	Year 2000

LIST OF FIGURES

LIST OF TABLES

1   CHAPTER ONE

1.1   INTRODUCTION

This chapter will present the research context of this study. It begins with a description of research background and justifies the need for conducting the research. It will also state the aim and objectives this research intends to achieve. Lastly, it will describe the structure of the thesis.

1.2   RESEARCH BACKGROUND

Materials used in construction constitute a major proportion of the total cost of a construction project. This may be about 60% of the total project budget (Song, 2005; Nasir, 2008). Therefore, material inventory management used in the construction is vital and plays an essential role in the process. Material inventory management is especially important when construction projects are large and complex, and a single process involved will cost a huge sum of money. The tracking of materials for a construction project from one location to another constitutes one of the major challenges in relation to material inventory management used in construction projects (Navon and Berkovich, 2006). This tracking of materials ensures that they are available in the required quantity when they are needed in the right place and at the right time.

Location and tracking of materials are always an issue that is of great concern in construction projects, as these materials normally come in bulk with minimal identification (Lu et al., 2011). Traditional tracking methods together with inadequate management of these materials, especially during their receipt on site, makes it very difficult to account for the location of these materials when they are needed, thereby leading to the need to reorder the materials, to wastages and higher incurred costs. The traditional method used in inventory management by many construction companies in the United Kingdom most times provides information that is unreliable regarding the materials needed in a project. These traditional methods have many limitations that has made them unsuitable in modern construction industry in which most projects are becoming so sophisticated that good knowledge of ICT is necessary to enhance project management (Sardroud, 2012).

Improper handling and management of material has an adverse effect on the performance of these material in the construction projects. Other issues which affect management of material for a project can include storage area constraints, construction site delivery and ordering of

materials, and site logistics for material distribution and handling (Abdul-Rahman et al., 2006; Aibinu and Odeyinka, 2006; Udeaja et al., 2013).

Many approaches are being used in material inventory management. These different approaches includes material logistics plans, Just-In-Time (JIT) concepts which are applied to resolving constraints arising from storage space and the application of Information and Communication Technology (ICT) tools such as Barcoding and RFID (Radio Frequency Identification) for tracking of materials automatically. Most of these approaches currently in use for inventory management by most construction companies are not successfully used or are under developed. Some of these companies undertake inventory management manually. These are most time inefficient, error prone and problematic in exchange of information in relation to supply chain material management (Sahari et al., 2012).

These approaches such as Barcoding, Radio Frequency Identification (RFID) and other wireless tracking technologies are not adequately utilised in construction projects inventory management development. Operational efficiency in inventory management is not sufficiently supported to enable faster and easier material management and tracking. Thus, this research work will review management of materials in construction industries and provide guidelines that can be formulated to select a suitable approach to material inventory management in the sector.

The research work will be of benefit to interest stakeholder groups especially in the construction industry. It is expected that it will make an invaluable addition to the body of knowledge in improving material inventory managements for construction projects in the United Kingdom. It is also expected that it will be available to the general public for their perusal, criticism and appraisal.

1.3   PROBLEM DEFINITION

Most stakeholders in the construction industry aim to complete construction projects as early as possible so that return on investment can be achieved as fast as possible. To enable quick completion of projects and non-delay requires that constraints to time are reduced to the barest minimum from the normal completion time. Most delays lead to longer completion times, higher overhead costs and wastage of resources. Material inventory managements if not effectively implemented, will lead to unnecessary delay to project completion time, higher overhead cost and wastage of resources; thus, the need to improve inventory management.

Material tracking approaches that exist in construction projects for material inventory managements has several drawbacks. Manual method of data collection and recording which are relied upon for material tracking practices and other related to tracking activities is labour intensive (Ergen and Akinci, 2007). According to Sardroud et al. (2010), the collection of data by manual methods during materials tracking depends on the staff skill. Furthermore, materials received are often either not recorded at all or improperly recorded (Ala- Risku et al., 2006).

In addition, manual materials tracking data are normally transferred and kept in paper-based format making them difficult to be accessed and traced in the future. Thus, information may not be available in a timely manner to departments that need to access them during the decision-making process (Sardroud et al., 2010). Again, Demiralp et al. (2012) asserted that manual tracking of material practices consumes time, leads to incorrect installations, results in late deliveries and leads to dislocated components. Manual material tracking practices provide less assurance for materials identification.

Nonetheless, inventory management process for material tracking practices has been improved by opportunities created by advances in Information and Communication Technology (ICT) in construction projects. Many technologies have been introduced to overcome material inventory drawbacks in material tracking practices (Sardroud et al., 2010; Moselhi and El-Omari, 2006; Grau et al., 2009; Robinson and Udeaja, 2015) - technologies such as wireless technology, Radio Frequency Identification (RFID), bar-coding, Global Positioning System (GPS), and others, can facilitate materials tracking for materials control and inventory management. Moselhi and El-Omari (2006) stated that wireless technologies, RFID, bar-coding and other inventory management technologies could enhance the accuracy and speed of data collection in construction projects in a cost-efficient manner.

The use of Bar-coding technology in materials tracking provides instant updated information on quantities of equipment and materials passed between the working groups and store keepers (Chen et al., 2012). Conversely, RFID technology provides real-time information and unique identification in construction projects (Sarac et al., 2010). The use of ICT in tracking of materials for construction projects offers great advantage and needs to be adopted to overcome inventory management related challenges (Robinson and Udeaja, 2015).

1.4   MAIN RESEARCH QUESTION

What are the key different approaches to inventory management practices that are being adopted in the UK construction industries and what guidelines can be formulated to improve material inventory management practices in this sector?

1.4.1   Sub-Questions

1. What are the key different approaches to material inventory management that are being adopted in the construction industry worldwide?
2. What are the approaches to material inventory management in the UK construction industry?
3. What are the current challenges in the UK construction industry with regards to material inventory management?
4. What recommendations can be formulated to improve material inventory management in the UK construction industry?

1.5   AIMS

To analyse the key different approaches to material inventory management used in the construction industries, and to formulate a process for real-time material tracking that will improve material inventory management approaches in the UK construction sector.

1.6   OBJECTIVES

1. To review key different approaches to material inventory management that are being adopted in the construction industry worldwide.
2. To analyse the approaches to material inventory management practices used in the UK construction industry.
3. To identify the current challenges/ problems in the UK construction industry with regards to material inventory management.
4. To formulate a process for real-time material tracking that will improve material inventory management approaches in the UK construction sector.

1.7   RESEARCH HYPOTHESIS

The introduction has presented the background for carrying out this research project and argued the fact that although construction materials management is an area that heavily relies on information, there is a need to come up with approaches to material inventory specifically designed for it. In the light of the above argument this project's hypothesis is as follows:

"Effective management of construction materials in the UK construction industry can be enabled through improving approaches to material inventory management in the sector."

1.8 SCOPE OF THE RESEARCH

The population targeted by this research is most especially a selection of construction industries in the UK, the main contractors that are registered with them, and stakeholder groups in the construction sector in United Kingdom; and material inventory.

1.9 STRUCTURE OF THE THESIS

- **CHAPTER ONE**: This chapter will present the research context of this study. It begins with a description of research background and justification for conducting the research. It will also state the aim and objectives this research intends to achieve. Lastly, it will describe the structure of the thesis.

- **CHAPTER TWO:** Review of the Literature. This chapter will review existing literatures deemed appropriate and related to the research study on material management in the construction sector and emerging information and communication technologies in the sector that support inventory management. The evidence literature review for this research will be garnered from a melange of works such as journals, company reports, workshops, doctoral theses, conference books and seminar proceedings, and other internet sources.

- **CHAPTER THREE:** Emerging information and communication technologies being adopted in the construction sector that support material inventory management, will be discussed.

- **CHAPTER FOUR:** Research Methodology. This chapter will describe the research methodology that has been adopted for the thesis.

- **CHAPTER FIVE:** Case Studies on the Approaches to Material inventory management in the UK Construction Industry. In this chapter, six construction projects will be used as case studies to investigate current material inventory management processes, Implementation of ICT, challenges, the potential of utilising new wireless technologies (for example Radio Frequency Identification) to improve the practices for tracking of materials.

- **CHAPTER SIX:** Analysis on Key Findings from Case Studies. This chapter discusses a summary of the key findings and the details of the undertaken case studies, which will be classified into five key case study unit of analysis (i.e. embedded unit of analysis).

- **CHAPTER SEVEN:** Evaluation of the Process for Real-Time Tracking of Materials. This chapter discusses the process of tracking material in real-time to improve material inventory managements in the construction industry. The tracking of material process is a system approach that aids an automatic tracking of materials on the construction site. In this chapter, an introduction to material tracking components in real-time will be discussed; these include delivery of materials, storage of materials, materials usage, centre for on-site material control, and transmission report. This is then followed by a description of the material tracking process in real-time; and a discussion of the key features of the processes to improve material inventory managements in UK construction industry.

- **CHAPTER EIGHT:** Conclusions and Recommendations. This chapter draws a conclusion to the thesis. The chapter will begin with a concise run-through of the research and establishes how the research aims and objectives were accomplished. Highlights of the main conclusions gathered from the research work will also be presented. Other accomplishments of the research in contribution to knowledge, the main limitations of the research, further research recommendations and suggestions, will be presented in this chapter.
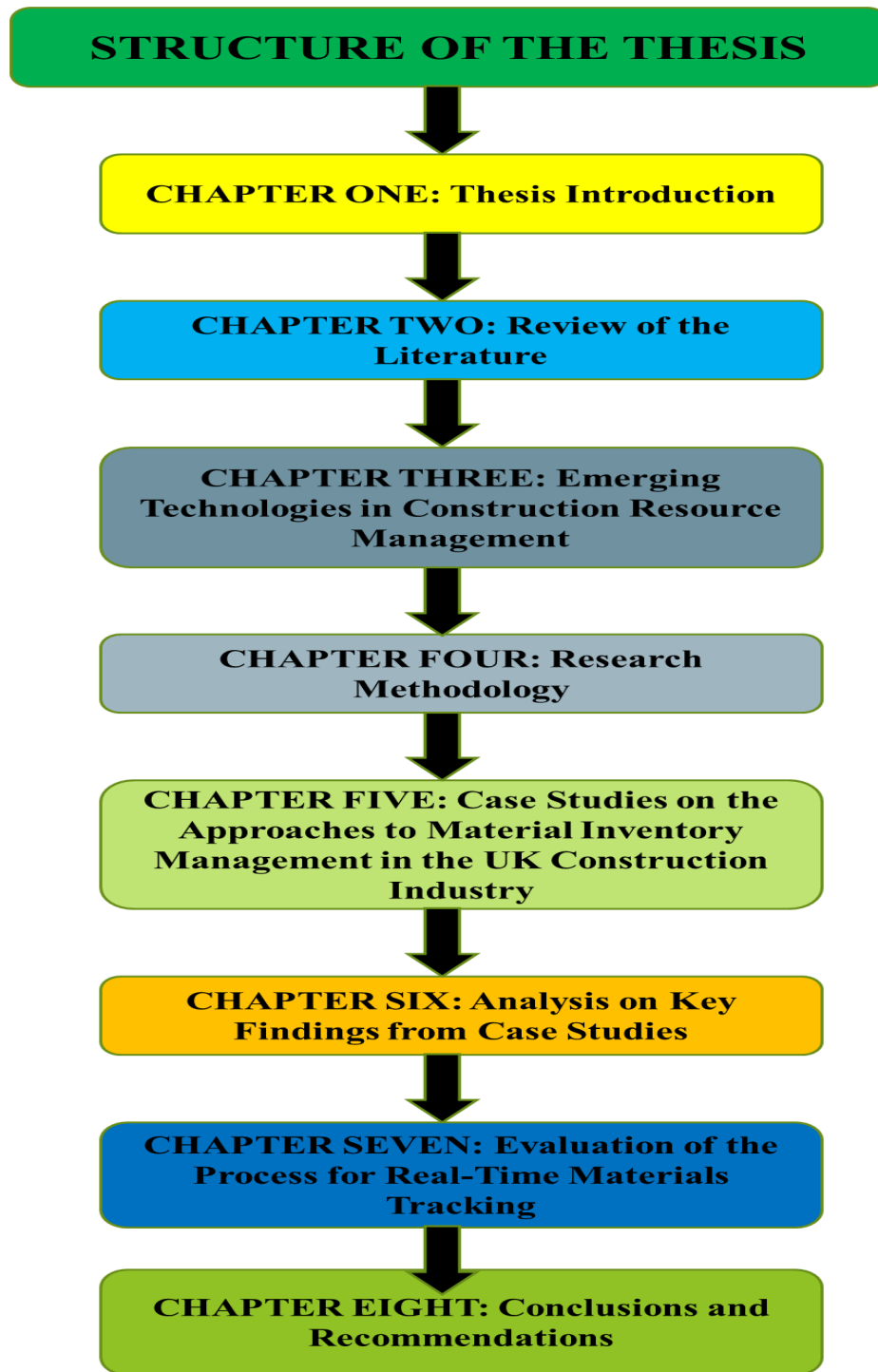
Figure 1.1: Structure of the Research Thesis

1.10   CHAPTER SUMMARY

A summary of the research context of this study was presented in this chapter. It started with a brief research background and justified the need for conducting the research. The chapter also presented the problem definition that necessitate the need for material inventory. The research question presented which led to the aim and objectives this research intended to achieve. Lastly,

it described the structure of the thesis. The next two chapters will deal on review of several literatures that will aid the conduct of this this research.

2   CHAPTER TWO

REVIEW OF THE LITERATURE

2.1   INTRODUCTION

This literature review considers existing literature (such as methodologies, theories, case studies, journals and models) deemed appropriate and related to the research study in material inventory management in the construction sector; and emerging information and communication technologies in the sector that support inventory management. The evidence literature review for this research will be garnered from a melange of works such as journals, company reports, workshops, doctoral theses, conference books and seminar proceedings, and other internet sources. According to Blumberg et al. (2005), one of the pivotal parts of any research study is a review of prevailing literature. Some of the reviewed topics vital to this study are summarized below.

2.2   INVENTORY MANAGEMENT

Inventory is a means of taking stock of goods/ materials in store such that anticipated demand for them by customers can be met (Lu et al., 2011). The two points of view to inventory that are vital to an organisation are the operational and financial aspects. Inventory can be defined in construction term as materials for construction projects stocked by the firm for the smooth functioning of the work process. It is essential that material inventory is well managed for smooth delivery of the project.

Inventory is a major asset and represents a sizable investment in businesses that sell or manufacture products. In extraction, manufacturing, wholesaling, retailing, importing/exporting, and other fields, inventory constitutes one of the largest controllable assets of a business. There are two major economic purposes of inventories (Wisner et al., 2014): they act as buffer zones in the system of production and distribution and may be seen as investment or speculation.

Inventory management involves a balance between customer service, or product availability, and the cost of inventory (Wisner et al., 2014). There are several factors that influence inventory decision-making. In this paper, only two will be considered: the cost factor and the uncertainty factor, which includes demand uncertainty and time uncertainty.

Unlike a fixed-order quantity model, suppliers oversee managing the inventory at the location of customers and sending the right amount at the right time using information technology (Romano, 2014). Today, VMI literature has generally focused on the relationship between the manufacturer and the distributor (Taleizadeh et al., 2015). In most cases, it has been the large distributor, or purchaser, who has required the suppliers to institute VMI. These implementations have been required primarily to benefit the distributor without much thought as to the effect on the supplier (Southard, 2001).

2.2.1 Importance of inventory management

Having an effective and efficient inventory management system is vital in business to ensure that business processes are carried out within the given time schedule. There are several reasons why inventory should be well managed which according to Muller (2011), include:

- Predictability: It is very important to have control of inventory material quantity (such material as parts, equipment, raw materials, and sub-assemblies), to enable full engagement in production scheduling and capacity planning within a given time. Inventory management will helps have full control over these construction processes

- Fluctuation in market demand: Some undesirable fluctuations in demand due to some market conditions may stall business processes. There is need to protect the business against these market forces using well managed inventory.

- Unreliability of materials supply: To guard against scarcity of materials, steady supply of project materials and unreliability of some suppliers, there is need for good management of inventory.

- Price protection: Cost inflation can be avoided when effective inventory management is done in buying and storing large quantities at appropriate time.

- Quantity discounts: When the quantity of the material that are needed in projects are managed properly, large/ bulk quantities can be bought at discount prices, thereby, saving costs to the business.

- Reduced ordering costs: Costs of ordering several materials can be reduced when large quantities of these several items are bought less frequently.

2.2.2 Processes in inventory management

Management of inventory of materials are interwoven with the logistics processes from arrival of the material at the project site, their storage and inventory waste disposal in a supply chain.

The main processes involved in inventory management in construction site are briefly discussed below.

- **Planning:** This is the initial stage and is very vital in the inventory management process. Appropriate planning needs to be done together with construction, engineering and other planning involved with the project (Kasim, 2011).

- **Purchasing:** To support the project's operations, purchase of materials and services that are needed are done. It is important that the right materials and services are carried out at the right time and quantities by the purchasing department, during material procurement.

- **Delivery of materials:** This involves the delivery of the procured or purchased material to the project site storage facilities. The materials delivered should be checked upon their receipts and compared against the information on the purchase order, to ensure the right materials are delivered in the right quantity and specification (Heck, 2009).

- **Storage:** The materials need to be kept in a safe condition until they are needed in the project operations after they are delivered. After the materials are safely delivered, they are added to the stock and recorded to the store database. Adequate information about the stored materials need to be recorded by the store keeper to enable easy identification of the material, their quantities, ease of retrieval for use when required.

- **Materials issuance:** This involves retrieval of the stored material when needed from the inventory lists. Good inventory management ensures faster issuance of the materials in the required quantity when the need arises.

2.2.3 Problems in inventory management

Several authors and researchers have written books on inventory management and problems in construction projects such as: Donyavi and Flanagan (2009); and Sardroud (2012). They listed these problems to include:

- Labour intensiveness of manual material tracking which are mostly inaccurate, error prone, cause wastage, delays in schedule completion and decrease in production.
- Shortage of materials, tools and equipment
- Inadequate storage space
- Missing of materials and material surplus
- Wrong delivery time
- Improper planning, etc.

2.3 MATERIAL MANAGEMENT

Various researchers have provided various definitions for material management. These various definitions, therefore, can be found in various articles, journals, references and books. Primarily, material management deals with planning, identification, procurement, receiving, storage, and distribution of materials (Rapp and Benhart, 2015). Material management has the purpose of assuring that the right quantity of materials needed is in the right place when needed. The material management department has the responsibility for the materials flow from the time of order, reception and storage of the materials down to the time they are used. This forms the basis of material management (Donyavi and Flanagan, 2009).

Kasim (2011) defined material management as the process of planning, procuring, moving, storing and control of materials for effective utilization of resources, facilities, capital and personnel. Navon (2006) defined material management as a process that provides the right materials at the right time and place such that a desired level of production is maintained at the least possible cost. It is aimed that material management effectively controls materials flow. Song (2005) noted that management of material structure should be correlated such that it allows for planning and coordination/ integration of material flow to resource usage, in an optimal way and at the least possible costs.

Patel et al. (2015) defined material management of field and office activities in construction as a process that involves planning, executing and controlling. Material management goal is to ensure that materials for construction activities are available when needed at their point of use. They surmised that material management is a system for planning and controlling of all necessary efforts that ensure that accurate quantity of quality materials is detailed in a timely manner, acquired at a appropriate cost and most of all, available at the point of use when needed.

Patil and Pataskar (2013) stated that implementation of material management systems should aim to planning, ordering, delivery checking, warehousing, use of materials control, and material payment. They opined that there should be interrelation among these activities. They see material management as the process that allows an organisation procure the needed materials for the attainment of its objectives. The process starts with the materials procurement from the supplier to its use/ incorporation into the product. The concept of material management is concerned with the management of materials down to its use and conversion

into the final product. Processes will include such activities as designing, procuring, receiving, storage, quality control, material control and inventory control.

Wisner et al. (2014) indicated that material inventory management system should have standard procedures for planning, undertaking, receipt, transportation and storage to ensure that materials control system is efficient. They stated that material inventory management involves the control of the movement of goods in a company; and a combination of financing, production, distribution and marketing with purchasing. Materials management, they opined, is a function that is vital for controlling and planning of flow of materials, hence, the need for materials manager to maximize company resources through inventory.

Romano (2014) stated that management of materials is an essential element in planning and control of projects. Materials equate to a sizable expense in construction thus, reducing the cost of procurement presents a vital opportunity for reducing project costs. Bad management of materials can as well lead to unavoidable costs in construction projects. Early purchased materials may lead to tying up of capital needed for other processes and may incur interest charges on the inventory of material excesses. Worse still may be the deterioration of materials during storage or being stolen, if the necessary security of materials is not provided. For instance, the storage locations of electrical equipment must often be waterproof.

Again, unavailability of materials needed for particular activities may lead to delays and extra expenses incurred to project cost. Consequently, it is imperative on project managers to ensure a timely flow of material. Management of materials is not only of interest during the monitoring stage but also during the stages of planning and scheduling, when decisions about material procurement are made (Rapp and Benhart, 2015; Christopher, 2016). In a project with fast-track schedule, the availability of materials may influence the project greatly. Adequate time must be allowed to obtain vital materials needed. In most cases, procurement from more expensive suppliers or dealers may be engaged to salvage time. Management of materials at the organization level can be an issue if control of central inventory and purchasing, is utilised for standard items. In such case, the central purchasing group would handle all purchasing and inventory by the company for various projects. In other to obtain reduced cost from bulk purchasing or reduce delay in providing material, the central purchasing group would also maintain inventories of all standard items (Monezka, 2015).

The management of materials problem in an organisation is akin to inventory control in an organisation where there is sustained demand for special items (Liwan et al., 2013). Computer-

based systems are particularly good for dealing with material ordering problems to ensure completeness and consistency of ordering processes. While the use of automated materials requirements planning systems are more common in the manufacturing realm. In each time period for these systems, the inventory records are merged with the master production schedule and the product component lists to determine the items to be ordered, the quantity that must be ordered and when such items must be ordered. Simple arithmetic is applied for these calculations: projected demand for each material item is subtracted by the inventory available (Patel et al., 2011).

When material inventory become too reduced, recommendation is made for a new order. Calculation for items not kept on the inventory or non-standard items are even simpler since there is no due consideration for inventory. Detailed record keeping is automated for a material requirement system and manager for the project are well informed of these purchasing requirements (Rapp and Benhart, 2015). The materials play more of economic role for the organisation since it is their duty to ensure that the total materials costs are kept as low as possible. The individual responsible for the materials handling has the onus to ensure that optimal cost is incurred for the materials needed by the organisation. Organisations have the aim of maximising profit. Profit maximisation is the basis for organisational survival and ensuring income exceeds cost of production while keeping customer's expectation in mind.

2.3.1 History of Materials as An Element for Management

The primary aim of any manufacturing or construction organisation is to develop products that can be marketed at a profit. According to Rao and Krishna (2009), achieving the above goal is through successful application and combining of what management authorities historically have called the five Ms: Materials, Manpower, Machinery, Money, and Management. Materials are vital to the construction industry, and it cannot operate without them. The right materials must be made available where and when needed. There has been a continuous shift in the relative importance of the five Ms in accordance with the world-wide economic situation. The shift in the construction industry has revolved around manpower, materials usage, and machinery. A close economic and historic view at the importance of materials in the construction industry has shown that before 1815, materials were taken for granted due to its availability and low cost (Brandon and Lombardi, 2009; Jaggar 1982).

With the industrial revolution in Great Britain from 1815 to 1850, there was a rapid population growth, as well as national economy, which has led to high demands for building for various

purposes. The construction industry had a dominant position in the national economy, and it became a vital source for many jobs and products which underpinned economic growth (Powell, 2013). There was not much change to site activities and labourers applied same skills as their forefathers. There were limited sources of construction materials. Portland Company was one of them, dealing in supply stone for construction. Otherwise, there were very small quarries used only intermittently, such as the one in Oxfordshire and Cotswolds. Generally, every village in Great Britain had its own materials quarries, and the price of materials was very affordable. However, material transportation cost was exorbitant when materials were required from another location. For example, in 1839, Keatton stone at the quarry near Stanford was at 1 shilling and 9 pence per Ft. Cub. If it were to be delivered the cost would rise to 3 shillings and 4 pence per Ft. Cub (Powell, 2013). Introduction of railways and waterways later reduced transportation costs to a third of what it was in 1839.

Britain witnessed a national economic growth from 1851 to 1914, which generated new buildings in many towns and suburbs on a scale never seen before. There was a change to building procedures and new manufactured goods appeared. Contractors obtained materials from suppliers who acted as a major source of short-term credit for firms on site. Labour cost increased due to lack of skills for the new specialised materials. There was decrease in materials prices with very short rises in 1873, 1900 and 1909. The effect of rising labour costs and lower materials prices was to stabilise building cost. The fall of materials prices was due to increased efficiency and productivity resulting from improved mechanisation and transportation. The market for new materials expanded due to accelerated transport particularly by rail. Coastal and inland water transport were less flexible and slower but still vital. Transport competition was further sharpened by the introduction of road vehicles (Powell, 2013).

The construction industry and associated industries experienced financial boom from 1915 to 1939. They were relatively unaffected by the devastating lost markets which struck other industries. There was increase in labour wages before the war in 1914, which accelerated during the war and reached a peak in 1920. Pre-war labour wage levels were doubled and tripled (Powell, 2013). Labour wages began to be fixed in 1920 on a nation-wide basis. Construction workers received better pay than all workers in other industries, (Ball, 2014). Building cost doubled, total materials cost was equivalent to two-third of the total building cost, and labour cost amounted to one-third. The stock of materials was dominated by the war situation. Most materials were in short supply by the end of the war. These were worsened by

transport problems. Materials prices were cut down by 1922 and nearly all controlled by either producers or trade associations, and thereby, pushing up labour costs sharply (Ball, 2014).

From 1940 to 1973, new buildings demand exceeded capacity to provide them. The government's sudden changes of programmes and planning influenced the construction industry in Britain. The industry was required to work as quickly as possible amid other uncomfortable regulations such as compulsory registration, control of materials, and licensing of work. All the latter regulations had a harmful effect on the industry (Ball, 2014). The result was that many experienced construction workers left the industry, which has pushed contractors to increase labour payments. In general materials prices increased by two-third between 1938 and 1946 and by another two-third between 1946 and 1955. From 1938 and 1955, cost of labour seemed not to have increased more than that of materials. By 1973 a typical project was likely to embody half of the total cost, and materials of less than a half of the total cost (Powell, 2013). The oil embargo made all industries to witness some changing points, and relative stability was replaced by inflation.

Before the seventies, any areas where building cost could have been cut or controlled would have been in both areas of machinery/transport and manpower, since they were expensive. On the other hand, construction materials were very affordable.

Today, it has become vital for the construction industry to have its significant resources under tight control since the cost of materials is half the total cost of building project and labour wages just less than a half of project. The cost of materials has increased and over the past six years, materials cost index, has been increasing at the same pace as wages cost index (Ashworth and Perera, 2015), apart from the period between 1991 and 2005 when the labour wages index pushed up sharply.

For the construction industry, materials management system implementation is worthwhile investigating as an essential element, especially when the following factors were considered:

•   Potential materials shortages

•   Automation and labour reduction

•   World-wide recession

•   IT developments which facilitate data sharing within an organisation

- Increasing world-wide competition in the industry which will tend to force companies to control the most significant element in their costs more effectively.

The construction industry has several stakeholders and efforts should be geared towards integrating, contractors, project owners, contractors, subcontractors, architects, and suppliers in the construction process, through access to information and communication and co-ordination (Pheng and Meng, 2018).

2.3.2 Origin Of Materials Management

The main goal of materials management is the acquisition of materials from the right source at the right price, at the right quality and quantity, at the right time and place. This has occupied the minds of many managers in all industries, and the construction industry is not an exception. The exception that the construction industry is fragmented, slow at introducing new managerial and technological concepts and at accepting change (Green, 2011; Jang, 2007; Safa et al., 2014; Aouad, et al., 2013; Tatari and Skibniewski, 2011)

The materials management idea began with the introduction of a "Materials Management Department" which was to take care of purchasing department of an organisation. Due to the amount of money handled by this department, its performance has always been scrutinised. Before 1900, purchasing was first recognised as an independent function, according to the first book "The handling of railway supplies, their purchase and disposition", published in 1887, in the USA by a railway marshal, M.Kirklman (Monczka et al., 2015; Wilson, 2016). From then until 1st world War, most organisations considered purchasing as a clerical function. During and between 1st and the 2nd World Wars, the success of a company did not depend on the existing demand but on the ability to procure materials to keep the business operating. Purchasing continued to gain more importance after the 2nd world war as it became recognised that (Rao and Krishna, 2009; Chen and Paulraj, 2004):

1. Profit in construction is relative to purchasing.

2. Purchasing functions became more defined

3. The number of competent people in purchasing increased.

Many companies have then elevated the chief purchaser to top management, and materials management became an important issue for increasing productivity and profit. The period from 1970 to date witnessed the 1973 oil embargo, which intensified shortages and price escalation. This situation has led organisations to focus on the capabilities of the buying/purchasing

department also known, in some companies as the materials management department. The manufacturing industry was first to introduce the concept of materials management, in the early sixties (Farmer 1977). The first publications in materials management in the construction industry were made in the early Eighties (Loudoun 1976, Wilson 1976, Chandler 1978, Jonliston 1982, Wyatt 1983). Research in this area, started in the USA when materials management was one of the areas studied in the Business Roundtable Construction Industry Cost Effectiveness Project (CICEP) in spring 1981, with productivity improvement being their chief goal. The result was published in 1983 and indicated that productivity and real cost savings could be acquired through better materials management. The CICEP study went on to say that materials management in engineering and construction industries suffers from neglect, was poorly managed, organised and executed (CII 1991).

2.3.3 Materials Management from Manufacturing To Construction?

In his book, Farmer (Farmer 1989), concluded that the concept of materials management was applied in different ways and that the approach taken was based upon the experiences and perception of the individuals involved.

Marsh, (Marsh 1985) joins Farmer, by arguing that materials management can be applied to any organisation willing to improve its savings, efficiency and productivity through the control of its materials. However, and like all organisational concepts, it needs to be tailored to the specific environment or domain in which it is applied, and the level of its success varies from a company to another. Many authors think that despite the inherent differences between construction and manufacturing industries, it would be beneficial to explore the possibility of transferring productivity concepts from manufacturing to construction (Sanvido and Medeiros 1990, Pheng 1992). Table 2.1 represents the areas of common interest to both industries, suggested by Sanvido and Medeiros (Sanvido and Medeiros 1990).

2.3.4 Need for Management of Materials in a Project

Every organisation faces challenges in relation to managing the flow of materials. Management of materials efficiently is very vital factor to a successful project completion. It is very important that organisation take the subject of control of its materials serious and handle it effectively for projects to be completed successfully. A big part of project's cost is accounted by the materials. The material cost of the project fluctuates during project execution and can range between 20-50%, (if not more), of the total cost of project (Song, 2005; Nasir, 2008). Unavailability of materials for a project can put the project to a hold hence the critical role

materials play in project operations. Furthermore, productivity can also be affected when materials are not available, causing delay and possibly suspension of operations until the required materials become available (Stukhart, 2007).

The challenge to managers is not only the unavailability of materials for the project activities, but excessive quantity of materials can also be a cause for concern to management. The total costs of production can be increased due to material storage. Finding an alternative storage area can also be a challenge if there are limited areas available for material storage. The alternative storage area might require re-packaging of material thus increasing the cost (Willis, 2008; Stukhart, 2007). Once procured materials are receive from the suppliers, the flow of the materials should be given special attention; and adequate provision made for material handling and storage upon receiving them.

It is self-evident that materials need to be acquired at the least possible cost so that organisation will save money for other costs (Nasir, 2008; Swinburne et al., 2010). Most construction companies experienced a decrease in productivity and an increase in costs, in the late 1970's. Managers of these organizations thought that these increments to expense were because of inflation, monetary issues and economic problems. Further consideration concluded that these organizations were not utilizing their assets efficiently and more so that those decrease in productivity might have been additionally attributable with poor administration (Stukhart, 2007). One of the major issues of concern in the construction sector is material management. 40% of lost time during the construction process can be down the unavailability of materials when needed, bad management, poor materials identification and insufficient stockpiling/ storage (Baldwin et al., 2009).

There is compulsory need for an effective material planning system. Udeaja et al. (2013) noted the need for sustainability of material re-use and a green supply chain management system in the construction industry. To secure work for future and to remain competitive, some companies have improved the effectiveness of their activities. Many have resorted to improving undertaken productivity strategies and minimized overheads. Through enhanced management of materials, there is possibility to save costs and make considerable improvement. Accessibility of materials and frameworks systems are fundamental to effective construction. Management of materials functions are often carried out based on fragmentation with less communication and no obvious established duties assigned to the contractor, owner or engineer.

Practices that better management of material might increase effectiveness to operations and decrease general cost. Due to high interest rates, competition, shortage of materials and rising prices of materials, senior management is more attentive to material management. The construction industry is becoming more aware that management of material needs to be addressed as a comprehensively coordinated management activity (Tan et al., 2010).

The associated costs with management of materials are not shown in related activities or added as overhead costs. Stukhart (2007) stated that investigation by the Construction Industry Cost Effectiveness Project (CICEP) reached a conclusion that top management have not recognized the benefit of material management in relation to issues of project cost; that adequate training is not given to staff involved in management of material activities; and that companies' computer systems do not provide good sources of data for materials control.

In the past, more attention has been paid by managers to the costs associated with plant, equipment and personnel, than has been given to materials. There have been related increases to material cost for manufacturing organisations and had become the highest organisational expenditure; hence, more attention given to activities related to material (Lu et al., 2011). Material costs has increased in UK to twice the labour cost between 1980 to 2000 causing organisations to concentrate more on activities related to materials (Kim et al., 2009).

Navon (2006) evaluated and developed automated prototype for control and management of materials purchasing, ordering, supply and utilization. Under real conditions, this model can be evaluated through implementation of a prototype system and subsequent application to ongoing construction projects. The model encompasses purchasing aspects of materials, provides thorough approach, material delivery to site and dispatch of materials for use in the project. The time required for materials management can be reduced by this model, minimize wastage due to manual material ordering; and ensure timely delivery of materials to the site, according to specifications and right quantity.

2.3.5 Management of Materials on Construction Projects

One of the most significant industries in the economy of nations is the construction industry and its success criteria is in terms of time of completion, budget, satisfaction of stakeholders and in accordance with specification (Nguyen et al., 2004). The term, construction, is the process of erecting the project physically and adding construction materials, equipment, supplies, necessary management to achieving the work and supervision (Clough et al., 2015). Projects involved in construction are complex; and engages many firms such as owners/ clients,

engineers, architects, vendors, suppliers and contractors. This process is often complex and heterogeneous; involving producing large/ small, unique and immovable products. This also involves resources supply such as material, equipment, money, and labour).

The management of materials in construction projects is an essential factor that contributes significantly to project success. Management of materials gets more difficult as projects become large scale and complex, requiring oftentimes the use of appropriate techniques and tools to enable timely delivery of materials, minimise wastage of material, well management of stock levels, and non-compromise of construction schedule, amongst other things. Management of material is notably problematic for projects that are complex and large, where there is need for sophisticated techniques and tools. Adequate consideration is needed in the materials' management in construction projects that are complex due to the varying involved elements in construction and how vital the projects are. In addition, appropriate Information and Communication Technologies (ICT) needs to be implemented, such that new management processes could be facilitated for complex projects. For instance, the potential of wireless technologies, tagging technologies and other emerging technologies may have an enormous impact on future management of material processes.

Project performance could be hampered severely by improper management and handling of materials on construction sites (Darren, 2017). During construction process, the consequence of improper management and handling of materials on site will affect the total cost, quality and time of a project (Kasim et al., 2012). Depending on the type of construction, the price of materials can vary from 30 to 80 percent of the total construction costs (Nasir, 2008). Nonetheless, Song (2005), suggested that 50-60% of the total construction projects cost is for construction materials. Stukhart (2007) stated that materials constitute a major component with value of 50%-60% on any project. Hence, the need to manage materials efficiently in construction projects because when materials are managed poorly, it will have an effect the overall quality, time and budget for the construction. Consequently, an effective management of material system is necessary so as to avoid such problems as construction project delay.

One of the major causes of time overrun in projects has been found to be delays in supply of materials (Kasim, 2011). There are many factors that cause project duration delay, but poor management of materials can have a dominant effect on site activities. Darren (2017) is of the idea that the key reasons for construction project delays in the UK were changes to design, materials' management problems, planning problems, construction materials shortage, and

ineffectiveness of site workers. Kasim (2011) also opined that the main cause of overrun in project duration were delays in supply of materials. Thus, major cause of delays in construction projects can be caused by materials delays. Integration of material handling process is also necessary from the design stage to materials usage stage. This could be enabled, with ICT implementation in materials management and a good management system. Thus, proper materials handling can enable a good management of materials on construction sites.

2.3.6 Processes in Materials Management

The processes involved in construction projects' materials management include planning, handling, procurement, stock and waste control, and other material logistics. A good environment for management of materials facilitates proper handling of materials on construction location. The following processes will be discussed to better understand management of materials: procurement, planning, handling, logistics, waste control and stock.

2.3.6.1 Planning

Planning process of construction practice entails knowledge of what must be built, and establishment of the right method, that meets the client's requirements in the most economical way (Chudley and Greeno, 2016). For certain work tasks, a detailed scheme is required to achieve its objectives. Appropriate planning is required in the case of materials and should be carried out concurrently with construction engineering and other plans of the project (Stukhart, 2007). Stukhart (2007) also remarked that planning of material will proffer guides in all other resulting activities and may greatly impact the project plan. Process of planning of materials covers each part of different plants' set up and records maintenance, such that target delivery frequency and inventory levels can be determined (Payne et al., 2005). Consequently, the flow of materials at the site can be enhanced through efficient management of the materials record to eliminate such problems as run out of stock of materials and non-delivery of materials.

Within a construction site, access and routing of materials planning has crucial undertone for the development of strategy for effective management of materials particularly in profit and productivity increase, and facilitating the timely construction projects completion (Kerzner, 2013). Stukhart (2007) also remarked that planning of material will proffer guides in all other resulting activities and can impact the project plan greatly. The process of planning of materials covers each part of different plants' set up and records maintenance, such that target delivery frequency and inventory levels can be determined (Payne et al., 2005). The need for efficient planning of materials is, to enhance organisations' profit and productivity, and enable the

construction projects' completion (Wong and Norman, 2010). Therefore, proper planning of required site materials can minimise the activity times and facilitate the elimination of project delays, resulting in quality services.

2.3.6.2 Procurement

According to Barrie and Paulson (2013), procurement is a term that entails a varying array of activities such as purchasing of materials, equipment, services and labour, needed for project implementation and construction. The purpose of procurement in materials management is to make quality materials available at the appropriate place and time, and appropriate budget. According to Payne et al. (2005), they noted that the main objective of procurement is to organise the purchase of material, and issue schedules of delivery and follow-up to suppliers, ensuring timely deliveries by suppliers. According to Fewings (2012), a breakdown in the purchasing process or in organising and overseeing the buying functions could have the following result:

- Materials wastage problems due to over-ordering;

- Inadequate administration procedures due to materials' over-payments;

- Deficiency in skilled negotiating procedures/ benefits loss; and

- Dearth of knowledge on where and when the best service may be accessible at any time).

To prevent such issue, it is vital to understand how the general procedure in purchasing takes place, as shown in Figure 2.1. Material procurement procedure begins with definition of the project requirements, followed by choice of sub-contractors or suppliers and ends with the transmission of materials to destination (Kent and Becerik-Gerber, 2010). Main challenges of many construction firms are purchasing of materials from quality source, timely delivery and at the best price. Hence, procurement of material needs a control strategy such that targeted objectives will be achieved. A properly authorised requisitioning procedure must be initiated in all requests for purchases and quotations. It is the duty of the project manager to control the procedure and must make sure the standard requirement, quality and timeliness were followed in the purchasing of materials.
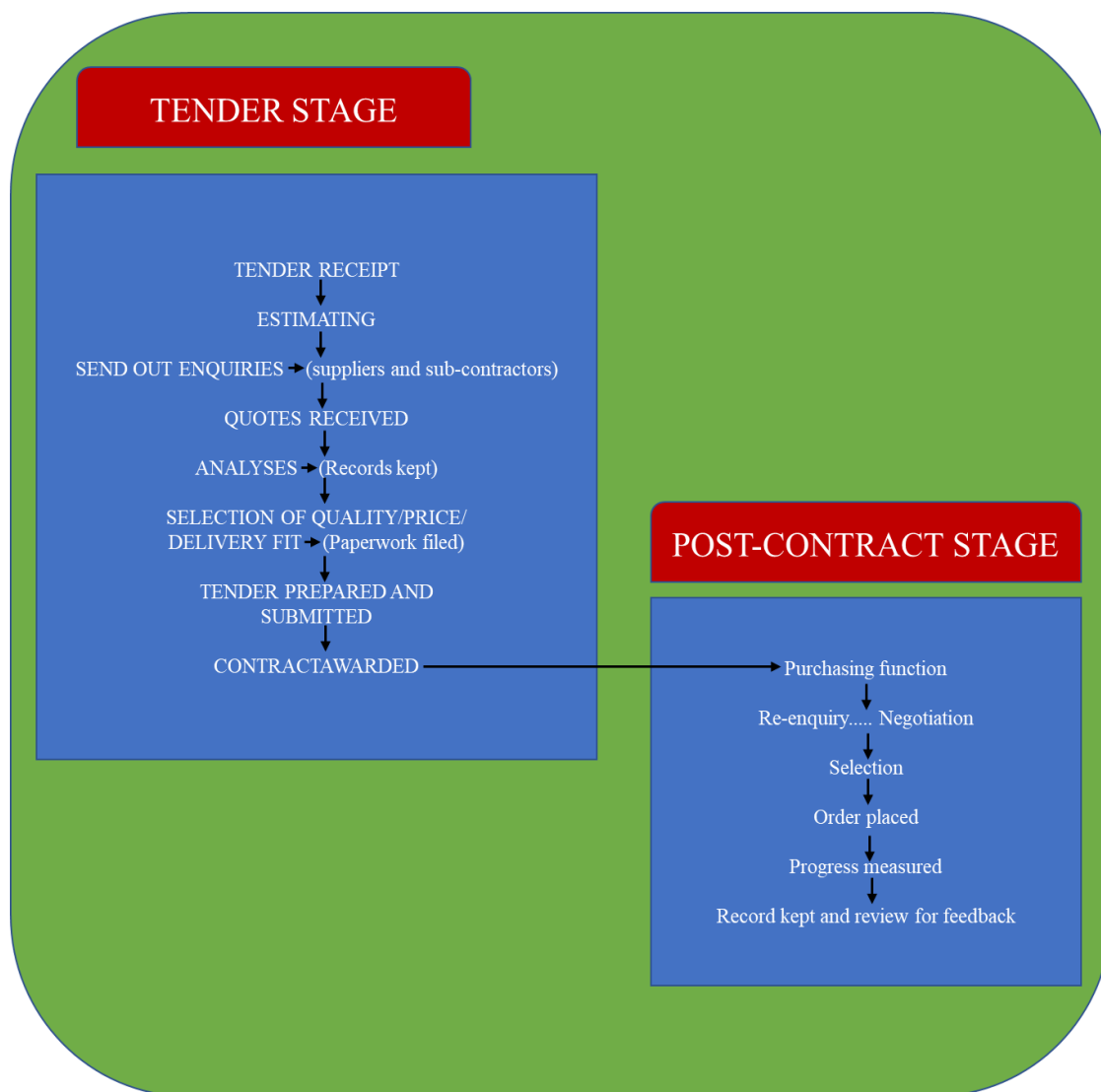
Figure 2.1: Typical Purchasing Procedure (source: Schaufelberger and Holm, 2017)

2.3.6.3   Handling

Tompkins et al., (2010) stated that effective handling of material involves using the appropriate method to provide the materials in the right amount, sequence, time, condition, position and cost. This entails controlling, handling and storing the materials in construction projects. Hence, handling of materials enables movement to establish appropriate location for materials and designing the system through a systematic approach. Material handling is the flow component that ensures placement and movement of the materials. The feature of appropriate material handling is viewed as being expensive and involves critical decisions making. In designing a system for handling of materials, quality considerations are taken due to the frequency of material handling. An important function of material handling is the selection of

the material handling equipment as it may provide effective manpower utilisation, enhance the processes involved in production, improve flexibility of the system and production increase (Temiz and Calis, 2017).

For handling of materials to be appropriately managed, it is necessary that critical quality decisions are made, and adequate fund set aside. The range of material handling estimated costs is from 10-80% (Hampton et al., 2012) from the total costs of construction projects depending on the facility type (Tompkins et al., 2010). The designing of materials handling systems involves making certain quality considerations of the percentage amounts allocated to material handling. An important function of material handling is the selection of the material handling equipment as it may provide effective manpower utilisation, enhance the processes involved in production, improve flexibility of the system and production increase (Temiz and Calis, 2017). Also, handling of materials engages material scheduling as an essential part on site, which has such benefits as (Kasim et al., 2012):

- gives the amount in each operation involved;

- important to distribution of materials on the site; and

- demonstrates a good way of analysing quantities needed by sub-contractors, among others.

Handling ensures that materials must be delivered to site without damage and any wastage. Most general problems linked to materials supply which attribute to high proportion of wastage is inadequate handling and unloading facilities, (Fewings, 2012). Hence, to foster significant improvement to total system productivity and reduce the percentage of materials wastage, handling needs to be done with safety when materials are moved at the site.

2.3.6.4 Logistics

The concept of logistics emphasises movement to meet customer's requirements through implementation, planning, storage and flow control from raw materials to the final production of all goods (Stukhart, 2007). Varied, heavy and bulky raw materials are normally used in construction and proper handling is required during the supply process. Therefore, the active movement of materials is required in construction industry in both the factory and the worksite from the suppliers down to the production area (Furuta et al., 2015).

In construction projects, the basic target of the concepts of logistics is to enhance communication and coordination between movements at the stages of design and phases of

construction, especially in the process of flow control of materials (Thunberg, 2016). Other material control flow problems that can arise include materials wastage during handling, storage, and transporting when enormous quantities are procured on site without compliance with the production needs; and delays in supply of materials due to early purchase of materials before they are needed. Furthermore, Sullivan et al. (2010) suggested that the time and cost of a construction project can be affected most during the routing of materials. Hence, for effective management of materials during logistics process, the following factors should be taken into consideration:

- forecasting of materials movement; and

- routing and access of material should be properly planned within a construction site.

2.3.7 Stock and Waste Control

Total Productivity Management report by the European Construction Institute (ECI, 2014) stated that delivery of materials to the project site is a vital, related-productivity aspect, that needs careful development of quality system for early monitoring and control. The bulk of the construction materials delivery needs adequate stock control management. The technique used for stock control ensures that all items such as raw materials, assembly components, processed materials, general stores, consumables stores, spares and other materials for maintenance, work in progress; and to ensure availability of finished products when required (Murray and Akhtar, 2016).

Enormous amount of waste can be generated during construction activities and waste from materials in the construction industry has been established as a major problem (Murray and Akhtar, 2016; Udeaja et al, 2013). They also said that in the USA, construction materials waste, contributes approximately 29% of waste, more than 50% contribution in the UK and about 20-30% contribution in Australia. This is because of various constructions materials being used during the process of construction. The cause of construction projects wastage shows that wastage can emanate at any stage of the processes involved in construction from beginning of projects, through the design, operation and construction of the project (Chapman et al., 2016). Hence, through appropriate consideration in proper material reuse and need for minimisation, waste can be reduced in both the stages of design and phases involved in the construction projects (Fewings, 2012; Robinson and Udeaja, 2015; Swinburne et al., 2010; Tan et al., 2010).

To avoid waste, damage of materials and any other loss, close attention is needed for material storage on site, such that operations are not affected on the construction project. During

materials supply, such problems often emanate due to inappropriate storage and protection facilities (Fewings, 2012). Studies carried out on construction site have identified that materials normally need a large appropriate space for storage, which is seldom available on site (Thunberg, 2016). Nonetheless, Stukhart (2007) suggested few considerations that need to be considered during planning for the storage space such as experience, historical information and timing during the initial stage. Management of materials on site should help to reduce profit loss due to wastage, damage theft and run out of stock. Hence, the need to take into consideration the need for storing space from the start of the construction process stage.

2.3.8 Problems/ Challenges of Materials Management

Many factors contribute to bad management of materials in construction projects. According to Nasir (2008), transport difficulties, waste, excessive paperwork, improper handling of materials on site, misuse of the specification, inappropriate delivery of materials and lack of proper work plan, all affect management of materials adversely. In the construction sites, delay in managing materials can cause materials shortage (Abdul-Rahman et al., 2006). Also, late delivery of materials ordered is an issue in the management of materials. In addition, Kasim, (2011) noted that the familiar challenges relating to management of materials include:

- Incurring more inventory cost and tendency for quality of material to deteriorate when materials are received before they are required;

- There is loss in productivity when materials are not received on time;

- Untimely commencement of projects from design documents and drawings;

- Subsequent changes to design;

- Loss/damage of items;

- Choosing contract type for individual materials procurement;

- Criteria for supplier evaluation;

- Stacking up and controlling of inventory; and

- Surplus materials management

The construction process in the traditional construction methods apply paper-based work. This results in having enormous paperwork and aiding poor management of materials in construction projects (Nasir, 2008). This may be inefficient, prone to error and problematic in

the information exchange and recording of components of materials in a supply chain. The implementation of Information and Communication Technologies (ICT) can aid the construction activities management to be more effective and quicker. The conventional methods could be transformed, and materials management improved through the advent of Information and Communication Technologies (ICT) systems. The application of ICT has also been boosted by new construction industry related software being developed, which can support effective materials management practices. Hence, ICT-enabled solution could overcome the problems of material management. For instance, enhancing materials supply management using intelligent systems to facilitate requesting, ordering and bidding of materials.

2.4 General Characteristics of Construction and Production

To start with, this segment overhauls the general qualities of production as far as its strategies, processes, systems, competing priorities and order points of penetration. At the point of examining together all the general characteristics of production, such qualities make a critical scope of potential outcomes to be chosen by an organization for dealing with its activities. Secondly, the main construction aspects in light of the above-named production characteristics are surveyed. This section will review the general aspects of construction such as construction project-based nature, the dispersed site locations, projects that are concurrent and multiple in nature and the project scheme uniqueness.

2.4.1 Characteristics of Production

The following streams are used to examine production: production strategies, production processes, systems, competing priorities and order points of penetration.

2.4.1.1 Production Processes

There is an idea that various production processes are derived from the communications between product features and processes (Primus and Stavrulaki, 2017). Hence, the production processes are controlled by the inborn attributes of the items they produce and their process necessities. The production volume, the product mix, the degree of customization, the arrangement of tasks to be done, the nature of the streams, the level of work repetitiveness, among others, are the main perspectives to be viewed as when product-process features are coordinated (Primus and Stavrulaki, 2017).

The process choices in the product-process matrix are shown in Figure 2.2 (Krajewski et al., 2007). This product-process matrix is characterized by five key process choices which link the

process with the manufactured products and they include: small batch process, large batch process, line process, Job process and Continuous flow process. Selection of the process choices can be for a single sub-process with a plant or for the entire plant (Krajewski et al., 2007).
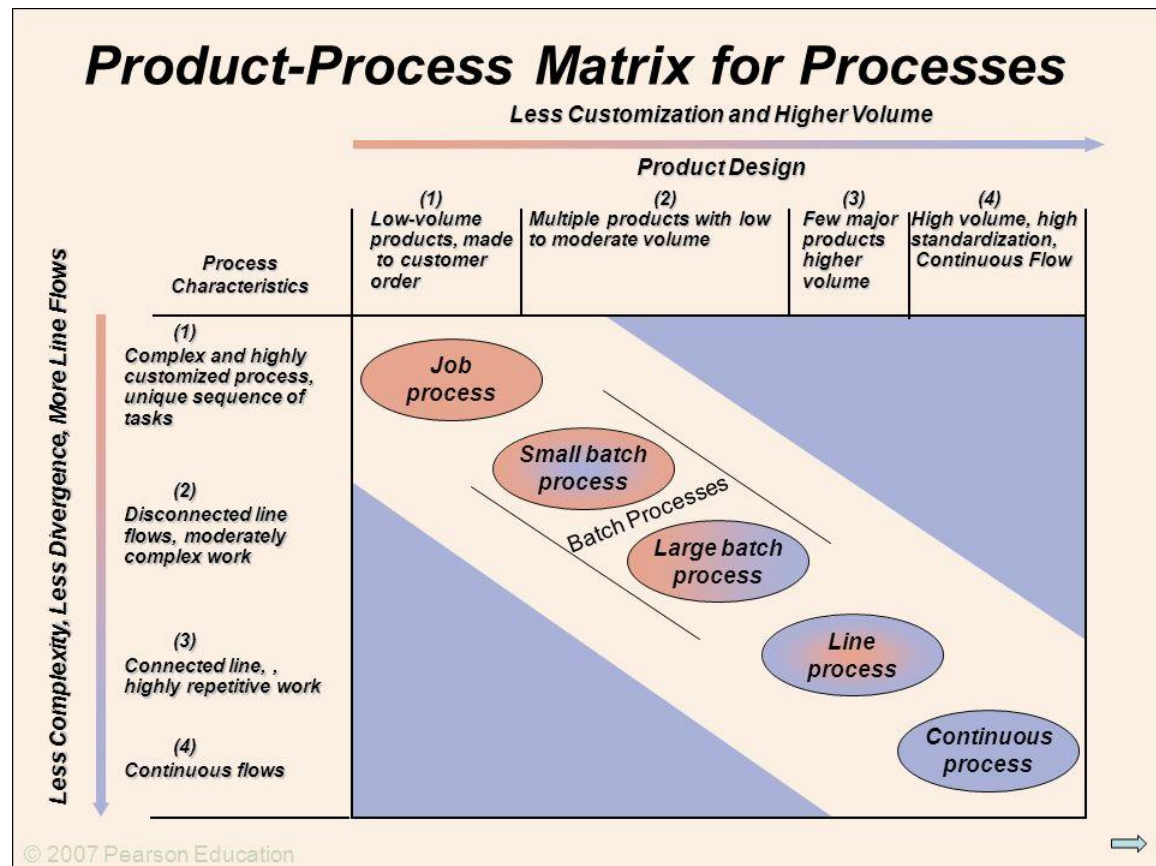
Figure 2.2: Product-Process matrix for processes (Krajewski et al. 2007)

The list below are the five key process choices:

a) **Continuous flow process**: In the product-process matrix, the continuous flow process can be found at boundaries of the matrix. This methodology for production deals with items with high volume and a product market position in most cases (Primus and Stavrulaki, 2017). Additionally, the process is defined by a continuous and sealed flow (Krajewski et al., 2007). This production process is appropriate industries that deals in chemical substance, for example, plastic, oil and gas.

b) **Line process:** This process takes the approach of traditional manufacturing. Such a methodology is identified with items with a high volume of demand. The high volume of demand necessitates that the production process is associated with standardized works, linked flow and are repetitive (Primus and Stavrulaki, 2017). There are a variety

29

of industries that apply this methodology for production and they include electronic appliances industries, shoe manufacturing industries and computer and technology industries, among others.

c) **Large batch process**: In the product-process matrix, the large batch process is can be found at the mid-point position (Krajewski et al., 2007). The large batch process is suitable for products having a moderate to a high volume of production demand (Primus and Stavrulaki, 2017). Also, this process is associated with both repetitive and complex works and both connected and disconnected lines. Heavy industries such as cement, mining and steel, adopt this product process choice.

d) **Small batch process**: This process is suitable for the manufacturing of a large variety of products and targets the production of low to moderate volumes of products. Hence, the small-batch process can be utilized as an approach in product manufacturing to produce components and parts that can be assembled later by means of the job process. The components and parts manufactured in this process show a low repetitive pattern, yet they can as well be utilized in various items made inside a similar plant or company. Kemppainen et al. (2008) link a batch with discrete assembling capacity and flow lines that are disconnected. Krajewski et al. (2007) express that typically a batch of one item is handled at each time: in scheduling, production is switched to the products to be manufactured next; sometimes, a batch of the main item is produced once more. According to Ariss and Zhang (2002), they noted that some batch processes utilize various systems to manufacture standardized items in moderate volumes, even customization of the products en-masse. Despite the low to moderate production ranges, the inconstancy inside production is too high to even think about dedicating a unique zone in the production floor to every item (Krajewski et al., 2007). Application of the small batch process is generally in the heavy equipment and aircraft industries and joined with the job process.

e) **Job process:** According to Slack et al. 2007), this process is also known as a project-based process. The job process targets manufacturing of a variety of items in huge amounts and considers the high intricacy of works and dissimilarity in the stages all through the production process. Across the different processes in production, Kemppainen et al. (2008) contend that the intensity of labour varies: more operators are required in the job process for each machines manufacturing floor. Job process,

according to Johansson and Olhager (2006), is differentiated based on the nature of flow: within the product-process matrix, the job process shows the lowest level of flow orientation. Krajewski et al. (2007) describe the job process a production approach that assigns resources to itself. Also, Krajewski et al. (2007) noted the job process key competitive priority is to attain full operation through flexibility. Despite the variability nature of the job process, implementation of the line process can be done with it because of comparative requests from clients. Shipbuilding and construction industries apply the job process in production. The project-based process will be discussed more in section 2.4.2.1 because it relates closely to the construction industry.

2.4.1.2   Production Strategies

As stated above under processes, there is an idea that various production processes are derived from the communications between product features and processes. Nonetheless, every one of the production processes requires a particular strategy to be appropriately utilized. Over the last 30 years, there have been various operations management pieces of literature investigated on the different production strategies and these are Engineer-to-Order, Make-to-Stock, Make-to-order and Assemble-to-Order (Primus and Stavrulaki, 2017; Olhager, 2003; Johansson and Olhager, 2006).

The quality of the product that will be manufactured determines the choice of production strategy to be applied (Arora et al., 2016). To determine the position of production strategy to be implemented, the following need to be evaluated; the degree of product customization, the degree of supplier involvement, volume of production, types of the production process (Choi and Linton, 2011), and patterns of demand (Slack et al., 2007).

Despite the simplicity of the production strategy concepts, it took many years for its concepts to be widely understood and developed by companies (Calleja et al., 2018). In their investigation, Calleja et al. (2018) compared various manufacturers based on their average inventory days, analysed the findings based on production strategies and mapped their general stages of production from suppliers to customers.

The following are the various production strategies:

a) **Engineer-to-order**: In this production strategy, customer's specific orders, technical requirements and specific designs are followed in the fabrication of the specific products. In other words, this strategy is usually applied in where there is high customisation of the specific product and its production process is typically project-

based (Gosling et al., 2013a; Gosling and Naim, 2009). Primus and Stavrulaki (2017) recommended project-based processes should be chosen for products that are highly customised and with low volumes. Examples of industries that apply the engineer-to-order production strategy include the construction sector (Hicks et al., 2001; Gosling et al., 2013a), industries that produce capital equipment for material handling, offshore and power (Hicks et al., 2000), etc.

b) **Make-to-stock:** This production strategy involves the manufacture of the products before customers make demands for them (Slack et al., 2007). The strategy is useful to produce standardised products which are driven by demand forecast and are manufactured in high volumes (Krajewski et al., 2007). Ordinarily, the qualities of these standardised products are similar for Line or Continuous processes as described by Primus and Stavrulaki (2017). Examples of products that produced using the make-to-stock production strategy include soft drinks, chemicals, garden tools and electronic components, etc (Krajewski et al., 2007).

c) **Make-to-order:** In this production strategy, the customer's specific orders and specifications are followed in the manufacture of the specific products (Slack et al., 2007). This strategy is usually followed when low volume of production is required and the final product requires a high level of customisation. This strategy is appropriate for small-batch and Job processes (Primus and Stavrulaki, 2017). This strategy also requires a high level of flexibility all through the production process (Krajewski et al., 2007). Examples of products that apply the make-to-order production strategy in their production include castings, medical equipment, etc (Krajewski et al., 2007).

d) **Assemble-to-order:** This strategy involves the manufacture of a wide of products after an order from the customer has been received (Krajewski et al., 2007). This production strategy is suitable for the manufacture of products that combines pre-assembled and standardised parts. The production of such parts can be done using batch and line processes, as portrayed by Primus and Stavrulaki (2017): various batches can be done in preparation of the customer's order request, and when such customer request is made, the batches can be combined to manufacture the requested product. Due to the nature of this production, the postponement approach is adopted in the assemble-to-order production strategy (Krajewski et al., 2007). The assemble-to-order production strategy

is applied in the manufacture of the following products: computers, prefabricated furniture and paints, etc (Krajewski et al., 2007).

2.4.1.3   Order Penetration Point

The idea of Order Penetration Point (OPP) has emerged from mapping various stages in a production system from suppliers to producers (which has been termed the supply chain). According to Olhager (2003), the stages are typically design, procurement and fabrication, final assembly, and shipment. Calleja et al. (2018) have examined the OPP as far as its implications in logistics (operational perspectives/ coordinations) and its effects on the general production strategy of an organization. Saeed et al. (2016) later connected the idea of the OPP with an approach in manufacturing, in which they termed the point as Customer Order Point (COP). As noted by Saeed et al. (2016), the COP is the point in the production process wherein the product is allocated to specific customer order. The COP likewise has a solid link with customization: it is the point wherein the customers' ideas are considered during the production process. In this unique situation, Saeed et al. (2016) have additionally displayed a noteworthy contribution garnered from the COP: the requirement for various approaches in production to upstream and downstream the Customer Order Point.

Olhager (2003) introduced the immediate connection between various production activities, production strategies and the positioning of the decoupling point as depicted in Figure 2.3. OPP positioning deals with the aspect of demand that generates the supply chain consequences. In another perspective, Olhager (2003) expressed that production downstream for the OPP is driven by genuine demand, which implies that a genuine order has been placed. On the other hand, production upstream for the OPP depends on demand projection. Conversely, the positioning of the OPP influences the supply chain, hence, the production approaches used by the supplier should be adapted to cope with the requirements of the customers.

According to Olhager (2003), the positioning of the OPP is influenced by factors/ variables that are categorized into three, based on production, market and product. These are:

a) **Market-related variables:** these are attributed to customer order frequency and size, highly seasonal demand, product demand volatility, product customization and range, delivery lead-times requirements and product volume (Olhager, 2003). A wide range of different implications is generated by such market-related factors among the production strategies. Make-to-stock production strategy gives no customization for products having short lead times and aims to produce products based on demand

predictions (Primus and Stavrulaki, 2017). On the other hand, engineered-to-order products will attend to specific requirements of the customer from the design stage and aims to produce products based on real demand (Primus and Stavrulaki, 2017).

b) **Product-related variables:** These are listed as the structure of products, material profile, design of the modular product and customization opportunities (Olhager, 2003). The modular design represents an important factor in the proper implementation of the assemble-to-order production strategy (Olhager, 2003) and has been closely linked with products mass customisation (da Silveira et al., 2001; Yang and Burns, 2003). According to Olhager (2003), the product structure and the material profile have been linked with various number of products assembled from raw material components and fabricated parts/ sub-assembly.

c) **Production-related variables:** These are listed as production process flexibility, number of planning points, production lead time (i.e. elapsed time), bottleneck position, resources having sequence-dependent set-up times (Olhager, 2003). In terms of production, research developments have been enhanced using the OPP for management of not only the production and handling of materials in the supply chain but also site production. Past research (Naim and Gosling, 2011; Mason-Jones et al., 2000) demonstrates that various approaches in the supply chain have to be embraced in the downstream and upstream of the OPP.

2.4.1.4 Competitive Priorities

Piller et al. (2015) are of the view that the relationship between corporate operations and strategy (such as the manufacturing function) is crucial and it implies more than high proficiency and low expenses. It is a complex task driving cross-functional effort between various areas of the organisation to make customer-driven production strategy operational. Slack et al. (2007) noted the need (particularly in operations), for objectives that specifically relate to meeting customer's requirement to be defined. In this regard, competitive priorities (i.e. performance objectives) forms the main operational dimensions that must be included in a process to match both internal and external needs of the customer (Krajewski et al., 2007). Past research has explored the roots, the importance, the implications and the applicabilities of such needs in the organizations (Thatte et al., 2018; Piller et al., 2015; Krajewski et al., 2007; Slack et al., 2007; Vachon et al., 2009).

The number of the previously-mentioned objectives or needs differs in literature. Also, how they are composed or sub-divided additionally contrasts both in practice and in the literature. Again, these needs likewise differ within an organisation, given that some of these priorities/ needs may be crucial for a fixed process (Krajewski et al., 2007). Slack et al. (2007) recommended five essential objectives that apply to all operation types. In some business conditions, extra objectives may be included to comply with specific needs.

The following are the five essential objectives:

a) **Quality:** is profoundly related in conformity to expectations of the customer (Slack et al., 2007). Thatte et al. (2018) investigated quality in eight-dimensional structures namely serviceability, features, performance, conformance, reliability, perceived quality and durability. Conformance tends to be the main conventional perspective embraced in production for quality. However, Thatte et al. (2018) pointed out that other dimensions also represent a possibility of improving competitiveness. Krajewski et al. (2007) in their view, showed quality to be of two sub-dimensions; consistent quality and top quality. Top quality entails providing much-improved customer services and superior product features (Krajewski et al., 2007). Krajewski et al. (2007) stated that consistent quality entails producing products that consistently match specifications, and this is accomplished by intense monitoring and process design.

b) **Speed:** This shows the lead time/ elapsed time between the customer's order for an item and the item's actual delivery time (Slack et al., 2007). Delivery speed is crucial for business and reducing lead time can enhance the delivery speed (Krajewski et al., 2007; Thatte et al., 2018). Also, inventories and operations risks can be reduced through improved speed (Slack et al., 2007).

c) **Dependability:** This entails delivering the customer's requirements in time (Slack et al. 2007). Nonetheless, the level of service should be consistent and standardized to improve predictability. Competitiveness for the company, in this context, can be boosted by reliability in delivery (Thatte et al., 2018). According to Slack et al. (2007), dependability may be valued more than other competitive priorities because of its importance for planning purposes. Furthermore, Slack et al. (2007) mapped out three implications of increased dependability namely process stabilization, time compression and cost decrease.

d) **Flexibility:** This is an indication of what level and how change can be made to an operation (Slack et al., 2007). Thatte et al. (2018) noted that previous literature for flexibility shows seven different dimensions to it namely; modification, volume, product mix, changeover, sequencing and rerouting of material. Krajewski et al. (2007) indicated that flexibility needs to be proficient and quick such that it aligns with customer's needs. Nonetheless, there may be some implications to such changes to how the operation is carried out, what the operation does and when the operation will carry it out (Slack et al., 2007). At least one of the various types of flexibility is needed in typical processes: delivery flexibility (Slack et al., 2007), volume, customization and variety (Krajewski et al., 2007; Slack et al., 2007).

e) **Cost:** This is an organisation's main objective, particularly the companies that operate in cost-driven markets (Slack et al. 2007). Customers are satisfied when products are at the minimum possible cost using low-cost operation (Krajewski et al. 2007). Profit margins for organisations with non-resilient cost structure can also be affected by external changes such as price reduction pressures. Furthermore, there are other cost-related factors to costs namely inventories, capacity utilization and productivity, etc (Thatte et al., 2018).

2.4.2 Characteristics of Construction

The following streams are used in the analysis of construction; multiple and concurrent projects, project-based construction system, uniqueness of scheme and dispersed site location.

2.4.2.1 Project-based construction System

Management of the construction infrastructure sector is carried out on a project basis. According to Koskela and Vrijhoef (2001), they described construction in three characteristics namely temporary project production, one-of-a-kind production and site production. Gosling and Naim (2009) noted that non-repetitive and temporary projects typically come with challenges to production modularization and standardization. Koskela and Vrijhoef (2001) argued that there is an insufficient level of communication in project-based construction process particularly due to the nature of its developments. The autonomy level within an organisation will influence the choice of project-based production processes (Vrijhoef and Koskela, 2000).

Furthermore, the influence of the project managers can be increased when there is a high level of autonomy in a project organisation (Koskela and Vrijhoef, 2001; Formoso, 2012). According

to Darling and Whitty (2016), a project can be said to be an organisational unit devoted to achieving a particular objective by putting cost, time and quality viewpoints into consideration. Darling and Whitty (2016) also noted that for a given project, management of project needs to relate performance and control to autonomous management. Site production is represented by a fixed position layout and is a condition of the specific project-based systems (Koskela and Vrijhoef, 2001). Joshi et al. (2003) stated that various researchers perceive the existence of particular managerial levels in operations management and construction.

2.4.2.2 Multiple and Concurrent Projects

As noted previously, the nature of construction firms is to engage in multiple projects. It is the duty of the project managers to autonomously manage such projects. Nonetheless, construction companies are also synonymous with handling projects concurrently as much as having multiple projects and these come with many implications. According to Remington et al. (2009), various implications they are encountered in managing projects that are running concurrently can be grouped into five different categories, namely:

a) **Capacity:** Remington et al. (2009) identified this in terms of conflicts in the management approach used, resource provisions and the controls utilized. In addition, Archer and Ghasemzadeh (2004) relate the management of multiple projects to being complex, especially when resources are generally scarce. Subsequently, the principal challenge in overseeing concurrent projects is to balance the company's resources to their various demands. According to Remington et al. (2009), it is exceptionally uncommon to balance the availability of resources (such as heavy types of machinery and cranes) and their demands.

b) **Complexity:** Remington et al. (2009) relate complexities to the interfaces between the projects and the organization and different concerned parties for the projects. The complexity in the management of concurrent projects is increased with the existence of multiples interfaces. Remington et al. (2009) recommend the creation of central capacity planner such that these complex scenarios can be managed. This will also enable optimisation of resource usage, activity development and to accommodate changes as they occur. According to Abdullah and Vicridge (2000), management of multiple projects is not an easy task and using traditional methods (such as network method or one-line) are not as effective as they ought to be.

c) **Conflict:** This classification includes three kinds of issues: organisational, people and system issues (Remington et al., 2009). These issues can exhibit behaviours that are unexpected and varied, causing the multi-project environment to produce unstable relationships. Furthermore, Serrador and Turner (2015) were of the view that the ability to achieve the goals of the project is hampered by these conflicts. According to Darling and Whitty (2016), it is difficult to manage human resources in a project environment because projects are temporary in nature and insist that it is difficult to oversee, and current projects will come to an end when people have interest in future assignments.

d) **Commitment:** This category is people's way of committing to individual projects and consequently to various coordinated projects when providing resources or working on projects (Remington et al., 2009). In most cases, there is a variance to the degree of commitment from one project to the next. According to Serrador and Turner (2015), one of the main issues affecting the success of a project is the lack of commitment.

e) **Context:** This is the setting (that is procedures, culture) of projects as noted by Remington et al. (2009) or associated issues identified with organisation, people or the systems. Serrador and Turner, 2015 pointed out the context of a project is another factor that impacts on the success of a determined project.

2.4.2.3 Dispersed Site Locations

Grimsey and Lewis (2002) highlighted that recognising infrastructure is simpler to recognise than define, and it is chiefly expressed in terms of these main areas: social development, water, energy, telecommunication and transport. Once infrastructure projects cover wider communities and areas, it influences daily life. Souza and Koskela (2014) stated that infrastructure projects are dispersed generally over areas and in some cases in remote areas.

The need for converging logistics is the characteristic implications of the construction site and remote areas. Li (2015) stated that logistics is concerned with the management of flows from one point to another, irrespective of industry. According to Vrijhoef and Koskela (2000), converging logistics demand that all materials' direction is to the construction site. From a control perspective, Li (2015) noted that the materials' flow begins from various supply units, and merge into a common point (i.e., in the construction site) in the supply chain. Moreover, the manufacture of special materials and parts is dependent on the customer's order, containing specifications that are unique to the project (Li, 2015).

The flow of materials is usually difficult to organise and coordinate to various dispersed projects, especially when they are located miles apart from one another. Kovács and Paganelli (2003) were of the view that the logistics flows are influenced by evolving market conditions and new production methodologies (such as agile/ lean manufacturing). Such influence can be in need to supply materials using just-in-time technique and reduction of inventories, regardless of the project location. Most times, these goals are difficult to accomplish in locations that are remote and dispersed.

2.4.2.4   Uniqueness of Schemes

Construction projects have characteristics that are unique. According to Eastman et al. (2011), they noted that complex infrastructure projects are constructed according to engineer-to-order (ETO) production strategy and require customised parts. Eastman et al. (2011) listed such components/parts as reinforced concrete tilt-up panels; precast concrete structures; timber roof trusses; mechanical, electrical and plumbing (MEP) systems; structural steel; architectural façades; and curtain walls of various types. In this unique circumstance, construction supply chains can be seen as having materials that are specialised and standardised.

Hicks et al. (2000) are of the view that engineer-to-order (ETO) firms normally engage in capital projects' design, production and construction. Such companies also consider projects capabilities and design as a necessary competitive advantage. In addition, such companies exhibit several levels in their production structure and customization and production features. General basic processes that form part of ETO companies are as follows:

a) **Design:** The design deals with product conceptualisation, specifications/ requirements description, simulation of performance and operation, and definition of characteristics of designs that will enable subsequent processes (Krajewski et al. 2007).

b) **Project management:** The project management process deals with policies definition, guidelines and management structure that will enable the project to be delivered in accordance with the project design. Some constraints that must be considered include cost quality, human resources, time etc. (Krajewski et al. 2007).

c) **Manufacturing:** This procedure is centred around the product's production, in accordance with its characteristics. The job and small batch process are the most common production processes in a typical engineer-to-order (ETO) production strategy (Krajewski et al. 2007).

d) **Assembly:** In this process according to Krajewski et al. (2007), modules to be used in the process of construction and commissioning are prefabricated and pre-assembled. Da Silveira et al. (2001) added that the effectiveness of this process and true input to the overall ETO production strategy performance is determined by its design process (da Silveira et al. 2001).

e) **Construction and commissioning:** The construction and commissioning are generally performed at the site where the product will remain. The construction process relates to assembling prefabricated modules as indicated by project specifications. The commissioning process relates to modifying and testing the equipment such that products are delivered to pre-defined quality, capacity and efficiency (Krajewski et al. 2007).

Table 2.1 summarises the general characteristics of construction in the infrastructure sector.

Table 2.1: General characteristics of construction in the infrastructure sector. (Adapted from: Krajewski et al. 2007)

Characteristics of Construction	Salient Points
Project-based production system	- Temporary mind-set - Autonomous units of production - The role of project managers - Fixed-position layout - Two managerial levels - Converging logistics
Multiple and concurrent projects	- Limited capacity - Increased complexity - Amplified level of conflict - Poor commitment - Particular context - Limited benchmarking - Limited exploitation of synergies
Dispersed site locations	- Common needs of communities everywhere (i.e. energy, water, transport) - Remote locations - Site construction - Complex logistics
Uniqueness of schemes	- Highly customized - Specific materials and components - Highly specialized sub-contractors

2.4.3 Site logistics activities

Carrying out the site logistics activities which impact on the flow of materials to the site is a mutual duty between head office and on-site management (Johnston, 2016). The choice of suppliers, requesting of materials and payment of records for materials in big organizations is generally performed by head office. Every one of the activities from when the materials are delivered to final addition into the site is left to the management on the site. Management on the site likewise purchases, requisitions, expedites and identifies every one of those materials

not acquired by head office (Slack et al., 2010). The different on-site management logistics activities include material expediting, reception, handling, warehousing and materials surplus disposal (Figure 2.3).
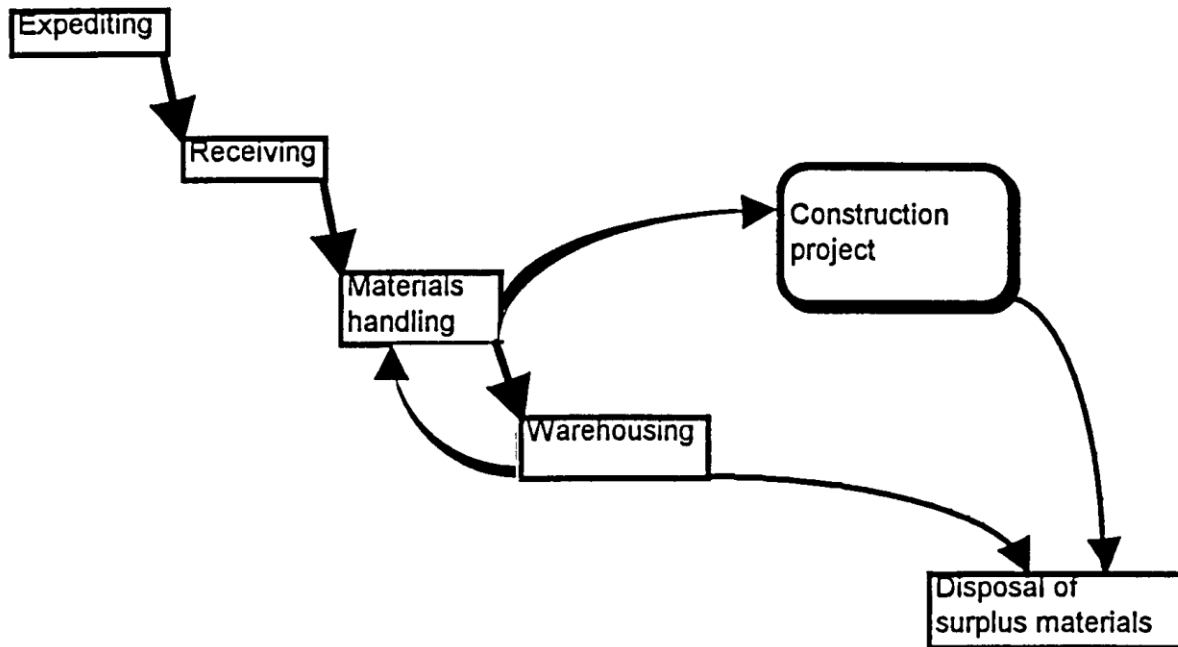
Figure 2.3: Site logistics management activities

2.4.3.1   Material Expediting

Speeding up is a continuous control method for guaranteeing that materials and equipment are provided as per the procurement contract and to avert material schedule disruption. Expediting can be categorised into proactive, status reporting and reactive expediting (Construction industry Institute, 2010).

Proactive expediting is more costly than the other two however is increasingly more efficient. It starts before the order is requested and continues through the life-cycle manufacture of the products ordered. It might be utilized for costly or for the products that are urgent or both (such as sensitive programme products that are delicate, as well as changes in the program that may expect things to be delivered sooner than planned (Pheng et al., 2018).

Status reporting can be possible either by communicating in writing or by telephone. It serves the purpose of gathering information of the ordered items and to guarantee that suppliers meet the delivery dates.

In reactive expediting, the buyer follows up at the supplier's facilities. It is more expensive but more effective than status reporting.

2.4.3.2 Deliveries and accepting of materials

Before the arrival of materials on-site, materials delivery needs to be coordinated with the arrangement for receiving materials and storage plans. The schedule and strategy material delivery are normally agreed between the supplier and contractor (Johnston, 2016).

Some of the materials may be delivered on-site in pallets, crates, bags or in bulk. The materials that are ordinarily received in bulk are bituminous paving materials, hard-core, pulverised ash, aggregates, cement and concrete (Johnston, 2016). Window and door components, screws, nails, screws will be delivered in crates or boxes.

If the site access is poor, there may be conflict between supplier and site management on the designated off-loading point (Johnston, 2016).

2.4.3.3 Receiving

Accepting of materials denotes the moment that the control of materials starts on-site. Getting ready for accepting materials starts before the contractor goes into an agreement with a supplier (Slack et al., 2010). Accepting courses of action during arrangement incorporate thought of data that ought to go on identification tags, for example, purchase order number and materials description. Receiving plans should address coordination and communication issues with suppliers and transporters and ought to have set up methods for offloading, inspection and managing accounts payable (Slack et al., 2010). Measures for guaranteeing the security of received materials ought to likewise be set up.

The site receiving report records confirms receipt of products, orders received, damage, shortages or excess deliveries that have been delivered on-site (Pheng et al., 2018). Packing slips can as well record shortages, damage and excess deliveries. Pheng et al. (2018) underlined two points at the receiving stage:

- pre-establishment of responsibility of quality on the site. Assessors must carry out this job reliably and proficiently; and

- suppliers must be expeditiously informed all things considered. Shipments ought not to be returned until suppliers have been advised.

2.4.3.3.1 Quality control at receiving

Received materials and equipment are typically inspected and site management ought to liaise with control personnel (i.e., site quality assurance) in carrying out this activity (Slack et al., 2010). Arrangement is made with supplier for products that do not comply with a purchase order or specifications, so they can be returned, taken care of or for parts and administration support. When arranging receiving activities and coordination with quality assurance, reports for all material also need to be done.

Quality Assurance is an inbuilt procedure starting from product design, through production to installation which guarantees that the customer's quality norms are strictly considered. Quality Assurance requires that just as achieving the necessary quality standards, the procedures utilized in accomplishing those standards be documented. Quality Assurance is conformed to by guaranteeing that supplied materials are followed by Quality Assurance Certificates. The general pattern for suppliers' quality assurance is accreditation and implementation to ISO 9000 whose main target is a complete quality improvement (Pheng et al., 2018).

At the point when materials arrive on the site, their products numbers are contrasted with the purchase order numbers. The transaction information is then entered either on a receiving report or straightforwardly into a database and also made available to the accounting department (Pheng et al., 2018). On the off chance that the materials are acknowledged, it ought to have been known heretofore what materials handling equipment should be utilized and the on-site location to which the materials will be moved. The products labels should show quantity and type of materials, which information can easily be accessed. Standardized identifications systems like bar codes and RFID are a good method for distinguishing items and tracking them down.

Aside from quality, different other purposes behind inspecting receiving products are to guarantee that: they are the products that have been ordered; the correct quantity is received and to ensure that received items are not damaged (Arnold et al., 2011). After examination, the things are either held anticipating further activity from the purchasing department if there are issues to be settled or they are sent to where they are quickly required or to stock if the request has been acknowledged. The receiving report is then sent to the procurement department. Quality control staff will likewise instruct procurement department on the status regarding the items if the quality of the item has been inspected. When the supplier's receipt for products is received by the purchasing department, it will be contrasted with the receiving report and

purchase order and each of the three records ought to agree. The accounting department is advised to pay the supplier if the purchasing department approves payment for the products received otherwise other courses of action or instructions are pursued.

2.4.3.4 Off-loading

Unloading of materials from the delivery vehicles consists of three methods: mechanical handling, tipping and manual handling (Johnston, 2016).

Tipping method of unloading materials is normally done using trucks that have elevated sides. Examples of delivery materials that can be tipped include excavated materials, aggregates and hard-core materials. Tipping materials where they are to be utilized is the most straightforward and likely the least expensive approach to off-load. Some materials will damage if they are unloaded by tipping and therefore require other off-loading methods, such as mechanical or manual handling.

Other site operations may be disrupted when manual handling is involved, and the method is rendered impractical especially when the materials to be off-loaded are large. The use of mechanical handling method in unloading is gradually eliminating and replacing manual handling method. Examples of mechanical handling method are the use of external/ lorry mounted equipment, forklifts, cherry picker, trolley, etc. (Johnston, 2016).

2.4.3.5 On-site Materials Handling

On-site handling of materials can be characterized into three groups: cranes and hoists; mechanical trucks; and conveyors (Arnold et al., 2011). Conveyors can be utilised to move things at an angle or on a horizontal/ level plane, or vertically between two spatially fixed focuses. Mechanical trucks are for moving things gently along a slope or moving things on a horizontal level. Mechanical trucks are more flexible and more usually utilized than conveyors (Arnold et al., 2011). Hoists and cranes move things vertically and are more adaptable within their radius of operation than both mechanical trucks and conveyors.

In construction supply logistics, the job of equipment is to move materials to the workforce or to the storage. Langford et al. (2014) defined the job of equipment management as a system that brings to the construction project venture a plan that can allow construction work to continue according to programme and to enable the site workforce in a proper way.

2.4.3.6 Inventory management

The role of overseeing materials management on the site incorporates all activities of planning, management and implementation toward guaranteeing that there is no material shortage. To mitigate against uncertainty in material deliveries, inventory is kept on-site.

In the construction business, the target of inventory management is to meet the production rate in a manner that is cost-effective. Pheng et al. (2018) are of the opinion that construction industries are keener on guaranteeing that materials are accessible to meet construction plans, but few companies exercise inventory control. Inventory management includes inventory cost control, tracking what items are in stock, and physical theft protection and against harm from the components. Inventory management is yet an issue on construction site (Pheng et al., 2018). To minimise inventory costs, the obligation regarding re-stocking might be put on suppliers (Pheng et al., 2018). It can also be useful to ensure automation of materials records on both small and large construction projects. The use of computer storage and cloud system have broadly turned out to be the most common techniques for staying up with the latest records of the status and materials location and to estimate deficiencies on most big construction projects (Slack et al., 2010).

2.4.3.7 Warehousing and materials issuing

The goal of warehousing is to limit cost and optimise customer service (Arnold et al., 2011). Efficiency in warehousing:

- attains timely customer service;

- expedites tracking of material efficiency;

- reduces the cost and absolute physical exertion of moving materials; and

- ensures communication links are established with customers.

According to Pheng et al. (2018), the material identification codes will still be useful for storage, materials issuing and for installation plans, even after the materials have been delivered, accepted and accounted for. Issuing and controlling of materials from the inventory and storage location can be improved using their identification labels.

2.4.3.8 Issue of materials

To be successful, the technique for issuing materials ought to be basic yet very well defined. Measures which can accomplish a successful level of responsibility in issuing materials are (Construction industry Institute, 2010):

- issuing just to staff approved to take out materials;

- using straightforward well-structured warehouse structures which ought to be totally filled in by the individual requesting the material;

- daily updating of inventory information by entering them into the system each time an issue is made; and

- utilising an automated system at every possible opportunity

2.4.3.9 Surplus materials

At every project conclusion, each project will unavoidably have some surplus materials. The Construction Industry Institute (2010) evaluated that surplus materials can lie between the limits of 0.1 to 10 percent of the total cost of materials for the project and it credited the causes of material surplus to:

- changes in design made after materials have been procured;

- planning inadequacies;

- poor management of materials strategies and computing systems; and

- poor control procedures for material on the site.

Good site materials management is the best technique for controlling the material surplus. At the point when a material surplus occurs, it is remedied by:

- utilizing the materials somewhere else within the project;

- taking the materials to a different project; keeping parts as spares for future replacement;

- returning materials surplus back to the suppliers;

- or selling the surplus to reduce project cost.

The Construction industry Institute (2010) noted that the site's capacity to control surplus is firmly connected to controls which counteract duplicate buys, overbuying because of improper inventory system and warehousing, and distinguishing materials thought to be required yet not really required when constructed.

2.5 TECHNOLOGIES IN MATERIALS MANAGEMENT

The global transfer of information can be made much faster than the traditional methods in the construction industry through the development of ICT. Perera et al. (2017) said that information and communication technology (ICT) are programs and electronic machines (including software and computers), and other devices such as the telephone, the telefax and the photocopying machine for information processing, transfer, storage and presentation. Paper documents has traditionally dominated delivery of information such as specifications and drawings.

There has been a rapid growth of information and communication technology (ICT) in other areas of industry (for example publications, manufacturing and advertisement) to aid expansion of their global business operations. Through emerging technologies in the construction industry, information and communication technology (ICT) development has been improved to support any type of activities in construction. Griffith and Stephenson (2016) stated that construction organisations that invest fund in advancement of technology for ICT create great opportunities for themselves. They may also expand usage of ICT through provision of better connectivity and powerful computer in construction activities (Sun and Howard, 2004). There could be improvement in material management and development through new information technologies in construction industry (Robinson and Udeaja, 2015).

2.5.1 Current Technologies

An efficient and effective materials control on site can be facilitated through implementation of information and communication technology (ICT) in material inventory managements. In materials management, common ICT usage is in the process of cost estimation using software, such as Lotus 1-2-3 and MS Excel (Perera et al., 2017; Sun and Howard, 2004). Various use of internet for electronic commerce and electronic mail (e-mail) includes electronic payments, invoicing and materials process receipts (Perera et al., 2017). In ordering and quotation activities, improvement of productivity can be done through activities change by contractors and suppliers from conventional to more innovative or sophisticated techniques and tools. Consequently, there is spectrum for increased utilisation of computer-based systems in

improving management of materials on construction sites (Ojiako, 2012). Examples of applications developed by many researchers for this purpose include the following:

- Expert System Advisor for Concrete Placing (ESCAPE)- which aids in planning and controlling concrete-placing operations without assistance of experienced personnel in charge (Malisch and Brown, 2017);

- Building Information Modelling (BIM): A digital information repository which helps to ease the management of information in a project.

- Robotics: which involve combination of science, engineering and technology to produces machines, called robots, which replicates or substitutes human actions

- Industry 4.0: this describes the growing trend towards automation and data exchange in technology and processes within the manufacturing industry;

- Enterprise Resource Planning (ERP): system which "collects, records, integrates, manages, and delivers data and information across all functional units of the enterprise;

- Pen-Based Computer - in automation of construction field-data collection (El-Omari and Moselhi, 2009);

- Construction Materials Planning System (CMPS) - applied in planning for the use of construction materials to attain the right materials in terms of meeting the work programs in time and quantities (Valero et al., 2015);

- Construction Materials Exchange (COME) - for improving effectiveness and efficiency of materials procurement process in construction (Perera et al., 2017);

- Internet-based Electronic Product Catalogue (IEPC) – which helps in providing information on product such as product category and other related information to the product by searching or browsing online (Guo J. 2009);

- Virtual Construction Material Router (VCMR) - for supporting planners and site managers during complex construction on the site and to enable decision support system for material movement (Mahjoubi and Yang, 2001);

- Material Handling Equipment Selection Advisor (MHESA) – used for selection of material handling equipment (Rao, 2007);

- Bar-code system – for material storage management (Chen and Li, 2007);

- Geographical Information System (GIS) and E-Commerce - for trading materials in construction (Jadid and Idrees, 2013); and

- Radio Frequency Identification (RFID) - To automate the task of materials management for real-time collection of data in construction using advanced, automated and data storage technologies for the collection, identification, transmission, storage, and information presentation using RFID technology (Sardroud, 2014)

In recent times, it has become more pertinent to make more use of computer-based systems to enhance management of materials in construction sites (Ojiako, 2012). The construction materials planning system (CMPS) is one example of the tools utilised in managing construction materials. CMPS is a computer-aided system for planning which integrates the management and scheduling of construction materials to provide the required materials at the right quantities and time such that the demand for scheduled activities in construction can be met (Valero et al., 2015). Another developmental tool utilised in managing construction materials is an intelligent system for selection of material handling equipment called MHESA (Rao, 2007). It is important to have these types of tools due to complex and tedious tasks involved in most construction, and to support engineers in the selection of cost-effective material that are appropriate for handling equipment.

The process of the construction activities has been aided by recent developmental tools like Information Technology in Construction (ITC) and computer software and they are widely in use. in construction. Examples of such developmental tools for construction activities include: Bar codes used for managing on site materials and for purpose of maintaining inventory records; and wide use of the internet for electronic commerce (like materials processes payments and receipts, and electronic invoicing) and electronic mail (e-mail) (Chen and Li, 2007). Other examples include the process of materials cost estimation, the successful and wide use of spreadsheets software like Lotus 1-2-3 and Microsoft Excel, that offer project managers and contractors with a convenient and a powerful tool for presentation and analyses (Sun and Howard, 2004).

The construction industry has experienced an increase in the use of ICT and has seen the development of new software relating the effective inventory management of construction activities (Ojiako, 2012). Cooke and Williams (2009) noted various advanced information and telecommunication systems opportunities that construction firms can invest in. An initial assessment of the techniques and tools that are in use in the management of materials has

suggested that, despite current advances in the information and communication technology construction development, most of them are not well developed and many in limited commercial use. Hence, there is need for more sophisticated solutions to be utilised in the future such as wireless communication and tagging technologies like radio frequency identification (RFID) and bar-coding. Other industrial sectors like retail, manufacturing, logistics and transportation have successfully applied these technologies to enhance sector activities. There also exist same potential successful application of same technologies in construction practices (BRE, 2010). The use of RFID technology will enable future construction site manager to carry out activities with construction materials all tagged and properly managed in the construction site (Sardroud, 2014). The use of an RFID reader for example, can help track the correct delivery of materials by a lorry to the required construction site and check for any missing components. Prins and Owen (2010) suggested the use of cyber agents together with electronic tags at the entrance of the construction sites to check varying materials deliveries.

2.5.1.1   Advantages of Current Technologies in Construction

An efficient and effective controlling process for materials activities can be created on construction site through the implementation of information and communication technology (ICT) in material inventory managements. To achieve productivity, proper management and handling of several types and sizes of construction materials. It is not practical in the today's construction business to use the traditional practices of paper documentation in managing on-site activities. More electronic business (e-business) and computer-based material handling activities should be implemented by contractors using internet at construction site. Contractors and suppliers could improve productivity in ordering and quotation activities changing from the conventional practices to more innovative or sophisticated techniques and tools in their construction activities. The use of conventional communications by paper documents between the suppliers and main contractors can be changed to electronic form in their business activities (Nawi et al., 2014).

Construction Software (2014) listed various software, which can provide support for on-site construction activities for materials management. Such are listed as follows:

- Construction Materials Management System (CMMS) – provide a link for delivery, procurement, reporting and warehousing to critical functions in construction, accounting, engineering and vendors;

- Material Quality Management System (QMS) – a system used for management of all material management process phases;

- BARRICADE software - records transactions, saves time, manages inventory, creates reports, generates invoices, improves cash flow and integrates with other accounting systems.

- Best Estimate – is an estimator that is pure, fast and simple, used by general modeller and renovator contractors;

- BidWorx – this a software for use in bid summary, benchmarking, materials and detailed time;

- Builders Software – this is generally a contracting business software on money, the people, materials and time;

- COMMANDconcrete – this is applied in financial management and batching system integration;

- Estimate Builder – this is used for accurate and quick estimation of materials and labour this is the primary reason for the creation of Estimate Builder;

- GoTakeoff – this enables complete listing of material in standard construction, within a matter of minutes;

Management of materials gets more complicated with large-scale projects due to the variety and vast amount of construction materials needed; hence, management of materials requires efficiency and effectiveness. A bar-code application system for construction waste reduction construction can proffer instant and updated information on quantities of materials swapped between the storage manager and the construction team leader (Chen and Li, 2007). Radio Frequency Identification (RFID) has the potential to enable management of materials processes in complex construction projects, especially in terms of its capability to facilitate the storage of a vast amount of data when compared to bar-codes (Sardroud, 2014). For instance, RFID makes materials identification possible in construction projects such that prominent level of confusion is reduced in delivery of materials from suppliers, and other needed locations at the construction site (Prins and Owen, 2010).

The potential implementation of RFID has been undertaken on many research projects that facilitates processes in materials management. Radio Frequency Identification (RFID)

conceptual design system for construction was used to track materials, vehicles delivering materials, materials handling equipment, and also to track vehicles delivering concrete to jobsites (Karmakar, 2010). The idea of using RFID technology to track delivery vehicles for quality control, has been applied by Karmakar (2010) for mixed asphalt plant. There has been proposal for use of RFID technology in tracking precast concrete pieces and information storage through the use of supply chain (Sardroud, 2014).

2.5.2 Current Technological Challenges in Construction

Other business areas such as advertisements, publications, manufacturing, has experienced rapid growth in the use of ICT (BRE, 2010). New ICT software relating to construction industry needs has been developed to support construction activities and effective management of construction projects. Nawi et al. (2014), noted countless opportunities for which construction organisations can invest in advances in information system technologies and other advancements in telecommunications. Hence, there are many benefits for further technological development on advances already developed such that more affordable, sophisticated and more reliable software can be created. On the other hands, a strong technology push can be enabled for wider use of IT in construction through the development of more powerful computers and better connectivity (Nawi, 2014).

A report by Building Research Establishment (BRE, 2010) noted that current ICT implementation in management of materials processes is not well developed and commercialised. The use of IT applications in the construction industry are now prevalent for enabling procurement knowledge management and collaboration. For instance, electronic payment, direct and indirect purchasing, and material aggregation are featured in product procurement systems. This has helped in paperwork elimination, reduced product and operational costs and reduction in cycle times. Notwithstanding, there is need for more sophisticated solutions to enable effective management of materials in the future and more efficient use of tagging technologies and wireless communications like RFID (Li et al., 2010). Therefore, this can enable the construction firms to have the opportunities to choose the required technology that will improve their material inventory managements practices.

2.6 AUTOMATIC IDENTIFICATION TECHNOLOGIES

In material inventory managements, there is tremendous potential for automatic identification technologies and these potentials are reviewed here.

2.6.1 Introduction

Automatic identification (Auto-ID) epitomizes a wide range of technologies that aid machines and other devices in identification of humans, objects or animals (Sardroud, 2014). Without human intervention or entry of data, these technologies can identify items, automatically capture data, identify data and gather data. According to the Nawari (2018), the utilization of auto-ID technologies is to minimise the amount of labour and time required for manually inputting data and to enhance accuracy of data. Hunter (2010) argues that Auto-ID technologies help to offer facilities in various manufacturing companies, service industries, materials flow systems, and purchasing and distribution logistics industry. The techniques used in auto-ID are many and they include: Biometric Systems (Voice Identification, Fingerprint Procedures), Barcode Systems, Active RFID, Passive RFID, Optical Character Recognition (OCR) and Smart Cards. A schematic diagram of some of the important automatic identification systems are shown in Figure 2.4:
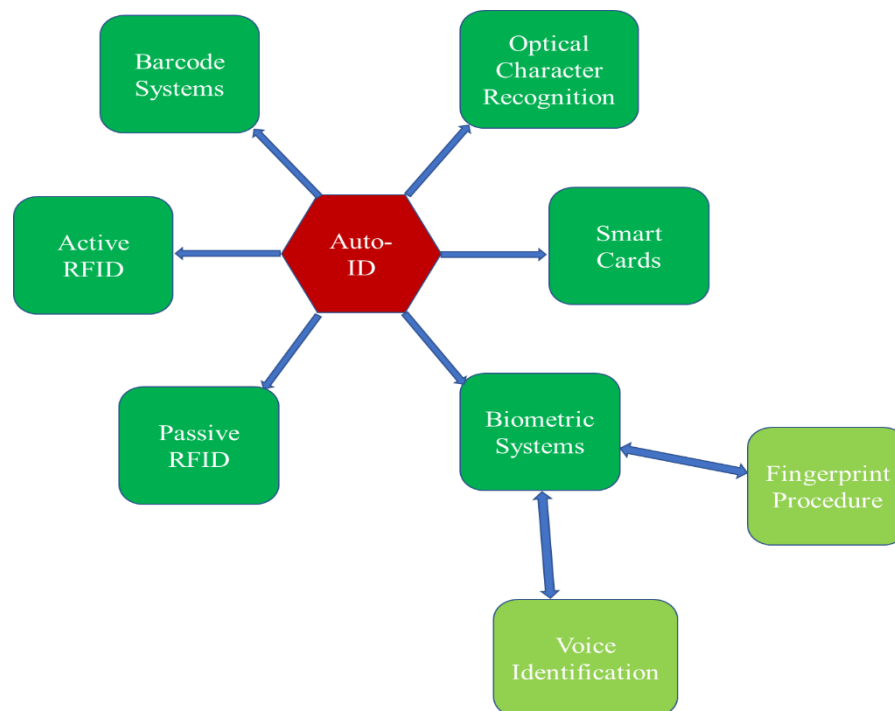
Figure 2.4: Automatic Identification (Auto-ID) Technologies (adapted from Wyld, 2006)

Bar-coding systems and several auto-ID technologies usually need the aid of a person to manually tag or scan a label to capture the data. Unlike bar-coding, RFID is designed to allow the capture data by readers on tags and data captured are transmitted to a computer system without the aid of any person involved. The comparison of these various auto-ID technologies is shown in Table 2.2, but further discussion on bar-coding and RFID technologies will be done in the subsequent sub-sections.

Table 2.2: The comparison of merits and demerits of different Auto-ID Systems (Finkenzeller, 2010)

System parameters	Barcode	OCR	Voice recognition	Biometric system	Smart card	RFID systems
Typical data quantity (bytes)	1-100	1-100	-	-	16-64k	16-64k
Data density	Low	Low	High	High	Very high	Very high
Machine readability	Good	Good	Expensive	Expensive	Good	Good
Readability by people	Limited	Simple	Simple	Difficult	Impossible	Impossible
Influence of dirt/damp	Very high	Very high	-	-	Possible (contacts)	No influence
Influence of (opt.) covering	Total failure	Total failure	-	Possible	-	No influence
Influence of direction and position	Low	Low	-	-	Unidirectional	No influence
Degradation/wear	Limited	Limited	-	-	Contact	No influence
Purchase cost/reading electronics	Very low	Medium	Very high	Very high	Low	Medium
Operating costs (e.g. printer)	Low	Low	None	None	Medium (contact)	None
Unauthorised copying/ modification	Slight	Slight	Possible (audio tape)	Impossible	Impossible	Impossible
Reading speed (including handling of data carrier)	Low ~4s	Low ~3s	Very low >5s	Very low >5-10s	Low ~4s	Very fast ~0.5s
Maximum distance between data carrier and reader	0-50 cm	<1 cm Scanner	0-50 cm	Direct contact	Direct contact	0-5m, microwave

2.6.2 **Bar-coding**

One of the instruments that is widely employed and well established for tracking and identifying products across most industries and around the world is bar-coding technologies. They are more frequently utilized than any of the other auto-ID technologies. The application of bar-coding in the construction industry, has been introduced since 1987 for management of materials, plant, tool control and plants (Chen et al., 2012). Construction material management effectiveness can be facilitated by the implementation of the bar-coding technologies. The use of bar-coding technologies enables an instantaneous and up-to-date details of materials quantities exchanged between the supervisors and inventory managers. The bar-coding technologies can also provide the functions below:

- On the site tracking of construction materials data in real-time;

- Automatic recording of historical data of construction materials used in the project;

- Automatic monitoring of materials utilized by the work teams; and

- Automatic transfer of real-time materials data to head office through Internet and/or Intranet.

Finkenzeller (2010) noted that bar-coding system is a form of binary code made up of field of gaps and bars (narrow and wide) configured in parallel arrangement which can be construed alphanumerically and numerically (Figure 2.5). These barcoding systems are usually printed on products or goods (paper and hard metals) and can be affected by harsh environments effects and rough handling (Wyld, 2006). The components of the bar-coding system include bar-coding labels, printer and laser scanner. The Universal Product Code (UPC) is used to code the bar-coding labels which are then printed on paper. The grocery industry generally applies the Universal Product Code (UPC) in systematic coding of products and this has become the most universally-used product identification standard. Other coding systems used in product identification include the Japanese Article Numbering (OAN) system and the European Article Numbering (EAN) system (EI-Omari and Moselhi, 2011).

Information coded on the bar-coding label can be read with the aid of a laser scanner. Such device for laser scanner can include wand (or pen) scanners, hand-held scanners, fixed position scanners (which is a reader used for product identification during the manufacturing process), table- (or wall-) mounted scanners (for under or beside passage of the barcode), and Personal Digital Assistant (PDA) scanner with an in-built bar-coding reader. The last component of the bar-coding systems is the printer, which is used to print the bar-coding labels. Practically, the bar-coding labels are scanned with the laser scanner (that is applied to products, equipment or materials) and data is gathered and put into computer systems for processing. Nonetheless, the bar-coding label can be stored in containers for bulk materials (such as gravels) which need to be uniquely identifiable. For labour control, each worker is given an identification card that details personal information and project specification.
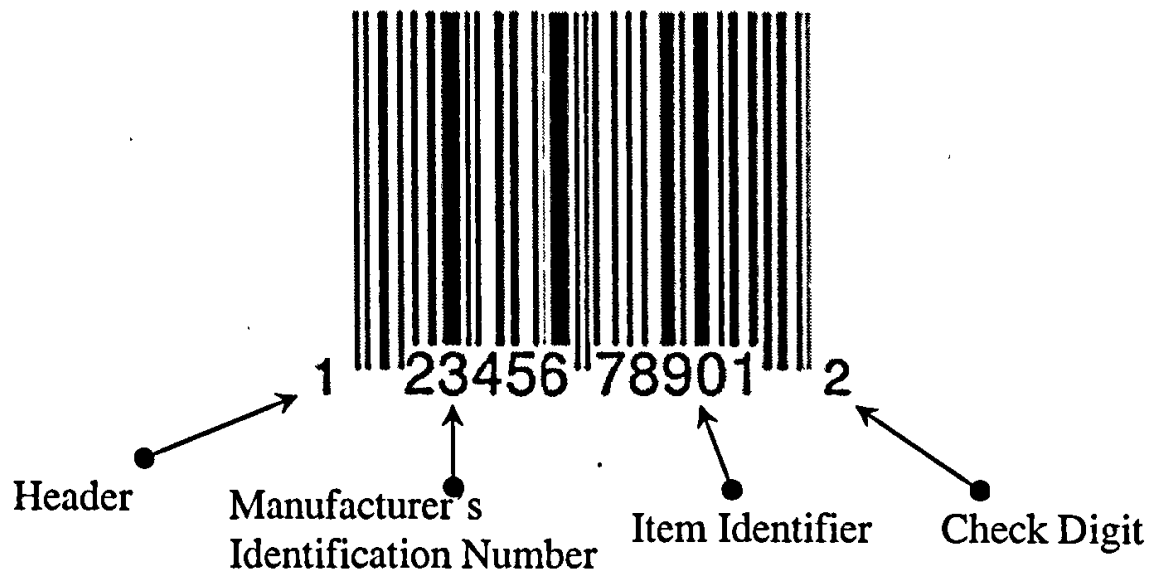
Figure 2.5: The anatomy of a Bar-code (source: Wyld, 2006)

2.6.3 Radio Frequency Identification

Another category of the auto identification technology is the Radio Frequency Identification (RFID). According to Hunt et al. (2007) pg.1, "*RFID is an acronym for radio frequency identification, which is a wireless communication technology that is used to uniquely identify tagged objects or people.*" RFID system is used to wirelessly transmit the identity of a person or an object with the aid of radio waves. Radio Frequency Identification (RFID) can be said to be a technology data carrier that can enable exchange of data between a host and the carrier in an information management system (Finkenzeller, 2010). The two main components of Radio Frequency Identification systems are the reader (that includes an antenna) and the tags (or transponders). These readers and tags combine to provide a non-contact solution to the user and to identify items and the locations in a unique manner. Some of the uses according to Hunt et al. (2007) include;

- The Department of Defence (DoD), Grocery supermarkets and suppliers uses it in their pallet tracking and supply chain crate applications

- In access control systems like the ones used in employee identification devices and keyless entry.

- It is used in point-of-sale applications (example is Speedpass used by ExxonMobil).

- In automatic toll collection systems such as devices placed at the entrances to turnpikes, bridges and tunnels.

- In devices used for animal tracking, such as the ones being used in management of livestock systems and pets.

- In vehicle immobilizers and tracking.

- Security ankle and wrist bands, and bands for infant identification.

The first use of RFID technology was for aircraft identification during the World War Il (Logistic Magazine, 2005). Caron et al. (2006) noted that Radio Frequency Identification systems are applied in tracking of luggage through airports, goods in warehouses, and vehicle's location. RFID implementation has been utilised effectively over the years in agriculture, manufacturing, retail, transportation, consumer products, and other sectors. It can offer enhanced services over the bar-code technology for tracking of materials in the construction industry (Wood and Alvarez, 2005). Radio Frequency Identification tags can be automatically scanned simultaneously, unlike bar-coding which scan tags individually; and must be manually separated and located before it can scan. According to Valero et al. (2015) RFID has the potential to identify and track equipment and products without line-of sight or contact in real-time. They offer higher degree of security because of the uniqueness of each tag which is difficult to duplicate. The read rate of RFID tags is about 99.9 percent (unlike the bar-code with 80 percent read rate). This is due to their ability to be read through almost all materials and manual data entry elimination.

The main differences between RFID and bar-code technology according to Moselhi and EI-Omari (2006) are given below: (the comparison is summarised in Table 2.3)

- The RFID has the capabilities to scan items much faster than bar-code and fewer labour hours are incurred it doesn't need items to be brought to too close to read its tag like the bar-code. This would save considerable amount of cost and time in the construction industry.

- The harsh conditions of construction sites can easily damage the bar-code tags unlike the RFID tags, which can overcome such conditions. This is big disadvantage in the use of bar-coding in construction sites.

- For large projects that involve the need for thousands of labels, consideration is made on the cost of the labels especially for RFID. Company may consider saving cost by using bar-code labels as they are much cheaper. Hence, RFID may not replace bar-code use entirely.

- Information stored in RFID tags can easily be changed unlike the bar-code tags. RFID systems enable such change (like working hours and location stored on a worker's ID), to be made when necessary.

Table 2.3: Comparison between Bar-code and Radio Frequency Identification (RFID) (source: Wyld, 2006)

Bar-code	RFID
Bar codes require line of sight to be read	RFID tags can be read or updated without line of sight
Bar codes can only be read individually	Multiple RFID tags can be read simultaneously
Bar codes cannot be read if they become dirty or damaged	RFID tags are able to cope with harsh and dirty environment
Bar codes must be visible to be logged	RFID tags are ultra thin and can be printed on a label, and they can be read even when concealed within an item
Bar codes can only identify the type of item	RFID tags can identify a specific item
Bar code information cannot be updated	Electronic information can be overwritten repeatedly on RFID tags
Bar codes must be manually tracked for item identification, making human error an issue	RFID tags can be automatically tracked, eliminating human error

2.7 WIRELESS TECHNOLOGIES

Broadly, wireless is a term that refers to any type of electronic or electrical operation that is achieved without the use of a physical wired connection (Alshammary, 2016). Examples of these wireless technologies include wireless networking, which does not require electrical conductors or physical wires to transfer information over a distance; others are cellular telephones; and personal digital assistants. Real time information (such as design, project resources and planning) can be provided in the construction site through implementation of wireless networks among management, staffs on site and other remote project participants. Mobile devices can be provided by management and to be located at various locations within the construction site, to enable communication among staffs as well as with the project site offices (Wood and Alvarez, 2005).

On construction sites, providing personnel with mobile devices linked with wireless systems will aid in the realisation of the wireless networks. Expansion of most prominent available mobile devices such as Personal Digital Assistants (PDAs), notebook PCs, tablets PCs and

mobile phones (see Figure 2.6) can be linked with Global Positioning System (GPS), RFID readers and cameras (Wood and Alvarez, 2005). The PDA can retrieve phone number and addresses, provide storage for the user, maintain a calendar, and create notes and to-do lists. Sophisticated PDAs can also run a spreadsheet, word processing, internet access and email. Both the desktop computer and the tablet PC has a similar operating system, however, the later utilises an electronic pen for input while the former uses keyboard.

Figure 2.6: Examples of' Mobile Devices (source: Wikipedia)

The potential application of wireless networks on the construction site is expected to improve materials management. Wireless networks can offer the opportunity of real-time information (such as status and location) and automatic tracking about tools, materials and suppliers. Supervisors and staffs will be able to cut down time spent searching an entire site and locating materials and suppliers, by accessing the management of materials system on a mobile computer. This lowers labour costs and improves labour productivity by ensuring staff on site have the correct materials as planned to execute their work. Hence, there will be reduction on the cost of replacing lost or misplaced materials.

2.8 RFID TECHNOLOGIES IN MANAGEMENT OF MATERIALS

RFID technologies are discussed in this section in terms of how they work, the components of RFID system, and their implementation in construction and other industries.

2.8.1 How RFID Works

Figure 2.7 shows the two primary components of an RFID system. The entire RFID system is made up of the tags and the reader including an operating antenna. These tags (/transponder) are usually located on the people or objects that need to be identified. The other component, RFID reader (/interrogator), enables read and read/write facilities using a mobile or fixed reader in data communication with the tags. Further details on the tags, readers and antenna components of the RFID system, are the following section.
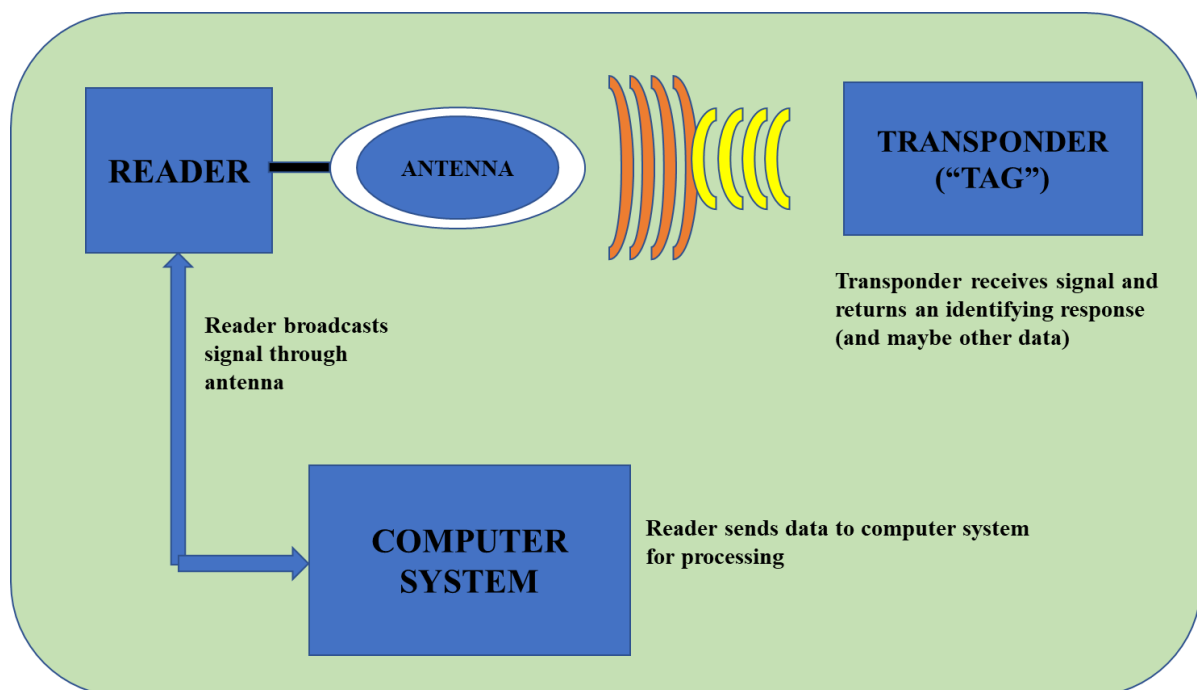
Figure 2.7: How RFID Works (source: Wood and Alvarez, 2005)

2.8.2 Components of RFID System

2.8.2.1 RFID Tags

The two types of RFID transponders (/tags) are the passive and active tags. Passive RFID tags are active only when a nearby reader powers them on and have no internal power source (Finkenzeller, 2010). Passive tags generally have longer life than active tags but their read ranges of a few inches to 30 feet is shorter. They also cost less than active tags. The passive RFID transponders are made up of a microchip that are connected to an antenna and packaged in a various way: examples include mounting on a substrate to create a tag; embedding in a key

fob, a plastic card or on the wall of plastic container; sandwiching between a paper label and an adhesive layer to create smart label (a printable RFID label); and packaging them specially to resist harsh cleaning chemical, heat or cold. Figure 2.8 shows an example of the RFID passive tags where the tags are scaled with an antenna for greater read-write capabilities of the tags.

Operating frequency of the passive RFID tags are: ultra-high frequency (860 MHz to 960 MHz), high frequency (13.56 MHz) and low frequency (124 kHz, 125 kHz or 135 kHz). Each of these frequencies provide its different application and radio wave. Passive tags having low frequency are suitably applied when the tags need to be read through water or materials at close range. The low frequency waves can also penetrate walls but cannot penetrate metal. Manufacturers and retailers take advantage of these features and cost of using the RFID passive tags to manage their supply chain. The passive tags have main challenge when reading them especially when the tags are in the centre of a pallet or on materials made of water or metal. RFID tags come in different shapes and sizes as shown in figure 2.9.
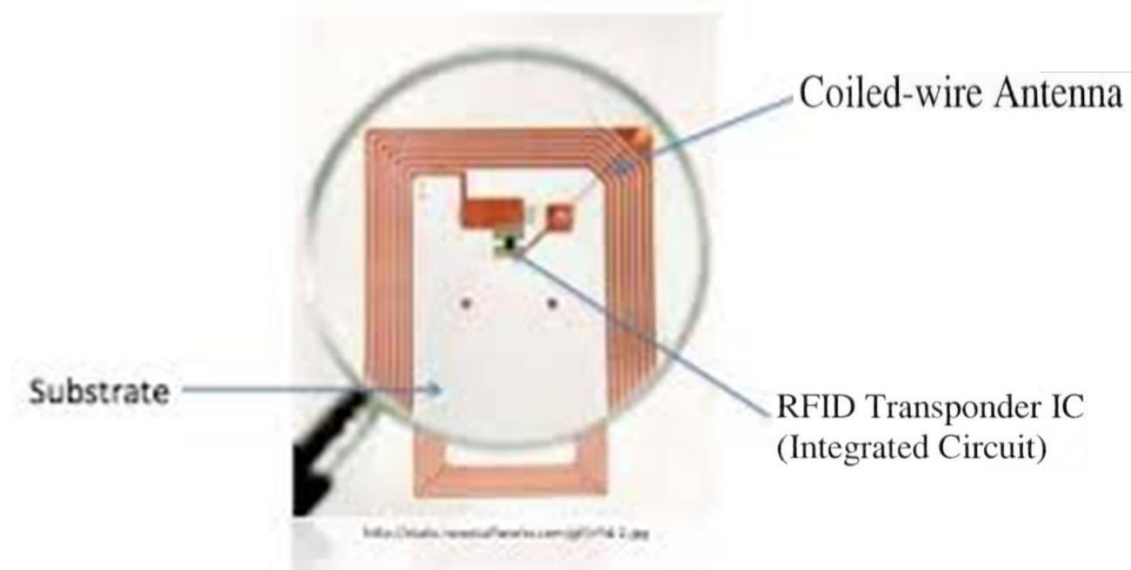
Figure 2.8: Passive RFID Tags - Antenna scaled with RFID Tags (source: Wikipedia)

Figure 2.9: RFID tags come in different shapes and sizes (Source: Arnall 2007).

On the contrary, active RFID tags are rewritable and have their own internal power supply. The active RFID tags features are much more expensive, larger and heavier, and with a better noise protection when compared with passive tags. Nonetheless, they are operated at frequency of 5.8 GHz, 2.45 GHz, or 455 MHz, have a shorter battery life of up to 10 years, and with read range of 20 metres to 100 metres (60 feet to 300 feet). The cost of the active tags generally depending on the ruggedness, amount of memory, on-board temperature sensor and battery life. Also, the increase in cost will depend on the durability and thickness of the plastic housing each active tag (Finkenzeller, 2010). Figure 2.10 shows an example of the active RFID tags.

Reliability of active tags are more in environments such as metal (vehicles, shipping containers) and water (including animal/human, which are mostly water). They are also reliable for generating strong responses at longer distances from weak requests. Furthermore, unlike passive tags, they have larger memories and can store additional information received by the transceiver. Active tags are generally used on large goods like large reusable containers, car containers, and rail cars, which need to be tracked over a long distance. There are two types of active RFID: transponders and beacons (Hunt et al., 2007). Active transponders are usually used in collection of toll payment, control checkpoint and other barrier systems. When the car

63

approaches a tollbooth, signal is transmitted by the active transponder within the car windshield to the reader and its unique ID is transmitted by the transponder to the reader. On the other hand, precise location of an asset can be tracked using active beacons in real-time locating system (RTLS). Such instance of use is in a large manufacturing facilities or distribution yard. Comparison among some of the active RFID tags found in the market are presented in Table 2.4.
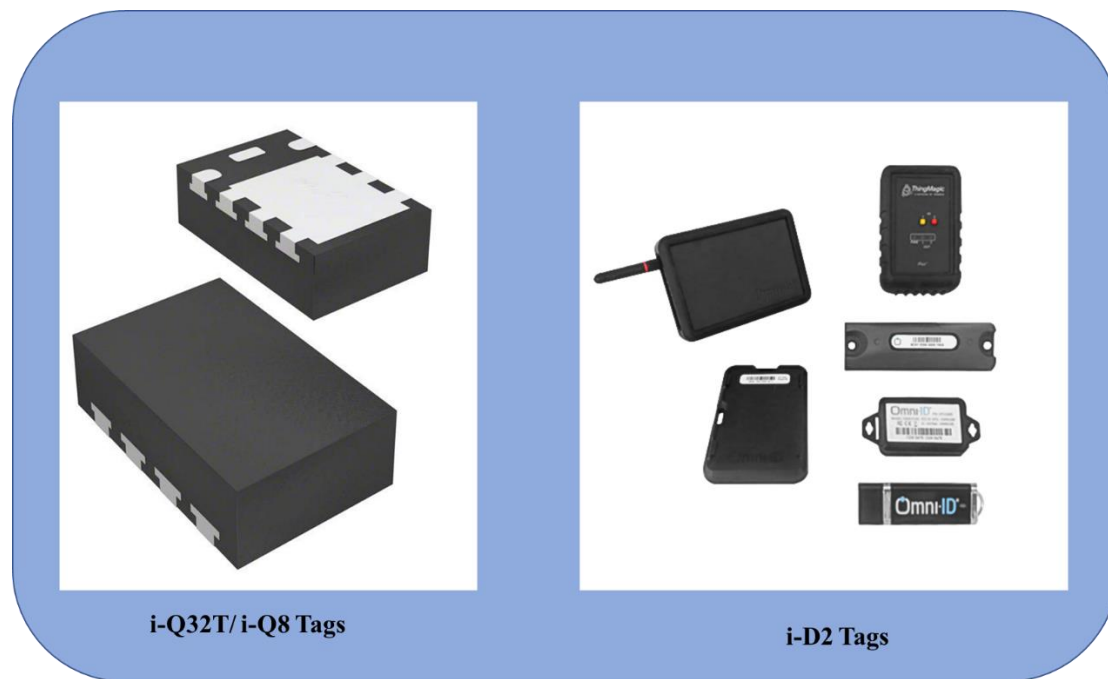
Figure 2.10: Examples of Active RFID Tags (source: Identec Solutions, 2013)

Table 2.4: Comparison among some examples of Active RFID Tags (Source: Arnall, 2007)

Tag Name	i-Q32T	i-Q8	i-D2
Energy derived from:	Battery powered	Battery powered	Reader's signal
Read/Write Ability:	Read/Write	Read/Write	Read/Write
Read Range:	Up to I00m	Up to I00m	Up to 6m
Data storage:	32 Kbytes	32 Kbytes	64 bytes
Frequency of use:	915 MHz (USA) 869 MHz (UK) Dual Frequency (for transcontinental application)	915 MHz (USA) 869 MHz (UK) Dual Frequency (for transcontinental application)	Any
Weight:	Bit-heavier than i-D2	Bit-heavier than i-D2	light
Size:	Bit-larger than i-D2	Bit-larger than i-D2	small
Applications:	Identification, Tracking/Tracing, Localisation, Temperature monitoring	Identification, Tracking/Tracing, Localisation	Identification, Tracking/Tracing, Localisation
Lifetime:	Up to 6 years	Up to 6 years	Up to 6 years

2.8.2.2 RFID Readers

RFID readers (or the interrogators) generally consist of a coupling element to the transponder, a radio frequency module (receiver and transmitter) and a control unit (Finkenzeller, 2010). Wood and Alvarez (2005) noted that the RFID readers/ interrogators may be mobile or fixed and are able to distribute data they support with the larger information system by data communication back and forth the tags. Radio waves are used to exchange data between the tags and the readers. Integration of the mobile RFID readers can be fitted into handheld computers (such as tablet PCs, PDAs, notebook PCs), personal computers, or strategically positioned and stationed in such spots as an assembly line or a facility entrance (Hunt et al., 2007). The RFID readers are composed of an antenna, which sends and receives signals and use scanners to communicate information and instructions and to the reader. Such instructions and information the scanner provides, is converted by the reader into a digital format, which can be used by the computer for analysing, recording, and reporting data.

There are many different readers in the market and different company products coming in different forms (mobile and fixed). Same also are the costs which depends on their identification rate, size, type and brand. A few examples of RFID readers are shown in figure 2.11. Such examples are portable RFID reader (e.g. i- Card 3) and fixed RFID reader (e.g. i-PORT 3). The cost of RFID reader also depends on its functionality (Jones and Chung, 2010). Data transmission and reception can be called by both i-PORT 3 and i-Card 3 RFID readers at

distances of up to 20 ft (6 meters) from an i-D tags and up to 300 ft (100 metres) from the i-Q tag. 1-Port 3 RFID reader can concurrently operate about four antennas to receive the tag signals. It is also reliable and fast in identification of tags. Real-time information can be provided by the portable i-Card 3, when and where they are needed.

Figure 2.11: Example of RFID readers from different technology brand (source: Identec Solutions, 2013).

2.8.2.3   RFID Antenna

The conductive element of the RFID is the antenna which allows the tag to send and receive data (Finkenzeller, 2010). The antenna is fixed on a RFID reader to broadcast an electromagnetic field. The electromagnetic field activates an active or passive tag when it is at read range. A magnetic field is formed when the coiled antenna of the reader couples with the coiled antenna of passive tag's high-frequency (13.56 MHz) and low-frequency (135 kHz). There are different shape varieties of the ultra-high frequency (860 MHz to 960 MHz) tag antennas. The antennas of the ultra-high-frequency and high frequency tags are normally fabricated from aluminium and copper. They can be configured in a variety of shapes, are virtually maintenance free and their sizes range from the size of a brick down to the size of a grain of rice (Hunt et al., 2007).

Typically, tag antennas and transponders are packed as scaled RFID tags (smart labels) which are made up of an antenna that is attached an integrated circuit (IC), with the shape in the form of a coil of wires as shown in Figure 2.12. Other examples of the RFID tags antenna are shown in figure 2.16 such as the linearly polarised antennas, i-Card 3 and elliptically polarised integrated antennas. When there is need to read a large quantity of tags at one time, it is more desirable to use the elliptically polarized antennas; or when there is need to interrogate tags moving at great speeds. But, when there is need to restrict the read zones and to collect selective data, it is more suitable to use the linearly polarized antennas (Jones and Chung, 2010).
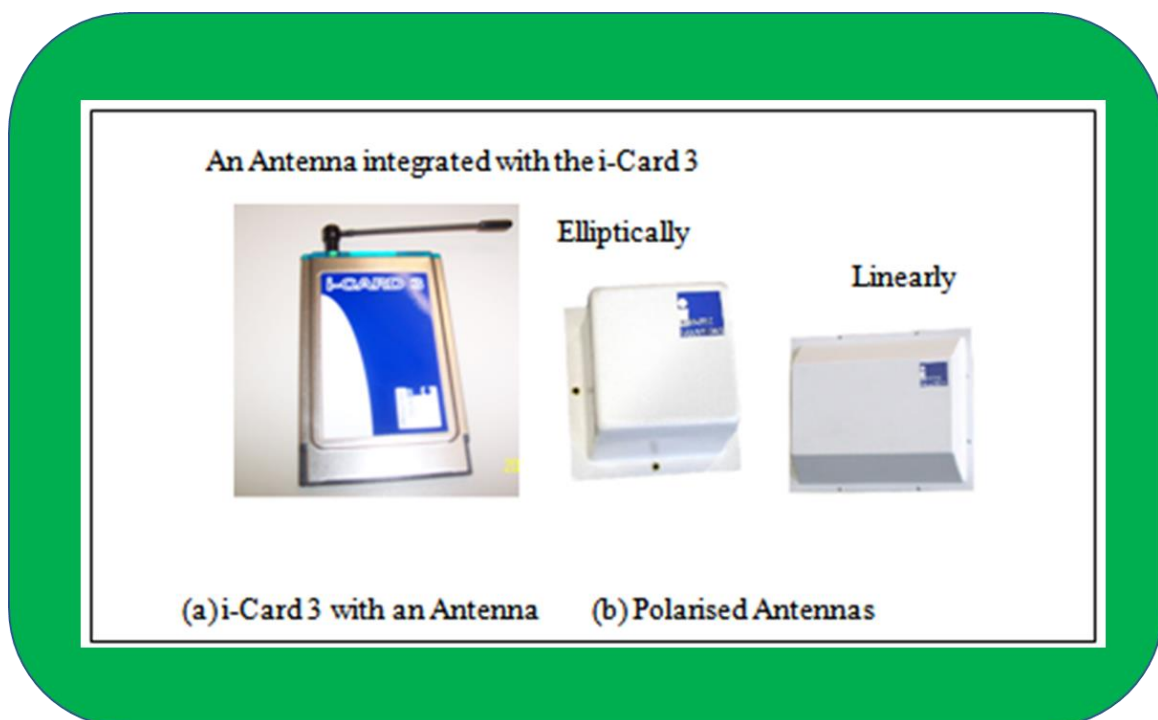
Figure 2.12: Examples of RFID Antennas (source: Identec Solutions, 2013)

2.8.3 RFID Implementation in Other Industry

The implementation of RFID uses in other sectors such as supply chain management, manufacturing and retailing, is growing in support for running of current business practices. Lee et al. (2013), stated that RFID has been used for more than two decades in manufacturing plants to reduce defects, and to track work and components in process. Also, in the retail industry, most retailers (such as 'Sainsbury', 'Tesco', 'Morrisons' and 'Wal-Mart-ASDA') are improving the efficiency of their supply chain and ensuring products are available on the shelf when customers want to purchase them. The supply chain management applies the RFID in tracking shipments among their partners in the supply chain. The payment system is one of the

popular examples of RFID use, where they are used as tool to pay for road tolls without the need for consumers to stop and pay.

Other current examples of RFID technologies usage in various industries noted below:

- RFID tags use in Electronic Product Code (EPC) by TESCO and ASDA

    These retailers make use of these types of tags to track and control their product. The tags are coded on pallets and cases of products to give such information as name, quantity, etc. about the products.
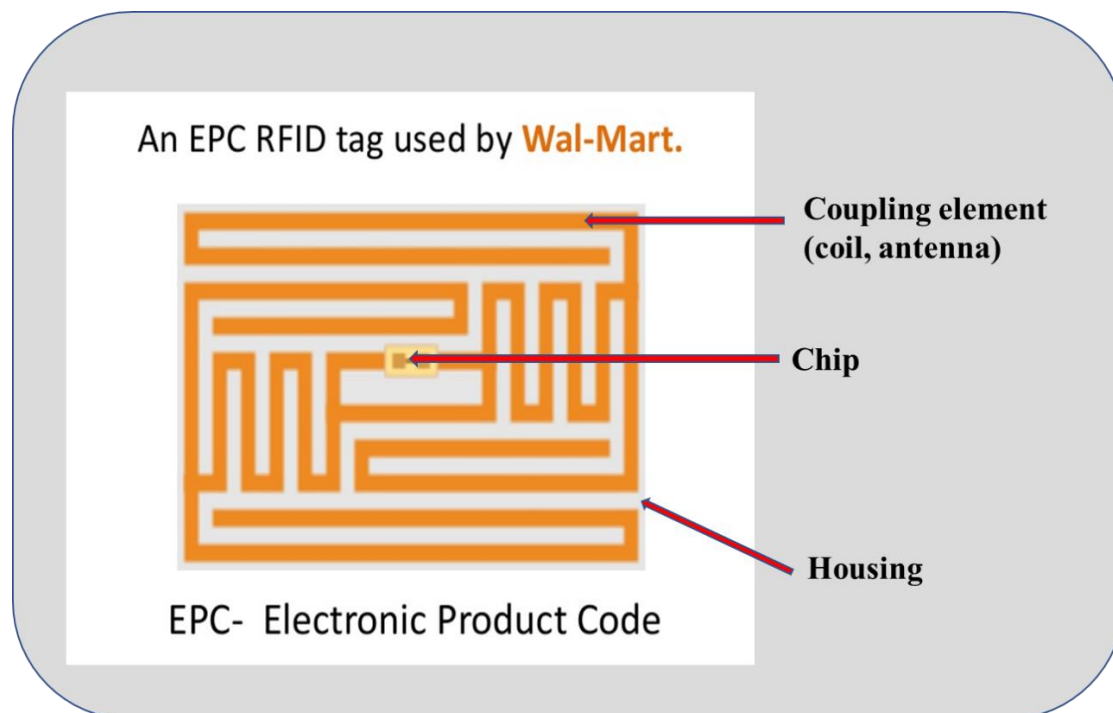
Figure 2.13: An EPC RFID Tag

- RFID tag use in payment systems (such as electronic toll collection).

    The transportation industry uses the tags for automatic toll collection at the toll booth of motorways without the need for the vehicle to stop. This automatically deducts the payment when vehicles pass through the toll booths.

Figure 2.14: An RFID Tag for electronic toll collection

- Electronic Road Pricing (ERP) gantry.

  Toll payment collection is made at this gantry in high-traffic areas from the vehicle active RFID units as used in Singapore.

Figure 2.15: An Electronic Road Pricing (ERP) Gantry (source: All Singapore stuff)

- Library RFID tags.

RFID technology is now being used to replace bar-code for items in the libraries (such as CDs, DVDs, books, CDs etc) to identify information on them such as material type and book's title.

Figure 2.16: Rectangular VHS Tag, Square Book Tag and Round CD/DVD Tag

- Human implant RFID chips

These RFID chips designed to for implanting and tagging of human and animal. Night clubs use these chips for customer's identification by implanting them in their arm.
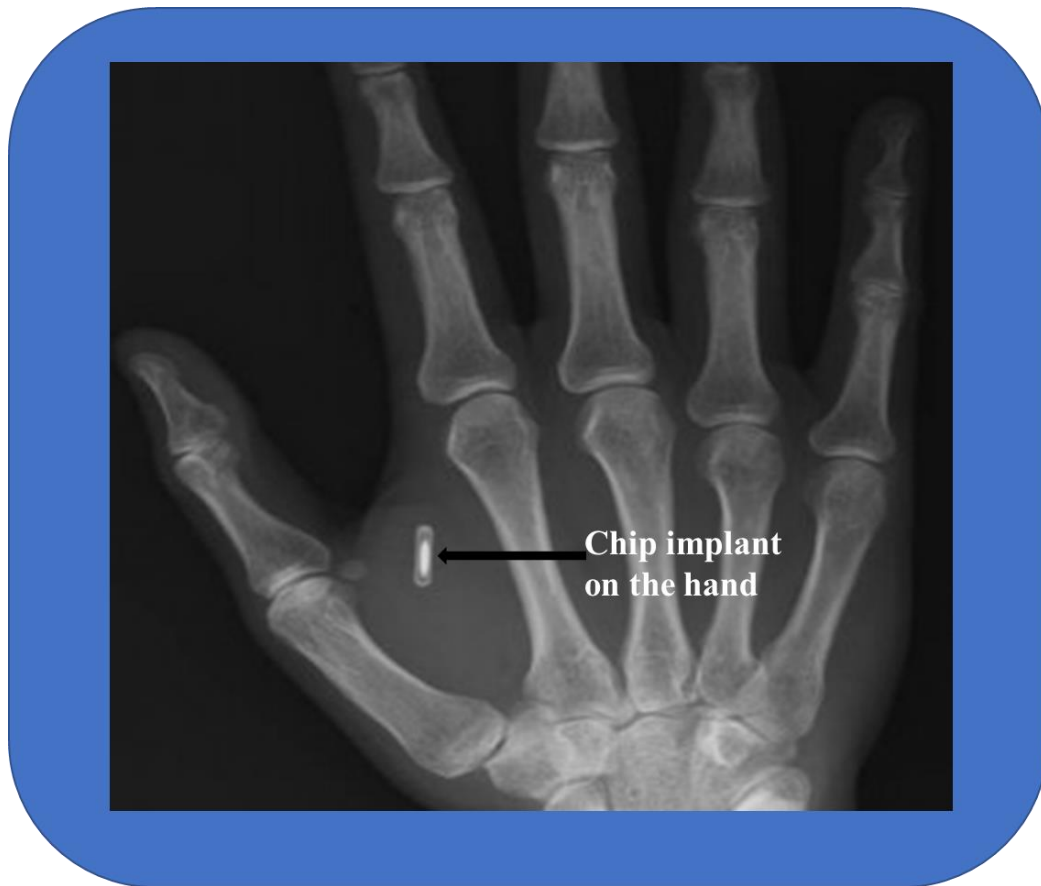
Figure 2.17: Human implants RFID chip

2.8.4 RFID Implementation in Construction

There has been a dramatic growth in the usage of RFID technology by industries, such as distribution, manufacturing, retail. Nonetheless, there is a brief history of RFID application usage in the construction industry. Nonetheless, Innovation and Research Focus (2016) stated that the UK construction sector has indicated interest in many applications such as tags that can be integrated into doors and boilers; which can also be utilised by many facilities management (FM) and housing associations in asset management systems. Presently, construction industry in the UK has carried out work into utilisation of RFID in quality control, component or system build, logistics tracking, asset management and waste reduction. The cost of RFID technology is becoming less expensive and should offer new opportunities to improvement of assets maintenance in construction. It can enable potential savings (efficiency and money) through the following:

- Improvement in productivity;

- Accessibility of 'Real Time' data capture;

- Tracking of job;

- Improved quality control;

- Improved stock control;

- Less use of paperwork;

- Lower the mistakes and associated cost of sending products to site incorrectly;

- Customer information improvement;

- Web-enabled system for customer information;

- Enhanced health and safety;

- Enabling manufacturers to offer new added value on maintenance services for products.

According to Valero et al. (2015), the use of RFID systems can also help the construction sector with the potential to enhance quality, safety, productivity, and the economy; improving project schedules, cutting material as well as labour costs. Wood and Alvarez (2005) also noted the use of RFID in managing and tracking unique tagged materials in the construction industry through the construction sites and supply chains. Some of the examples of RFID applications in materials management which they noted are as follows:

- Material inventory tracking: the use of RFID technology systems can enable real-time automatic, error-free inventory and tracking of unique materials through the supply chain from production, transport, delivery, receipt, storage, and installation issues. For instance, automatically identification of materials can be done as they are shipped and received. This reduced error-prone manual data entry allowing easy identification, updating and immediate downloading of data electronically into materials management systems.

- Tracking and expediting streamlined materials: enabling an RFID system can deliver information on material status earlier than the current manual processes; provide reliable advance information to field planners; ability to optimise planning on schedule and tasks that are critical; and finding available work quickly for crafts that might otherwise be momentarily under-utilised.

- Accurate inventories and status of materials: information accuracy can be provided about shipment, delivery, and inventory of material to avoid missing/ misplacement of items, or item not received which can disrupt project schedule. This scenario can readily be supported for instance, by employing a hand-held reader to affirm delivery of material.

In the past few years, various research projects have been carried out to explore the possibility of Radio Frequency Identification (RFID) technology implementation in the construction industry. These include:

- The Radio Frequency Identification (RFID) technology implementation to monitor materials planning and usage in a water supply project. The complex operational environment can cause the water supply projects to suffer from poor materials management (Ren et al., 2007);

- Radio Frequency Identification (RFID) application on construction job sites for tool tracking. Through the development of inventory system and tool tracking, capable of data maintenance and storage operation (Goodrum et al., 2006);

- RFID and bar-code integration to automate collection of data from the construction site to track schedule information and project cost (Moselhi and EI-Omari, 2006);

- Automated model development for management and control of materials through RFID technology application (Navon and Berkovich, 2006);

- Construction projects model to track the percentage of completion progress through the adoption of Radio Frequency Identification and other wireless technologies (Ghanem et al., 2006);

- Tracking the delivery and receipt of fabricated pipe spools task automation in industrial projects through the implementation of RFID technology. This will address some current methods for tracking pipe spools problems using the current tracking process automation (Song et al., 2005);

- Tracking precast concrete components and their historical information through utilisation of RFID from production up to post construction (Akinci et al., 2002);

- RFID implementation in the construction process to enable procedure that aid owners and contractors assess RFID configuration type that best suits their project applications (Jaselskis and EI-Misalami, 2003);

- Prototype system development at the construction site for spatial tracking and identification of structural steel members (Furlani and Pfeffer, 2000).

2.9 TECHNOLOGY ACCEPTANCE MODEL (TAM)

2.9.1 What is technology?

Technology is an empowering agent or a vehicle to disperse information. It is an enveloping term managing the utilization and learning of mankind's instruments and artworks (Oye et al., 2014). Technology is a wide idea that alludes to utilize information of devices and artworks, and how these apparatuses and specialties influence our capacity to control and adjust to the earth. In human culture today, technology is a consequence of science and building. An explicit definition for the word technology is hard to be resolved, in light of the fact that technology can allude to material objects of utilization to mankind, for example, machines, equipment or utensils, however it can likewise incorporate more extensive subjects, including frameworks, strategies for association, and procedures. Technology is the procedure by which people change nature to address their issues and needs. A great many people, in any case, consider technology as far as its curios: PCs and programming, flying machine, pesticides, water-treatment plants, conception prevention pills, and microwaves, to give some examples. However, technology is more than these substantial items. Oye et al. (2014) noted that technology incorporates the whole foundation essential for the structure, make, activity, and fix of mechanical relics, from corporate central station and building schools to assembling plants and support offices. The information and procedures used to make and to work mechanical curios, building know-how, producing aptitude, and different specialized abilities are similarly vital piece of technology.

2.9.2 Technology Acceptance Model (TAM) Theory

The technology acceptance model is a standout amongst the most compelling expansions of Ajzen and Fishbein theory of reasoned action (TRA). It was created by Fred Davis and Richard Bagozzi (Bagozzi et al. 2007). TAM replaces a significant number of TRA state of mind measures with the two technology acceptance estimates usefulness and ease of use. TRA and TAM, the two of which have solid conduct components, accept that when somebody frames an expectation to act, that they will be allowed to act without constraint. In reality there will be numerous requirements, for example, restricted capacity, time limitations, ecological or

authoritative points of confinement, or oblivious propensities which will constrain the opportunity to act (Bagozzi 2007).

The first is perceived usefulness (PU) and the other is the perceived ease of use (PEOU). Davis (2000) characterizes value as "how much a man trusts that utilizing a specific framework would upgrade his or her activity execution." Davis (2000) proceeded to characterize apparent usability as "how much a man trusts that utilizing a specific framework would be free of exertion" (Marangunić and Granić, 2015). A perceived constraint of TAM is that it doesn't mull over any obstructions that would keep a person from embracing a specific data frameworks technology (Ayeh, 2015). These factors that are excluded in TAM are framework plan qualities, preparing, support, and chief attributes.

The examination considering altering variables to Davis' technology acceptance model endeavour to enhance it by adding client assets and confinements to the model. In 1991, Mathieson, named these elements as outside control factors. These outer variables incorporate emotional standard, wilfulness, work significance, yield quality, and result certifiability (Marangunić and Granić, 2015). By adding power to the model, the specialists would like to enhance the prescient estimation of the apparatus. As of late Venkatesh et al. distributed enhancement in the expectation of acceptance from 17% to 42% (Venkatesh et al., 2012). Venkatesh and Davis endeavoured to consolidate these discourses of outside variables into a TAM model when they proposed a model in 2000 broadening the TAM. Their new model fuses extra hypothetical factors that incorporate social impact forms and psychological procedures (Davis, 2015).

Examination of current writing on technology acknowledgment indicates that extra factors should be incorporated that were not in unique TAM models. Instances of the kinds of factors are socioeconomics, administrative learning, social components, ecological attributes, and task-related qualities (Venkatesh et al., 2012). A few instances of conceivable extra factors are the inspirational components presented by Vallerand in 1997 (Oye et al., 2014). The recognition that users will need to play out an action since it is seen to be instrumental in accomplishing esteemed results that are particular from the action itself, for example, enhanced occupation execution, pay, or advancements are extraneous while the observation that clients will need to play out the movement for no clear fortification other than the way toward playing out the action essentially (Davis, 2015). This group of research approves and expands the use of TAM. Be that as it may, TAM is just equipped for foreseeing technology selection

accomplishment between 30% and 40% of the cases (Venkatesh and Bala, 2008). Subsequently, analysts have scanned for better technology acceptance models that can convey a higher expectation of progress (Marangunić and Granić, 2015). This requires a changed model that consolidates both human and social factors prompted the improvement of an all-encompassing TAM and in the long run the Unified Theory of Acceptance and Use of Technology model (UTAUT).

Based on the systematic review of the foundational technology adoption theories in literature, many Information System success measures have been extensively measured over time, and all possess key contributions to the concept of technology adoption. Nevertheless, none have explicitly measured change management factors which is a key aspect. Also, none of the models has shown the degree to which the measured constructs impact adoption. If intended users perceived threat, they will not readily accept change, and even if they were forced to use the new system being introduced, the extent to which they will use it effectively and efficiently will have a negative benefit for the organization (Davis, 2015). Despite the gaps and limitations, the reviewed technology adoption theories provide a platform to build an integrated model that incorporates change management factors and their impact on adoption. The section also reviews resistance to change, sources of resistance and its manifestations. This establishes the importance user resistance in the implementation of technology (Oye et al., 2014).

2.10 CHAPTER SUMMARY

This chapter reviewed various literatures on inventory management, material management, technologies in materials management and other wireless technologies and the acceptance of technology in the organisation (Technology Acceptance Model). History of materials as an element for management discussed various contribution by author on the demand for material from the 18th century to present day. The need for material management was discussed as it is a vital factor to a successful project. The processes, importance and problems of material management technologies were analysed. The evidence reviews of existing literatures on management of material practices identified many challenges/ problems in material management on construction projects such as supply delays, shortages, fluctuation in price, wastage and damage, and insufficient space for storage. The material supply delays, and inadequate areas of storage were identified as the main problems in the management of materials. A variety of approaches were currently being applied in resolving these problems of material management. These approaches included the implementation of Information and Communication Technology (ICT) system (such as barcoding, PDA, and RFID), proper

logistics planning of materials and Just-In-Time (JIT) techniques. The next chapter will discuss other emerging technologies in construction resource management.

3 CHAPTER THREE

EMERGING TECHNOLOGIES IN CONSTRUCTION RESOURCE MANAGEMENT

3.1   INTRODUCTION

The construction technological landscape is changing at an ever-increasing speed. The question for organisations is no longer if they are going to modernise their construction processes, but when and how are they going to keep up and adapt with ever evolving technologies. This chapter reviews some of the crucial construction technology trends that are impacting the industry. New construction technology has great potential for allowing companies to build faster and smarter, allowing them to be more economical and competitive. Modern inventions go beyond that to be more eco-friendly, build houses in inventive ways, pave roads with advanced materials, and perform with greater wisdom and efficiency, driving efficiencies in connectivity, analytics, and big data.

3.2   ENTERPRISE RESOURCE PLANNING (ERP)

ERP system Definition: An ERP system is defined as a system which collects, records, integrates, manages, and delivers data and information across all functional units of the enterprise (Ali et al.,2017).

With this definition as context, this section reviews ERP systems, their benefits and failures, reason for using ERP systems and their application. ERP systems can be traced back to the 1960's when inventory control was a challenge. The software of systems was designed to process inventory centred around traditional inventory concepts. The focus shifted inventory towards Material Requirement Planning (MRP) systems in the 1970's and focused in planning the raw material requirements. The 1980's saw the emergence of MRP-II concept, which involved optimizing the entire plant production process. MRP-II was an extension of MRP that included distribution management activities, Finance, Human Resource, Engineering, and Project Management (Kumar et al., 2011). This was again upgraded to Client-Server based ERP (Enterprise Resource Planning) systems in the 1990's and covered the cross-functional integration and coordination in support of the production process.

After the Y2K issues experienced in 2000, Extended ERP or ERP II or the Extended ERP was coined and many companies replaced their legacy systems with ERP II. The Internet-enabled age has created further advancement in ERP, which has facilitated the convergence of cloud, mobile, social and big data analytics. The modular nature of ERP has led to Software as a service (SaaS) solution that integrates the back office, front office and the Internet of Things (Ruivo et al.,2015). Some commercial ERP software includes SAP, Oracle, PeopleSoft J.D. Edward, Epicor, Infor, and Microsoft Dynamics, amongst others.

Organizations are investing in ERP systems to support their growth strategies because of pressures such as globalization of the economy, changing consumer demands, and rapid advances in technology. To make better decisions about global markets and risk assessments, these companies need access to better information integrated across the enterprise. There are a variety of reasons why businesses decide to implement ERP systems, including both operational and strategic business reasons. ERP systems have applications across both manufacturing and service industries. Some of these include (Botta-Genoulaz and Millet (2016):

- poor quality or visibility of information;
- uncompetitive organizational performance;
- business processes or systems not integrated;
- difficulty in integration acquisitions;
- obsolete or disparate systems;
- complex ineffective or inconsistent business processes;
- inability of legacy systems to support new business strategies;
- cost structures of current systems too high.

When successfully integrated and adopted, ERP systems promise ambitious benefits and can enhance the processes, interactions and information sharing between the functions in an organization (Sadrzadehrafie et al., 2013). In the face of global competition, financial pressures and striving to remain digitally relevant, a successful adoption of an ERP system can have benefits like customer responsiveness, enhanced data integrity and accuracy, improved flexibility, cost reduction, reduced complexity by eliminating delays, administrative intermediaries, and redundant steps in transactions.

3.3   BUILDING INFORMATION MODELLING (BIM)

Building Information Modelling (BIM) is a digital information repository which helps to ease the management of information in a project. Abanda et al. (2015) referred BIM as a "global digital technology" which is capable to easing the construction process, enhance efficient delivery and facilitate coordination and of project information. Another definition by Sampaio (2015) described BIM as an "innovative technology" which assist project activities throughout the lifecycle of a project. Moreover, Eastman et al. (2008) defined it as an associated set of processes and modelling technology to produce, communicate, and analyse building models. According to Zhao (2017), he is of the view that BIM had caused a transformation in the construction industry in such a way that construction stakeholders have developed an interest in its implementation for their diverse job nature (Olatunji et al., 2016; Olawumi et al., 2016; Olawumi and Ayegun, 2016). Worthy of note is the contribution by McCuen (2008) that BIM provides a single, non-redundant, interoperable information repository capable of supporting every construction project's stage, process, and functional units.

Demian and Walters (2014) highlighted project information management using BIM in construction projects and stressed that the adoption of BIM in the construction industry has enabled solutions to the problems in the sector. Fisher and Yin (1992) stated that the utilization of Information Technology (IT) in the United Kingdom dates to early 1970s and further opined that the globalization of construction works such as building components assembly and prefabrication will greatly increase the usefulness of Information Technology in construction projects. This prediction by Fisher and Yin (1992) is a current reality experienced in the construction industry as evidenced in most construction projects (Davies and Harty, 2013; Bansal, 2011). Moreover, Olawumi et al. (2017), and Olawumi and Chan (2018b) argued that for the construction industry to be competitive and strive, there is need for innovative and improved ways, methods, and techniques of delivering its products.

There are many problems and errors that occur within the construction phase, due to the difficulties in standardization, communication, and coordination. The adoption of building information modelling can aid this interoperability issue, which is deemed to be most likely a technology-led change that delivers the highest impact to the construction sector (World Economic Forum WEF, 2016). The European Construction federation anticipates that by 2025, the wider BIM adoption will unlock 15-25% to the global infrastructure market (BCG, 2016; McKinsey, 2017). If the adoption of BIM across Europe will yield 10% savings to the

construction market, then the £1.2 trillion market will generate an additional £120 billion (European Construction Industry Federation, 2017).

The main aim of BIM is to produce better outcomes and to enhance project performance. Building information modelling assists the construction manager to gather information and data from relevant disciplines and communicate them more effectively. This introductory section of Building Information Modelling will give insight to what it is, how the construction manager should apply BIM in the construction phase, what are the pitfalls and how to avoid them, and how BIM can aid the construction process.

3.3.1 BIM fundamentals

There are five fundamentals on which BIM leads to a better and more valuable project. It is an important tool for increasing efficiency and minimizing risk, thereby, improving design and construction.

- Visualization: With BIM, owners can visualize how a building will be constructed through a 3-Dimensional virtual model of the project. Owners can now envision the project in 3D rather than traditional 2D plans, which allow them to give better feedback about what they want. They can also conceptualize a building completely before construction even begins, allowing them to understand it better. This helps to minimize changes to orders during construction and saves time and money.

- Quantification: An owner or architect can generate real-time values for any design changes they wish to make with BIM software. It can also analyse information for cost overruns and lost effort. This results in a more efficient project that stays within budget and on schedule.

- Communication: It is vital for the successful utilization of BIM that all parties involved in a project collaborate and communicate. BIM enables the sharing of information in real time, streamlining information and facilitating integration of workflow. Additionally, BIM improves communication and understanding with beneficiaries. High quality, digital mock-ups can be created to give beneficiaries a clear idea of what the building will look like and how it will affect the surroundings.

- Coordination: BIM's ability to detect and resolve clashes is one of its most valuable capabilities. Using the enhanced system integration capability of BIM, it can analyse data from multiple systems, such as mechanical, plumbing, and electrical systems, and determine if there will be any conflicts or issues. In addition, by being able to detect

these issues before construction begins, it helps keep the project on schedule by preventing setbacks. This is extremely important to the project team as it prevents costly change orders later in the project.

- Simulation: By creating a 4-dimensional simulation, BIM allows all participants to have a better visual understanding of the entire construction process. Also, it helps determine the logistics of a project's schedule and prepare for its construction phase.

3.3.2 BIM adoption for management of construction project

Several research studies have been conducted in recent years on the impact of BIM implementation in the Architectural, Engineering, and Construction (AEC) industry. Extant literature, such as Bradley et al. (2016), outlined the benefits of Building Information Modelling in infrastructural projects while Fan et al., (2014) using a case study project, examined the influence of BIM during the construction phase. The findings from the case study reveal a better compliance to project schedule, a significant reduction in change orders and requests for information (RFI). Also, a study by Johansson et al. (2015) pointed out the capacity of BIM to facilitate execution of large projects by providing real-time rendering and visualization of the projects; while Karan and Irizarry (2015) argued that extending Building Information Modelling capacity using tools such as Geographical Information System (GIS) can improve its efficiency at the preconstruction stages.

Furthermore, Inyim et al. (2015) noted areas in which BIM has been of immense benefit to the construction industry to include communications, information management and service. Studies (by Kim et al., 2015; Kim et al., 2016; Matthews et al., 2015; Morlhon et al., 2014; Neto et al., 2016; Oti et al., 2016; Olatunji et al., 2017) also revealed the advantages gained through the implementation of Building Information Modelling in project information management to include:

- facilitating collaboration among key stakeholders;

- complying with project's delivery schedule;

- resource planning and management; and

- real-time simulation and analysis of building performance among others.

The influence of BIM at the facility management stage of the building lifecycle has also been examined by extant literature (see Park and Cai, 2017; Kang and Hong, 2015; Pärn and

Edwards, 2017). In addition, the enrichment of Building Information Modelling (BIM) to aid sustainable development has been argued by some empirical studies (see Ham and Golparvar-Fard, 2015; Ilhan and Yaman, 2016; Kim et al., 2015).

3.4 INDUSTRY 4.0

Industry 4.0 refers to the fourth industrial revolution, although it is concerned with areas that are not usually classified as industry applications, such as smart cities. The first industrial revolution came with the advent of mechanisation, steam power and waterpower. This was followed by the second industrial revolution, which revolved around mass production and assembly lines using electricity (Masood and Sonntag, 2020).

The third industrial revolution came with electronics, I.T. systems and automation, which led to the fourth industrial revolution that is associated with cyber physical systems.

3.4.1 Industry 4.0 Technologies

Industry 4.0 describes the growing trend towards automation and data exchange in technology and processes within the manufacturing industry, including:

- The internet of things (IoT): Internet of things describes physical objects that are embedded with processing ability, sensors, software, and other technologies that connect, exchange data, communicate and interact with systems and other devices via the Internet or other communications networks e.g., desktops, thermostats, laptops, smartphones, and tablets etc.

- The industrial internet of things (IIoT): This refers to interconnected instruments, sensors, and other devices networked together with computers' industrial applications, including energy and manufacturing management e.g., asset tracking and monitoring, automation of manual processes, predictive maintenance, improving safety and security etc.

- Cyber-physical systems (CPS): This is a computer system/ intelligent system in which a mechanism is monitored or controlled by computer-based algorithms.

- Smart manufacture: this is a wide range of manufacturing that employs high levels of adaptability and rapid design changes, computer-integrated manufacturing, digital information technology, and more flexible technical workforce training.

- Smart factories: this may also be referred as "digital factory" or "intelligent factory. They create an opportunity for new forms of efficiency and flexibility by connecting

different processes, information streams and stakeholders (frontline planners, workers etc.) in a streamlined fashion.

- Cloud computing: this is the availability of on-demand computer system resources, especially data storage and computing power, without the user having a direct active management. Cloud computing usually have its distribution over multiple locations and each location having one or many data centres.

- Cognitive computing: this refers to technology platforms that are based on the scientific disciplines of signal processing and artificial intelligence. It combines reasoning, machine learning, natural language processing, vision, speech, computer interaction, that imitate the functioning of the human brain and aids to improve human decision making.

- Artificial intelligence: this refers machine demonstrated intelligence, as opposed to natural intelligence displayed by animals including humans. It is the ability of a robot controlled by a computer to carry out tasks that are usually done by humans.

This automation creates a manufacturing system whereby machines in factories are augmented with wireless connectivity and sensors to monitor and visualise an entire production process and make autonomous decisions. Wireless connectivity and the augmentation of machines will be greatly advanced with the full roll out of 5G. This will provide faster response times, allowing for near real time communication between systems (Yadav et al., 2020).

The fourth industrial revolution also relates to digital twin technologies. These digital technologies can create virtual versions of real-world installations, processes, and applications. These can then be robustly tested to make cost-effective decentralised decisions.

These virtual copies can then be created in the real world and linked, via the internet of things, allowing for cyber-physical systems to communicate and cooperate with each other and human staff to create a joined up real time data exchange and automation process for Industry 4.0 manufacturing (Yadav et al., 2020). This automation includes interconnectivity between processes, information transparency and technical assistance for decentralised decisions. In short, this should allow for digital transformation. This will allow for automated and autonomous manufacturing with joined-up systems that can cooperate with each other. The technology will help solve problems and track processes, while also increasing productivity.

Industry 5.0 is already being spoken about and involves robots and smart machines allowing humans to work better and smarter. Esben Østergaard, Universal Robots chief technology officer and co-founder, explained that Industry 5.0 will make the factory a place where creative people can come and work, to create a more personalised and human experience for workers and their customers. By connecting the way in which man and machine work together, estimates say that Industry 5.0 will mean that over 60% of manufacturing, logistics and supply chains, Agri-farming, and the mining and oil and gas sectors will employ chief robotics officers by 2025. The European Economic Social Committee asserts that the proliferation of robotic automation is inevitable (Castelo-Branco et al., 2019).

3.5 ROBOTICS

Robotics involves the combination of science, engineering, and technology to produces machines, called robots, which replicates or substitutes human actions. A robot is a programmable machine created to assist humans or mimic human actions. Robots were originally built to do monotonous tasks (like building cars on an assembly line), but since then have been used to perform tasks, such as assisting with intricate surgeries, fighting fires and cleaning homes. The level of autonomy of robots varies according to their design, ranging from human-controlled bots that carry out tasks that humans can fully control to fully autonomous robots that are autonomous without any external influences.

The scope of what is considered robotics continues to expand as technology advances. In 2005, 90% of all robots were assisting in the assembly of cars in automobile factories. Originally, robotics consisted mostly of mechanical arms for welding, screwing, and restitching parts of cars. Now, we see a much broader definition of robotics, one that includes programs designed to explore Earth's harshest conditions, robots that support law-enforcement and even robots that assist in almost every area of healthcare.

3.5.1 Characteristics of Robots

Although the world of robotics is expanding, certain characteristics of a robot remain consistent:

- Robots are all made up of some type of mechanical construction. The mechanical aspect of the robot allows it to complete tasks in the environment that it was designed for. One example is the Mars 2020 Rover's individual motorized wheels made of titanium tubing that are made to help it firmly grasp the red planet's harsh terrain.

- Robots require electrical components that control and power the machinery. To power a large majority of robots, an electric current (a battery, for instance) is required.

- Most robots contain some form of computer programming. A robot would be nothing but a simple machine without the computer programming code that tells them what to do. Programming gives a robot the ability to know when and how to perform a task.

As artificial intelligence and software continue to advance, we're bound to see the promise of the robotics industry sooner than later. With the advancements in these technologies, it is expected that robots will continue to get more intelligent, more flexible, and more energy efficient in the near future.

Furthermore, they will continue to play an important role in smart factories, taking on more difficult challenges and helping to improve the security of global supply chains. The robotics industry, while relatively young, holds a lot of promise for progress that science fiction could only dream of. Robots will be found performing tasks many of which humans can't imagine doing alone, from the deepest depths of our oceans to the farthest reaches of outer space.

3.5.2 Robotics and automated systems in construction

While robot use in construction is not new, the technology has been explored since the 1960s. In the past decade, there has been an increase in investment, research, and real-world use of robots in construction (Ajoudani et al., 2018). In this section, we will present a brief overview of the different types of robotic and automated systems being used in the construction industry. These systems are varied, and there is no consensus concerning their classification. New developments in technology are continuously moving the boundaries between classifications. The categorization outlined here is meant to facilitate a quick understanding of a very complex and varied technology landscape and to inform the reader of the different types of systems/ technologies available (Bock, 2015). The first construction robots were developed in Japan to support and enhance the quality of building components for modular homes (Bock, 2007).

There are four general categories of automation and robotic technologies for construction:

(1) Off-site prefabrication systems: these are offsite prefabricated construction robots. The effective usage of robots in Japan's car manufacturing sector led to the adoption of these robots. Later, construction robots and automated construction site systems began to appear on construction sites. Robotic arms and machines have been utilised in industry production lines for decades, so it's no surprise that same technology is being applied in the growing market for

prefabricated homes. Katerra, a California-based prefab construction company, incorporates robotics in its industrial lines (Ajoudani et al., 2018).

(2) <u>On-site automated and robotic systems</u>: these are on-site production robots. When people think of robotics in construction, they typically picture something like this. There have been several constructions robots' prototypes and tests in the past couple years, including Hadrian X, a bricklaying robot, or Robo-Welder, a robot that can work on a variety of welding projects from Shmizu Corp. Similarly, there are various examples of on-site 3D printing robots, such as this French social housing complex that claims to be the world's first 3D printed house (Bock, 2015).

(3) <u>Autonomous vehicles</u>: There are a variety of construction site equipment, ranging from diggers to bulldozers, that are ready for automation. Built Robotics, for example, provides technology to move soil and rubble without the need for human intervention. Building and site clearance work could someday be done 24 hours a day, seven days a week, rather than being limited to working hours.

(4) <u>Exoskeletons</u>: The physical demands of construction site work often lead to injuries, especially when lifting heavy loads. This is where exoskeletons could be helpful. Exoskeletons are pieces of kit worn by construction site workers that provide robotic functions. As well as helping wearers lift heavier weights, they can also reduce fatigue. Exoskeletons are not strictly a robotic system, because they support the capabilities of the wearer instead of replacing them altogether. However, exoskeletons were included here because this focuses on all hardware technologies that improve construction activities (Ajoudani et al., 2018; Yang et al., 2018).

3.5.3 Obstacles to using robots in construction

Robotics will make up some £70 million in construction industry sales by 2018, increasing to more than £225 million by 2025 (Yang et al., 2018). Despite the promising sales forecast, robotics adoption in the construction industry is far below that of other traditionally manual sectors. Some of these slow take-ups in construction are due to:

- The complexity of construction sites: The most popular use of robots has been in mass manufacturing lines, where they are fixed in place and repeatedly perform the same tasks. Outdoor construction sites are very different from this, with unpredictable weather and a unique, finished product (such as a road, building, bridge, or anything else). The judgement and complexity involved in construction sites makes robots' usage a very challenging place.

- Costs: The up-front costs of investing in robotics are high, including Research and Development. With many construction firms operating on thin margins, the investment is deemed too high by some. For the time being, it is more economical to hire and train people rather than invest in robots.

- Improvement in robotic technology: Robots are being used in construction in a variety of ways, as you have just seen. Nevertheless, these robots have not yet been widely adopted, and there aren't many firms actively using them on-site. There needs to be significant progress before the technology can be widely adopted.

- Legal/health and safety issues: In many countries, health and safety legislation makes the use of robotics in construction a serious barrier because construction sites can be dangerous. Lawyers and insurance companies are understandably concerned about the risks of unmanned, autonomous robots traversing a busy building site.

Over the 21st century, Artificial Intelligent-driven robotic automation has been a big story - but it has also been over-hyped. While hailed as the future/ next big thing, robots have not yet been able to meet our utopian or dystopian expectations of sci-fi (science fiction).

3.5.4 Advantages Of Robotics In Construction

There are many robotics initiatives in construction, each developing at its own pace. Some of the advantages robotics can be in construction include:

1. Helping to solve the skills shortage in construction: Since construction is a labour-intensive industry, automation robotics has proven to be very effective in reducing labour costs and improving productivity and quality in other industries - so why not construction? Construction has been plagued by a shortage of skilled labour for several years. Using robots can help address this shortage and improve productivity as well as raise wages for skilled workers. During the transition period - which could take a decade or more - those with advanced skills will have a greater chance of getting hired.

2. Increasing speed by moving to off-site production: The production of individual components, or modules in factories can allow for greater automation compared to what can be done on-site. Modular construction off-site may have a significant impact on building construction; however, it will take time for the transition to take effect. Many companies, such as Katerra, already produce these modules. In these factories, the construction is mostly carried out manually, but as the scale increases, automation will become more common. To combine high-level building components into finished

building modules (e.g., bath or kitchen modules), large-scale prefabrication (LSP) approaches are also being considered.

Furthermore, additive manufacturing techniques such as 3D printing already have an impact, resulting in examples like two-story municipal buildings and 3D printed bridges.

3. Making sites more efficient: Construction sites around the world are trialing and piloting automated and robotic systems. Bricklaying, steel-truss assembly, welding, installation, painting, and concrete laying are all being automated with varying degrees of success. A typical example is the robot arm that performs bricklaying known as Hadrian X. These are known as single-task construction robots (STCRs) because they execute a single task repeatedly. Getting these individual robots to work together on a construction site - a very chaotic environment - has been challenging. There has been some talk about robotic factories on-site to standardize the environment a bit - but they are still in their infancy, and they may cause more problems than they solve.

4. Providing safer work environments: Keeping the work site as safe as possible is one of the most critical responsibilities of a construction manager. Aside from the concerns of keeping workers injury-free, there are considerable costs associated with an unsafe site. Some of the most dangerous tasks (such as demolition), could be made safer for workers by using robots.

3.5.5 Disadvantages of robots in construction

1. Complexity of the construction process: It is estimated that 80 different trades may be involved on a construction site. There may be new solutions that can do the work of these diverse trades, but it seems that construction sites will always be changing. Since robots do not have a lot of autonomy and are not able to think for themselves, it is difficult to put them to use in such an unstructured and constantly changing environment. To allow robots and humans to work together safely, some form of standardisation of sites would be required.

2. User resistance: Most of the robotics research has been focused on the development of new systems. Construction workers are rightfully concerned that robots are going to replace them. Yet, so far, the interaction between construction workers and robots has not received the same attention as the development of new systems.

3. Technology limitations: Robot technology continues to advance, but construction poses its own set of challenges. To effectively use robots in construction, it is necessary to

address many challenges, such as: battery life restricting operations, stringent regulations that increase adoption costs, coping with outdoor and rugged environments, potential additional risks to health and safety, complex operation requiring additional training and increased cost etc.

3.6   CHAPTER SUMMARY

The review of emerging technologies has identified some key technologies aiding the construction industry to advance efficient construction and which can enable stakeholders can view related details about the project from beginning to end. Modular construction is growing in popularity worldwide. Invention of 3D printing helps to create models for perfecting a design and is being touted by many as the future of project. Green and Innovative materials are desirable and lucrative investment for construction firms. Mobile and cloud-based systems can connect workers to projects in real-time, which ensures seamless connection between back offices and workers in the field. It means real-time inputs of critical project data for analysis and response. Wearables are also improving the ways workers interact on the job. This technology can ensure the moving parts of a job are in place and accounted for. Robots aren't replacing construction workers any time soon but making workers' lives a lot safer and better. Construction firms with the budget can apply robotics to any task that can be automated. BIM technology supports engineering, architecture and construction professionals to effectively plan, design, modify and manage buildings and their infrastructure through document management, coordination and simulation during the entire lifecycle of a project (plan, design, build, operation and maintenance). The next chapter will discuss the methodologies that will be used for the research.

4   CHAPTER FOUR

RESEARCH METHODOLOGY

4.1   INTRODUCTION

This chapter will describe the research methodology that has been adopted for the thesis. It will begin with introduction to research methodology, several research methodologies and research approaches used in research; and then research approach that has been selected for thesis and justification for selection of such research methodology. It will also explain the research methods that have been adopted for the thesis and ethical issues in research.

4.2   RESEARCH METHODOLOGY INTRODUCTION

Research is conducted such that systematic study and investigation are carried out to enable establishment of facts and coming up with new conclusions. It is skilled art that investigates a problem such that solutions can be found (Neuman, 2006). The research methodologies chosen for this work is being primarily driven by the topic to be researched; the specific research questions; and the resources available.

According to the Concise Oxford English Dictionary (COED, 2017), research is defined as the systematic study and investigation of sources and materials such that facts can be established, and new conclusions reached. Greenfield (2016) noted that research can be said to be an art helped by inquiry skills, collection of data, experimental design, analysis and measurement, presentation and interpretation. Neuman (2006) stated that various researchers have also defined research as organised systematic effort geared towards problem investigation that require a solution.

Fellows and Liu (2015) defined research methodology as the application of logical thought process to a specific investigation using principles and procedures. It is the use of principles and procedures on the process of logical thought to any investigation (Klien and Myers, 2011). According to Sharp et al. (2012), good research must be systematic, focused, rigorous and integrated, whatever the chosen method. According to Walliman (2011), when making a choice for an appropriate research methodology, the basic drivers to check include:

- the research topic;

- the specific questions that needed to be answered from the research; and

- the available resources/ data for the research.

"Nested" research methodology is a type of research methodology according to Cooper et al. (2005), which can be grouped into three main themes: research techniques; research philosophy and research approaches, the interrelation among these themes is shown in Figure 4.1. The inner boxes of the research techniques and research approaches is energised and guided by research philosophy that forms the outer box. The qualitative and quantitative methods of research are incorporated by the research approaches. Research techniques are made up of the tools needed in data collection such as questionnaires surveys, observation, literature review, interviews, workshops, experiments, etc.

Figure 4.1: A Nested Research Methodology (Source: Cooper et al., 2005)

In social research, there are two main philosophical schools of thought (Bryman, 2015), these are epistemological and ontological philosophical schools. The logical investigation of the diverse ways in which several types of things are thought to exist, and the nature of their various kinds of existences, is involved with the ontological philosophy. The ontological philosophy can be divided into two approaches: realist and relativist. On the other hand, an epistemological philosophy consideration involves question of knowledge acceptability in a discipline, and the method of acquisition of knowledge. Epistemological philosophy can be grouped into positivist and interpretivist approaches. The summary of philosophical philosophy considerations is shown in Table 4.1.

Table 4.1: A Summary of Philosophical Considerations (Table adaptation from Bryman, 2015).

ONTOLOGICAL CONSIDERATIONS	
Realist	**Relativist**
The external world is composed of hard and tangible pre-existing structures	Multiple realities in exist as subjective construct of the mind
Existence of structures are independent of individual's ability to acquire knowledge	There is variance in the socially-transmitting terms across various languages and cultures
EPISTEMOLOGICAL CONSIDERATIONS	
Positivist	**Interpretivist**
Natural science methods are applied to the social reality and beyond	There is emphasis on realism of context and absence of universal truth
The laws of causation are conformed by the world and reductionism can be applied to reduce complex issues	Interpretation and understanding are derived from the researcher's own frame of reference

Love et al. (2002) stated that the interpretivist approach deals with the development of theory and knowledge, ideas development building, inducted through observation and interpreted through social constructions (that is, qualitative approach); and whilst Blumberg et al. (2005), said that the positivist connected with development of knowledge through investigation of social reality and observation of objective facts (that is, quantitative approach). According to Easterby-Smith et al. (2018), they suggested three issues of key importance that need to be understood in the philosophical research, these include:

- that the research can aid clarity of research designs;

- knowledge of philosophy can enable the researcher to know the design that can work and ones that cannot; and

- knowledge of philosophy can enable the researcher to create design and identify which design that may be beyond the experience of the researcher.

More explanations on the research approaches are detailed in the succeeding section.

4.3   RESEARCH APPROACHES

A research approach is applied to allow a specific style of research to be unfolded and enable different methods of doing research to be employed which is termed as a research method by Yin (2014) and as a research strategy by Naoum (2013). The basis that governs the selection of a suitable research approach according to Yin (2014), are listed as follows:

- the type of questions posed, and the nature of the enquiry being made;

- the investigator degree of authority on the actual behavioural cases; and

- the focal extent on contemporary cases.

The research approach deals with the process of interpretation used in obtaining adequate answers to questions posed and concerned the sources and types of evidence to be collected (Easterby-Smith et al., 2018). The three types of research methodology are qualitative, quantitative and mixed method (Fellows and Liu, 2015; Neuman, 2006). These are discussed more in the following sub-section.

4.3.1   Quantitative Research

According to Fellows and Liu (2015), quantitative research is defined as a method which studies the relationships between facts, seeks to collect valid data; and how these relationships and facts connect with findings and theories of any previously executed research (literature). The quantitative research method can be used to answer relationship questions between measured variables with the aim of controlling, predicting and explaining phenomena (Leedy and Ormrod, 2015). The quantitative approach applies the use of statistical and mathematical and techniques to spot casual relationships and facts. The samples for this method can be larger and more representative (Willcocks et al., 2016). Figure 4.2 outlined the crucial steps in quantitative research according to Bryman (2015) and lays emphasises on the ideal account of a research progress.

Figure 4.2: Quantitative Research Process (source: Bryman, 2015)

The results from a quantitative research samples which are often large and representative, are usually generalised (within acceptable error limits) to the larger population (Bryman, 2015). Patton (2015) noted that the validity of results is dependent on the accuracy of its measured targets and meticulous choice of the instrument for measurement. There are two types of quantitative data analysis: these are content analysis and statistical analysis. When collected quantitative data are analysed using of either inferential statistics (e. g. regression, correlation) or descriptive statistics (e. g. pie charts, histograms), it is termed statistical analysis. On the other hand, content analysis tends to group communication acts into categories with peculiar features and a qualitative picture of the respondents' ideas, feelings, concerns and attitudes is provided to the researcher (Emmit and Gorse, 2003).

The research community has criticised the quantitative research approach and some of these criticisms are noted as follows (Bryman and Bell, 2011):

- Quantitative researchers fall short of differentiating the world of nature from people and social institutions;

- Measurement process of the quantitative approach are spurious and artificial in terms of accuracy and precision;

- It relies on procedures and instruments which prevents the connection between everyday life and research; and

- The analysis of connections between factors makes a static perspective of social life that is free of individuals' lives.

The two most commonly-used approaches in quantitative research are as follows.

4.3.1.1 Experimental Research

In experimental research, there are two types of techniques used in collection of data, these are: field and laboratory experiments. Fellows and Liu (2015) stated that field experiments are not operated in extraordinarily-constructed laboratories but in a dynamic economic, social, political and industrial arena, while laboratory experiments are enhanced to assess connection between distinguished variables. Experimental data collection methods generally tend to be less time consuming, easier to be replicated and less expensive to use when compared to other techniques (Blumberg et al., 2005; Neuman, 2006).

Nonetheless, Dahlberg and McCaig (2010) noted that the main demerit of using this method is the extreme difficulty involved in studying human individuals. According to Neuman (2006), the disadvantage of the experimental research is that experimental methods cannot be used to address some questions because it is impossible to manipulate control and experiment. Because one or a few hypotheses can only be tested in an experiment at a time, the use of experimental research is limited.

4.3.1.2 Surveys

Neuman (2006) stated that survey research is a process of posing several individuals the same questions and analysing their answers. Observations are made from this method that are fashioned in a definite manner. The type of data collection method in survey research are **web survey, questionnaires** (self-administered and mail) and **interviews** (telephone interviews and face-to-face interviews). Selecting method of data collection is vital because it impinge on cost of data and the quality and to prevent interviewer bias, but the conditions under which a questionnaire is to be completed cannot be controlled by the researcher. Obtaining quality data is generally easier using the interview survey than using a questionnaire survey. Cost wise, it is cheaper to use the questionnaire survey. On the other hand, time wise, it is inexpensive and

faster to use web-based surveys by e-mail or over the Internet because they allow design flexibility such that visual images (and even video or audio in some Internet versions) can be used.

4.3.2 Qualitative Research

A research in which descriptive and meaningful analysis of data is produced is called qualitative research, such data can be person's own observable behaviour or written words (or that concerns groups of individuals). The qualitative research approaches were originally developed in social science, such that social and cultural phenomena can be studied by researchers. Qualitative research was defined by Creswell and Poth (2017) as an inquiry process of understanding that is based on unique traditional method of inquiry probes human or a social experience. According to Dainty (2004), the qualitative methodology characteristics are given below:

- Development of concepts from data (Inductive);

- Holistic viewing of subjects and settings;

- There is an awareness on the effect of the study on the people by the researchers;

- Understanding is benefitted from the perspective of informant;

- They look beyond the defined examined aspect (that is, humanistic methods are used);

- There is a rich data collection, but analyses of such data is difficult;

- The researcher required to gets close to the phenomena and to the data examined; and

- Validity of data is emphasized.

Figure 4.3 below depicts the outline of qualitative research process.

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┌─────────────────────────────────────┐
│   1. General Research Questions      │
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                │
                ▼
┌─────────────────────────────────────┐
│ 2. Selecting Relevant Site(s) and Subjects │
└─────────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────────┐
│   3. Collection of Relevant Data     │
└─────────────────────────────────────┘
                │                          ┌──────────────────────────────┐
                │                          │ 5b. Collection of Further Data│
                ▼                          └──────────────────────────────┘
┌─────────────────────────────────────┐
│     4. Interpretation of Data        │
└─────────────────────────────────────┘
                │ ▲
                ▼ │
┌─────────────────────────────────────┐
│  5. Conceptual and Theoretical Work  │
└─────────────────────────────────────┘
                │
                ▼
┌──────────────────────────────────────────────────────┐
│ 5a. Tighter Specification of the Research Question(s)  │
└──────────────────────────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────────┐
│   6. Write up Findings/conclusions   │
└─────────────────────────────────────┘
```
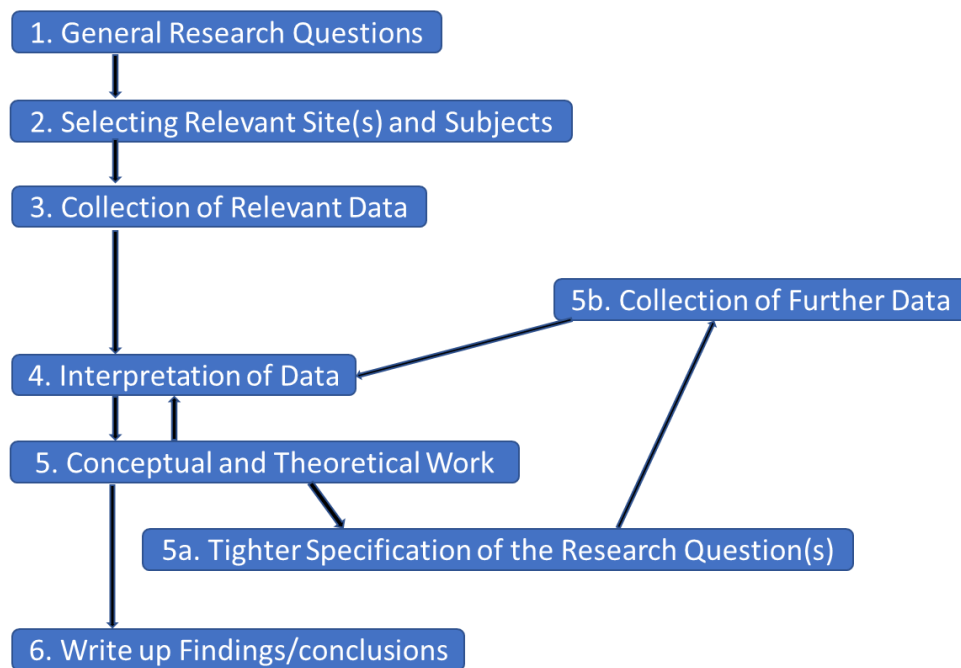
Figure 4.3: An outline of Qualitative Process (source: Bryman, 2015)

In qualitative research, the main steps involved are not fixed and the question for the research are often directed by theoretical issues, which in sequence, direct collection and analysis of data (Neuman, 2006; Bryman, 2015), and run under the belief that reality is not easily divided into measurable, discrete variables (Creswell and Poth, 2017). Adoption of qualitative research approach can be used in the following situations as argued by Bryman (2015):

- Where the topic has no existing research data and there is uncertainty on the most appropriate unit of measurement; and

- When the assessment of the concepts to be researched are done on a simple scale, with no clear differentiation and entails examining attitudes or behaviour.

Furthermore, considerable use of inductive reasoning is used in qualitative research (Bryman and Bell, 2011; Neuman, 2006). Qualitative research emphasizes words and relates to the theory instead of data quantification in terms of collection and analysis (Bryman and Bell, 2011). They offer several specific observations and then inferences about bigger and more broad phenomena (Neuman, 2006). However, Bryman and Bell (2011) identified some criticisms about the limitations of a qualitative research strategy from the research community, such limitations are as follows:

- Generalisation problems. The generalisation capability of the research results is reduced because of sample sizes and sampling methods used qualitative research.

- Subjectivism of the qualitative research. There is weakness in the strength of deeper understanding provided by a qualitative strategy as it limits result confidence.

- Replication is difficult. Replication of qualitative strategy by other researchers is limited, which is another weakness of it. For instance, the focus of one researcher may differ from the focus of another researcher.

- Lack of transparency. There is lack of clarity and difficulty in establishing the process of qualitative data collection and analyses.

Dainty (2004) stated that emphasis on 'lived experience' of people by qualitative data, are simply apt for finding the meanings individual place on the structure, processes and events in the life of people (that is, their presuppositions, assumptions, perceptions and prejudgements). Analysis of data analysis entails having an understanding and interpretation of collected data in a logical and systematic manner to avail valid conclusions. According to Emmit and Gorse (2007) qualitative research methods of analysis are categorized into three, these are conversation analysis, discourse analysis, and semiological analysis. A type of analysis that deals with the circumstantial sensitivity of language with a view on its social action and interaction is termed conversational analysis. Conversation analysis requires transcripts or audio' recordings of interaction so that necessary detailed data can be provided. Understanding of the relationship between different events can be enabled through conversation analysis. The second category is the discourse analysis entails scrutiny of statements and discussions transcripts and is marginally broader in term than the conversation analysis. The discourse analysis considers the linguistic context and content when establishing interaction intention and meaning. Semiological analysis considers the link between the meanings and interaction created within a specific context or culture and the appearance and structure of the text.

The distinct types of the qualitative approaches are discussed as follows:

4.3.2.1 Case Studies

Yin (2014) gave a technical definition of a case study as an empirical inquiry that probe a contemporary phenomenon in the context of its real-life; when there is no clear evident of the boundaries between context and phenomenon; and which uses multiple sources of evidence. Case study uses different methods of data collection (such as archival records, documentation,

direct observations, interviews, physical artefacts, and participant-observations) to examine a particular case (single entity) or multiple cases through a sustained period. Vissak (2010), stated that some elements of a good and effective case study research are follows:

- A good case study must follow systematic research design;

- It must begin with theory and research hypothesis development; and

- It must implement an evaluation criterion that independently checks potential biases and to ensure that case study has its methodological rigour.

According to Yin (2014), when 'why' and 'how' questions are being asked in a research, the preferred strategy to use is the case studies. It is also preferred when the researcher has limited control over events, and the phenomenon of the research is contemporary within the context of real-life. Ahmed et al. (2016), stated that method or data is not the key feature of the case study approach but the attention to understand the processes as they occur in their context. Furthermore, Leedy and Ormrod (2015), noted that case study research has key strength in being suitable for use in learning more about situation that are poorly understood or a little known. Case study may also be vital for probing how changes occur on an individual over time, perchance to certain interventions or circumstances.

Moreover, to gain an insight into behaviour, the researcher may spend more time on-site interacting regularly with individuals who are being studied so that common trait and unique features shared by them in a given classification, can be discovered. Yin (2014) pointed out that some challenges involved in doing case study research such as: the needs for direct examination in the actual current situations (time, cost, access difficulties); multiple methods requirements, entities for mixed method, and tools, deficiency of controls; and the context and temporal dynamics complications. Nonetheless, case studies have become more objective, theory-based and rigorous. Three important factors to consider when designing a case study are: the unit of analysis must be defined; appropriate cases to study should be selected and making necessary decision on how to collect data and what data will be collected (Vissak, 2010).

The case study designs are divided into three types, which according to Naoum (2013), are as follows:

- The descriptive case study: this is akin to the descriptive survey concept (that is counting) but differ in its application to detailed cases;

- The analytical case study: this is related to the analytical survey concept (that is relationship, counting and association), but differ in its application to detailed cases; and

- The explanatory case study: this adopts the theoretical approach to problem solving. The explanatory case study tends to show the relationships among the objects of the study and explains causality. It also probes the reason things happen the way they do. Specifically, facts are collected by the researcher and the connection between them are studied.

4.3.2.2   Action Research

An amalgamation of both research (knowledge, understanding) and action (improvement, change) is termed action research, contributing to existing knowledge is not only function of action research, they also help resolve some of client's practical concerns especially when the situation they are trying to resolve is problematic. According to Gill and Johnson (2010), action research has the main aim of contributing both to the goals of social science and to people's practical concerns in their present problematic situations, by relating within a mutually acceptable ethical framework. Action research has four main characteristics, according to Blumberg et al. (2005), these are:

- They are bounded by context and address real-life problems;

- It is a collaborative undertaking by practitioners, researchers and participants;

- They continuously reflect process of action and research; and

- Its validity and credibility are measured by assessing if the actions taken solved the problems and realised the needed change.

Some of the main merits of using action research: includes provision of relevant experience to researchers, working closely with the community in which they are practicing; this can be used in many modes of research; both in new theory generation and contradictions/ reinforcements of an existing theory; and in combination with other methods of research such that the research project can be diversified (McNiff ,2013). Accordingly, Brumberg et al. (2015), noted that the major weakness involved in this method is that less care is put on conventional principles, although this method may be the result of the project outcome.

4.3.2.3 Grounded Theory

Leedy and Ormrod (2015) noted that a grounded theory is a method of research that uses multiple stages of data collections and information refinements to construct a theoretical model. Grounded theory's main method of data collection includes: observation, interviews, documentation, video-tapes, historical records and other potential research questions that are relevant. McNiff (2013), stated that grounded theory has become prominent in social research because it allows systematic explorations of processes and it does not need large sample sizes. Grounded theory also becomes necessary when an existing theory is too abstract to proffer guidance or where a theory is non-existent.

4.3.2.4 Ethnographic Research

According to Creswell and Poth (2017), ethnographic research is used to interpret and describe social group or system or a culture. Bryman (2015) asserted that ethnographic research studies a cultural group that is intact over a sustained period of time through primarily observational data collection. According to Leedy and Ormrod (2015), ethnographic research is focused on investigating everyday behaviours (such as language, interactions, rituals) of people in a giving group with the intention of spotting belief cultural patterns, cultural norms and other social structures. The prices of data collection in ethnographic research involves participant observation of a group of people or through one -to- one interviews with the group and this is site-based field work. This entails the study of the meaning of behaviour by the researcher, and of interaction and language of a group that share a common culture over a period of time.

4.3.2.5 Phenomenological Study

Leedy and Ormrod (2015) noted that phenomenological study can be defined as the study that tries to understand the perception and perspective of people, and to understand a certain situation. Creswell and Poth (2017) asserted that phenomenological study is a method of research through examination of human experience using detailed description of the individuals that are being examined. The main focus of this method involves an examination of a distinct phenomenon that are perceived and typically lived by human beings. This phenomenological study has the main aim of having a better understanding of the invariant structure, the essential/ essence of the experience and to recognize the existence of a single unifying meaning of the experience (Creswell and Poth, 2017). The main aim of data collection in this method involves exclusive use of unstructured interviews and a typical sampling number of five to twenty-five individuals (Leedy and Ormrod, 2015).

4.3.3 **Mixed Method**

According to Mertens and Hesse-Biber (2012), they noted that it entails the combination of approaches to study identical phenomenon. In addition, Love et al. (2002) noted that the representation based on argumentation in gaining better picture by making multiple measurements using several methods or several levels of analysis (i.e. a combination of quantitative and qualitative data collection and analysis in one study) is termed mixed method. Generally, the process entails using different data to increase findings' credibility or validity. It is gathering evidence from various sources to lay more emphasis on perspectives or a theme (Creswell and Poth, 2017). Fellows and Liu (2015) noted that two or more data collection techniques are employed in mixed studies. They also noted that to eliminate disadvantages of each approach, quantitative and qualitative approaches are utilised, whilst gaining the merits of each and of the combination as shown in figure 4.4. During design, the qualitative data can aid the quantitative study data by helping with conceptual instrumentation and development, while the quantitative data can aid the qualitative study data by locating deviant samples and discovering representative samples (Chilisa, 2012).

Easterby-Smith et al. (2018) stated that mixed method involves four distinct categories. These include:

- Theoretical mixed method: this entails hiring models from one discipline, and using those models to describe the situations in another discipline;

- Data mixed method: in data mixed method research, collection of data is done over different sources or from different time frames;

- Investigator mixed method: this is where data collection is done by different individuals on the same situation and then compare their results; and

- Methodological mixed method: this entails the use of both qualitative and quantitative data collection methods such as interviews, field study, telephone surveys and questionnaires.

According to Love et al. (2002), the combination of quantitative and qualitative research approaches has two main advantages. These include:

(1) It enhances the transmission of knowledge in a tangible form.

(2) Greater researcher confidence in result validity and/ or reliability can be provided through convergent findings, whereas greater theoretical elaboration and definition can lead to divergence as a researcher attempts to bring together several pieces of complex puzzles into a clearer picture.

However, Chilisa (2012) suggested that a better understanding of an investigated phenomena can be aided through mixed method methods, if more information is revealed but may be lost if a single methodological approach is applied. For example, the use of semi-structured interviews or case studies in qualitative methods can proffer better understanding of the same study, but when combined with questionnaire survey of the quantitative method, can provide a broader understanding of the studied subject.
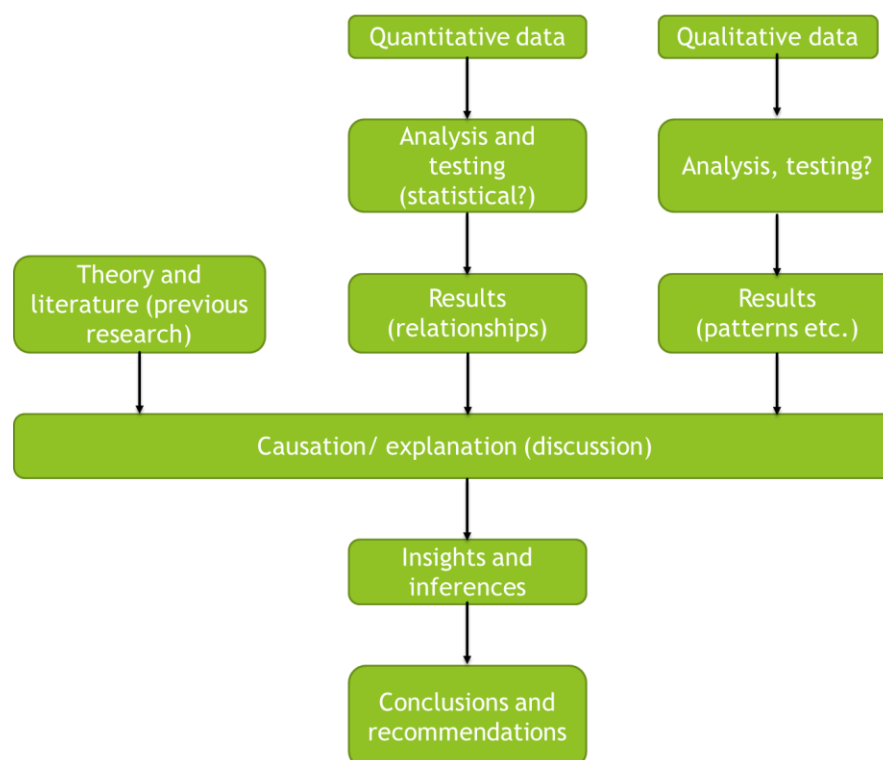
Figure 4.4: Mixed method of Qualitative and Quantitative Data (Source: Fellow and Liu, 2015)

Furthermore, Yin (2014) noted that there may be problems in the mixed method method implementation. These are: (1) It may be more expensive to collect data from multiple sources other than single source of data collection. (2) There is need for each investigator to have a full knowledge of how to conduct a full variety of techniques involved in data collection. (3)

Inappropriate use of any of the techniques can result in the loss of any opportunity to establish converging lines of inquiry or to address a broader array of issues. A summary of the distinguishing characteristics of the qualitative and quantitative research methods are stated in table 4.2 (including merits and demerits)

Table 4.2: A Summary of the Differentiating Characteristics of the Qualitative and Quantitative Methods of Research (Table adapted from: Neuman, 2006; Leedy and Ormrod, 2015).

CHARACTERISTICS	QUALITATIVE RESEARCH	QUANTITATIVE RESEARCH
Purpose	- To explore and interpret - To describe and explain - To build theory	- To explain and predict - To confirm and validate - To test theory
Objective	Discuss issues in-depth and seek details to understand people's perceptions and gain insight.	Gain real data and study links between relationships and facts according to theory
Theory	Theory can be causal or non-causal is often inductive-concerned with development of theory from specific instances	Theory is largely causal and is deductive-associated with verification of theory and hypothesis testing
Process	- Unknown variables - Holistic - Flexible guidelines - Emergent design - Personal view - Context-bound	- Focused - Known variables - Established guidelines - Statistic design - Context free - Detached view
Research procedures	Research replication is very rare and its procedures are particular	Procedures replication are frequent and they are standard
Data Collection	- Informative, small sample - Observations, interviews, documents	- Representative, large sample - Standardized instruments - questionnaires,

4.4   RESEARCH STRATEGY DECISION

A choice on an appropriate research technique to be embraced for a specific research venture is basic to create great quality research items. Nonetheless, numerous researchers battle with the difficult inquiry of how to pick a proper research methodology for the examination of research problems issue they are trying to explore (Bell et al., 2018). As indicated by Yin (2014), investigate technique ought to be picked as an element of the exploration circumstance. The three conditions that it is dependent on are: the kind of research question; the control that the examiner has over real social occasions; and the attention on contemporary rather than phenomenal histories. Table 4.3 demonstrates these three conditions, showing how to identify each with the five typical research techniques.

Table 4.3: Different Research Strategies situations (source: Yin, 2014)

Strategy	Form of Research Question	Requires Control of Behavioural Events	Focuses on Contemporary Events?
Experiment	How, Why'?	Yes	Yes
Survey	Who. What, Where, How Many, How Much?	No	Yes
Archival analysis	Who, What, Where, How Many. How Much?	No	Yes/No
History	How, Why?	No	No
Case study	How, Why'?	No	Yes

Consideration of the scope and required depth affect the choice of research strategy (Fellows and Liu, 2015). The choice between a narrow and deep study at one extreme and a broad but shallow study at the other, or an intermediate position, is depicted in figure 4.5.
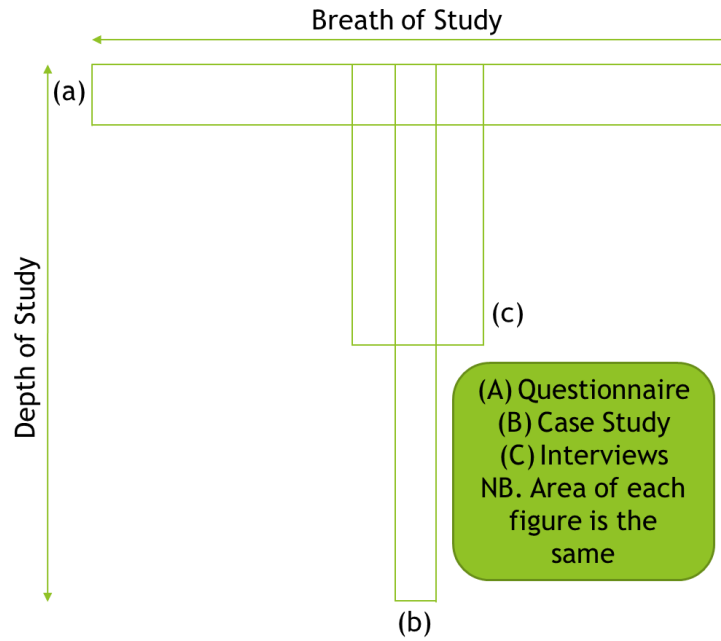
Figure 4.5: Depth and Breadth in 'Question-based' Studies (Figure Source: Fellow and Liu, 2015)

According to Leedy and Onnrod (2015), in arranging the research methodology, it is critical for the researcher not to exclusively pick a suitable research approach, but in addition, to consider the sorts of investigative information an examination of the issue will require and methods that are feasible for information gathering. The guide for the development of any methodology for research is that the research questions must be addressed (Creswell and Poth, 2017). To meet these targets, a research study ought to have a definite research plan for observation and data gathering that is associated with the objectives of the research.

4.5   RESEARCH METHODOLOGY SELECTION

This research project has the aim of formulating a process for real-time material tracking that will improve material inventory management approaches in the UK construction sector. Figure 4.6 depicts the selection of the research methodology for the purpose of achieving the research aim.
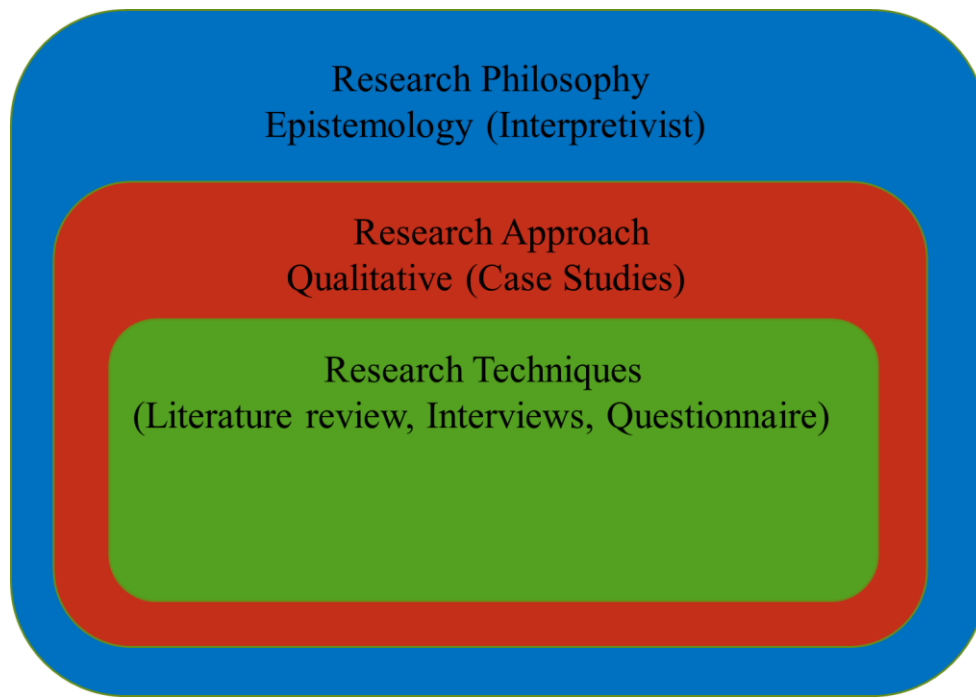
Figure 4.6: Research Methodology Selection

The research paradigm for this research is based on the epistemological philosophy and this study supports an interpretivist (qualitative) approach. This methodology is utilized such that useful knowledge can be gained into individuals' discernment and comprehension of management of materials in detail. The idea of this research aims to investigate the clarification of the construction industry perceptions in the management of materials and the usage of ICT into their practices of overseeing materials management on site. A case study strategy is applied in this research since it investigates opportunities and to accomplish further bits of knowledge into the examined area. As indicated by Lambe (2015), the case study approach is comprised of a point-by-point examination that endeavours to give an investigation of the specific circumstance and procedures engaged with the phenomenon under investigation.

Field and laboratory experiments are not included in this study, as the nitty gritty data required will mostly be founded on personal experience, which can be gotten using case studies without setting up a research laboratory for trials. The research techniques utilized for collection of data are evidence review of questionnaire, literature and interviews. The semi-structured interview was for the most part utilized for gathering information for the case study approach, and have also been used to gain information on the appropriateness and functionality for the evaluation of the technology acceptance.

4.5.1 Selection of Multiple Case Studies and Interview Techniques

The following section discusses the selection of the multiple case studies and interview techniques adopted for this research.

4.5.1.1 Multiple Case Studies

According to Blumberg et al. (2005), case study research is classified into two main types: single case studies and multiple case studies. Yin (2014) on the other hand, noted that case study research can be grouped into four types which includes: single-case (holistic) designs (Type l), single-case (embedded) designs (Type 2), multiple-case (holistic) designs (Type 3), and multiple-case (embedded) designs (Type 4). This research has chosen Type 4 approach-the multiple-case (embedded), with the end goal of making a comparison of the management of materials practices between case studies. Six construction projects involved in the multiple case studies were used as the unit of analysis whilst five 'case study unit of analysis' (i.e. embedded unit of analysis) were applied on each of the six construction projects (refer section 2.5.2). As indicated by Perry and Wiewel (2015), multiple-case studies have the ideal number of between four and ten cases. Figure 4.7 depicts the basic types of case study designs.
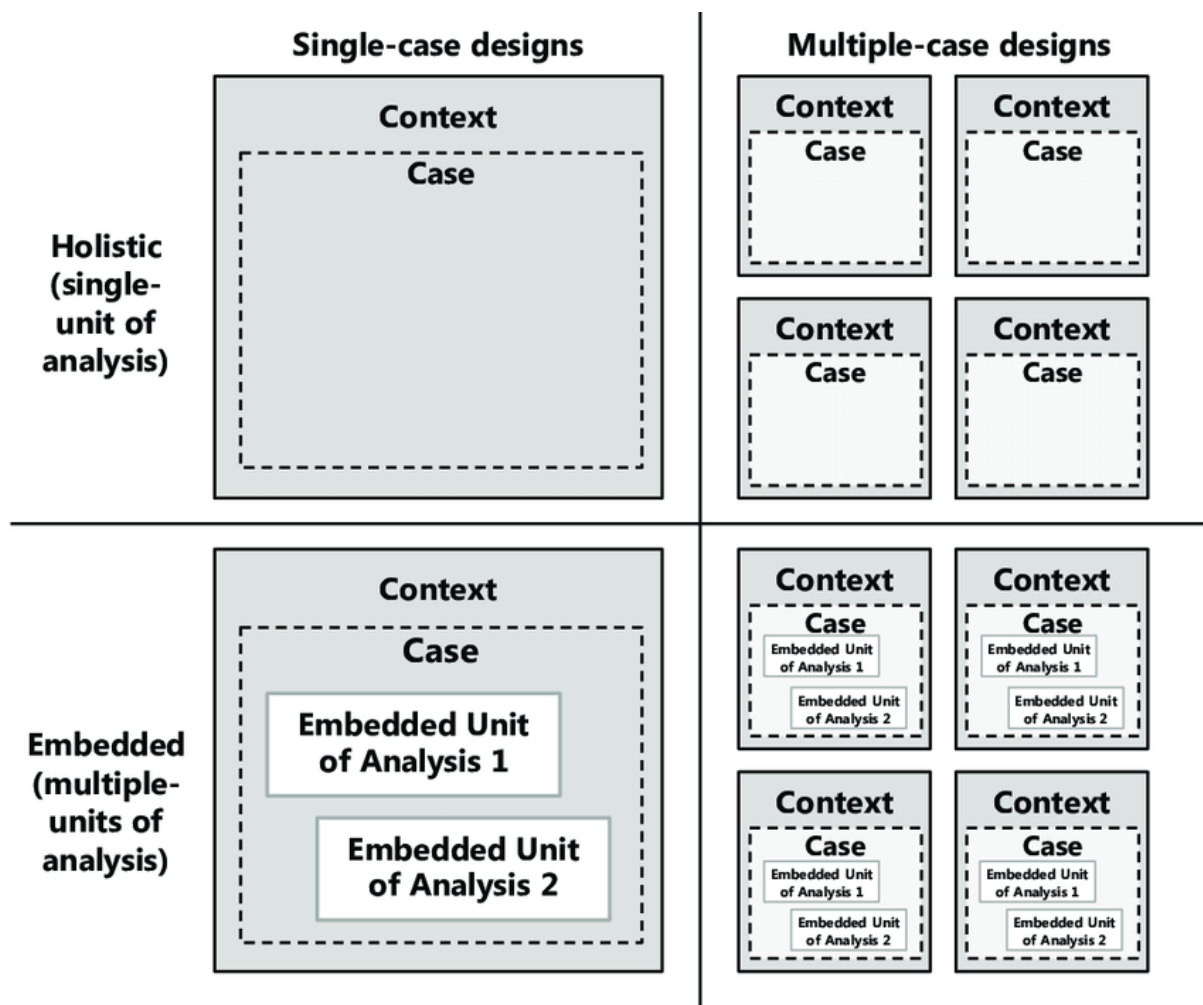
Figure 4.7: Basic Types of Designs for Case Studies (source: Yin, 2014)

A three-stage process was also developed by Yin (2014) to serve as guide to case study research, and for conducting a systematic case study approach as alluded in Figure 4.8. These procedures incorporate a define and design stage; a prepare, collect and analyse stage; and an analysis and conclusion stage. The case selection (under define and design stage) is then shown on the stages involved with the theory development while every case study is conducted and individual case report produced (i.e., tender, prepare, collect and analysis stage) and finally providing for an analysis and the conclusion stage a cross-case report.
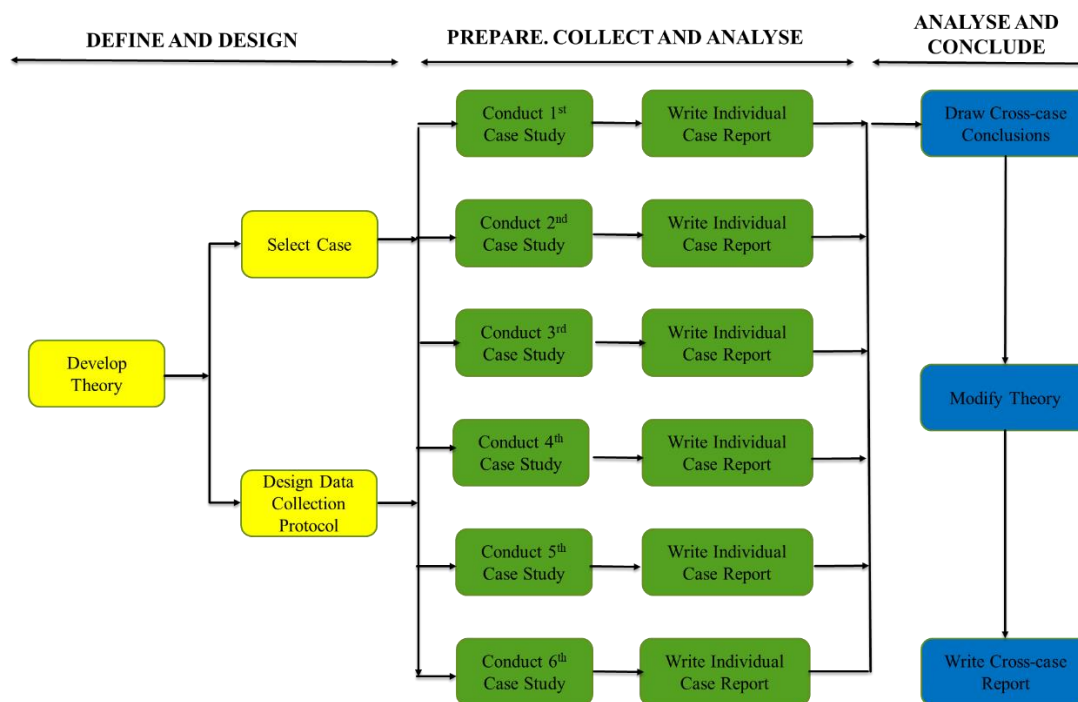
Figure 4.8: Case Study Method (Source: Yin, 2014)

A case study protocol is an essential factor when undertaking the case study research. the importance of the case study protocol is to boost the reliability of the case study research and to provide a guideline for the researcher in carrying out the case study. This will help solve the 'looseness' of the case study research (which is an inherent problem). As noted by Yin (2014), one approach to battle this 'looseness' is to set up a convention that outlines the procedures and general rules that will be utilized during the collection of data. The methods give the necessary steps to be applied such as projects overview, conclusive procedures for collection of data, and the instruments that will be utilised for data collection. Perry and Wiewel (2015) stated that, when building up a protocol for a case study, four important considerations are needed. These are:

- The unit of analysis definition: Defining the units of analysis to be used in the course of the research is one of the major issues faced in the case study design. The choice of the unit of analysis pushes the researcher to articulate the frame of reference concept and encourages the development of a proposition. Babbie (2015) noted that although the units of analysis are commonly characterized as people, groups, or association, they could nearly be any action, process, feature, or measurement of organisational conduct.

- Selection of Case: Whilst a single-case study needs just to concentrate on one case, the multiple-case study cases to be chosen with the goal that they are recreating/replicating

one another; either the recreation is done directly or predictable systematic replications. Utilizing a single-case structure, the researcher to make a solid justification in supporting the decision for using the case. Conversely, the use of the analytical conclusions freely emerging from the multiple-case study will be stronger than those originating from a single case alone.

- Collection of data: A methodical arrangement must be produced that stipulates what data is to be investigated to completely examine the research hypothesis and how this is to be gotten. According to Yin (2017) 'research protocol' is to be utilized to efficiently reports all choices relating to the research design, and to incorporate the arrangement of substantive inquiries mirroring the real inquiry.

- Data analysis: The investigation of each study research analysis looks into whether or not the proof inside each case is valid internally, conclusive, and supportive of the pre-determined hypothesis over the multiple cases. The study favoured procedure, which has formed the information gathering/ collection of data.

4.5.1.2 Interview Techniques

This research uses the interview technique to gather data necessary for the research. The interviews involve the interaction between two individuals with the end goal to finding their views and to gather explicit data; and can be divided into three methods of approach, which includes telephone interviews, face-to-face interviews and work interaction with the individuals.

The face-to-face interview method entails personal meeting approach in a two-way discussion started by an interviewer to acquire data from a participant. Blumberg et al., (2005) stated that the principal quality of this methodology is that the interviewer can pre-screen respondents to guarantee he/she fits the profile population needed; and the shortcoming of this methodology is that it is too exorbitant (both in cash and time). Blumberg et al., (2005) also noted that the telephone interview methodology is useful in masterminding individual meetings and screening huge populaces for irregular sorts of participants. The principal points of interest of this methodology are that it is less tedious and more affordable. The key shortcoming is that the rate of response is lower than for equivalent face-to-face interviews (Crano et al., 2014).

Three classifications of interviews are named as: structured interviews, semi-structured interviews and unstructured interviews (Fellow and Liu, 2015; Neuman, 2014). The structured interview involves the interviewer overseeing the completion of a questionnaire by making

inquiries and recording the reactions and making strengthening inquiries to get more points of interest and to pursue new and intriguing angles with a just little degree for examining those respondent's reactions. Under the semi-structured interview, the research interview may pursue the standard inquiries with at least one or more tailored inquiries to get further clarity or to test a person thinking. under the unstructured interview, the interviewer presents the point quickly and records all the respondent's reactions (Leedy and Ormrod, 2015). Table 4.4 makes a summary of the fundamental contrasts between structured, semi-structured and unstructured interviews.

Table 4.4: Interview Techniques Comparison (source: Wright et al., 2018)

Category	Process	Advantages	Disadvantages
Structured Interview	• Questions are set in advance • Each interview is conducted in exactly the same way • The question and their order are the same for all respondents • The range of possible responses is determined by the researcher	• Quick and easy to answer • Answers are easy to code and analyse • The direction of the inquire is clear • High degree of reliability – straightforward 'factual' information • Products comparable' data • Reduced possibility of interviewer bias	• Inflexible • Participants may be forced into giving responses which do not reflect their true feelings about an issue • Gathers a limited amount of information: lack the richness obtained by more open-ended interviews
Semi-structured Interview	• Very much like questionnaire • Open-ended questions • Permissible to stray from the subject area and ask supplementary questions • They can be used both to give and receive information	• Less intrusive to those being interviewed as the semi-structured interview encourages two-way communication • Confirms what is already known but also provides the opportunity to learning • Gives the freedom to explore general views or opinions in more details	• Requires interviewing skill • Need to meet sufficient people in order to make general comparisons • Time consuming and resource intensive • Preparation must be carefully planned so as not to make the questions prescriptive or leading
Unstructured Interview	• Exploratory approach • No prepared list of questions • Open-ended questions	• Allows flexibility • Respondents can answer in their own word • The nature of the response is not limited • The result of this more open-ended approach is a richness of data • More complex and sensitive questions possible	• Requires interviewing skill lack of standardisation • The answers are difficult to analyses • Depends on the ability respondents to express themselves • Time consuming • Largest potential for interviewer bias

The succeeding section talks about the adopted methodology for the research in detail such that the objectives and aim can be achieved.

4.5.2 Case Studies: Semi-Structured Interviews

To garner primary data needed for this research, the case study approach was utilized. Six construction projects will be involved for the case studies or in the units of analysis, and each will be investigated for its existing material tracking for inventory management process. Several criteria will be applied to selected construction projects in the research.

The case studies will utilize semi-structured interviews in which the participant will be chosen based on purposive sampling (Orcher, 2016). Purposive sampling according to Oliver (2006), is a form of sampling in which the decisions regarding the individuals involved in the research (respondents) are determined by the researcher based upon variety of criteria set by the researcher. Thus, participants for this research will be selected based on their inventory management experience and involvement; and the overall site management such as the project manager, the site supervisor or the site inventory manager.

The question schedule for the interview will involve a standardised and predetermined list of questions prepared for the interview which acts as guideline for the interview. According to Cavana et al. (2013), this is vital as the semi-structured interview need to be worded and ordered carefully in a detailed scheduled interview. The case studies finding will reveal the inventory management processes carried out in each of the project, key problems relating to tracking of materials, implementation of technology for tracking of materials, several approaches to improve tracking of materials, resource modelling and the inventory management integration.

From each case study, the identification of problems in tracking of materials enables the researcher to propose the Information and Communication Technology (ICT) for adoption, particularly RFID technology, to overcome related problems in tracking of material within construction projects. However, the decision for RFID technology adoption was made based on literature review results which shows the merits of RFID technology for tracking of materials. Implementation RFID technology enables automatic scanning of material (Ozumba and Shakantu, 2008; Sardroud, 2012), labour hours reduction in scanning materials, tracking of work-in progress, improvement of anti-theft protection and better management of inventory (Mehrjerdi, 2011).

4.6   THE METHODS ADOPTED FOR THIS RESEARCH AND CONCEPTUAL FRAMEWORK

To achieve the aim of this research, the research process will be designed such that a mechanism to improve material inventory management on construction projects is formulated. The four research objectives that were noted in chapter one in section 1.6 were developed in order to achieving this aim. The overall research process was formulated to achieve the aim and objectives of this research as illustrated in figure 4.9. Firstly, to review material management practices and implementation of Information and Communication Technology (ICT) on construction projects, a literature search was made. Secondly, to review current practices on ICT implementation and on materials inventory management, the multiple case studies approach and site observations were used.
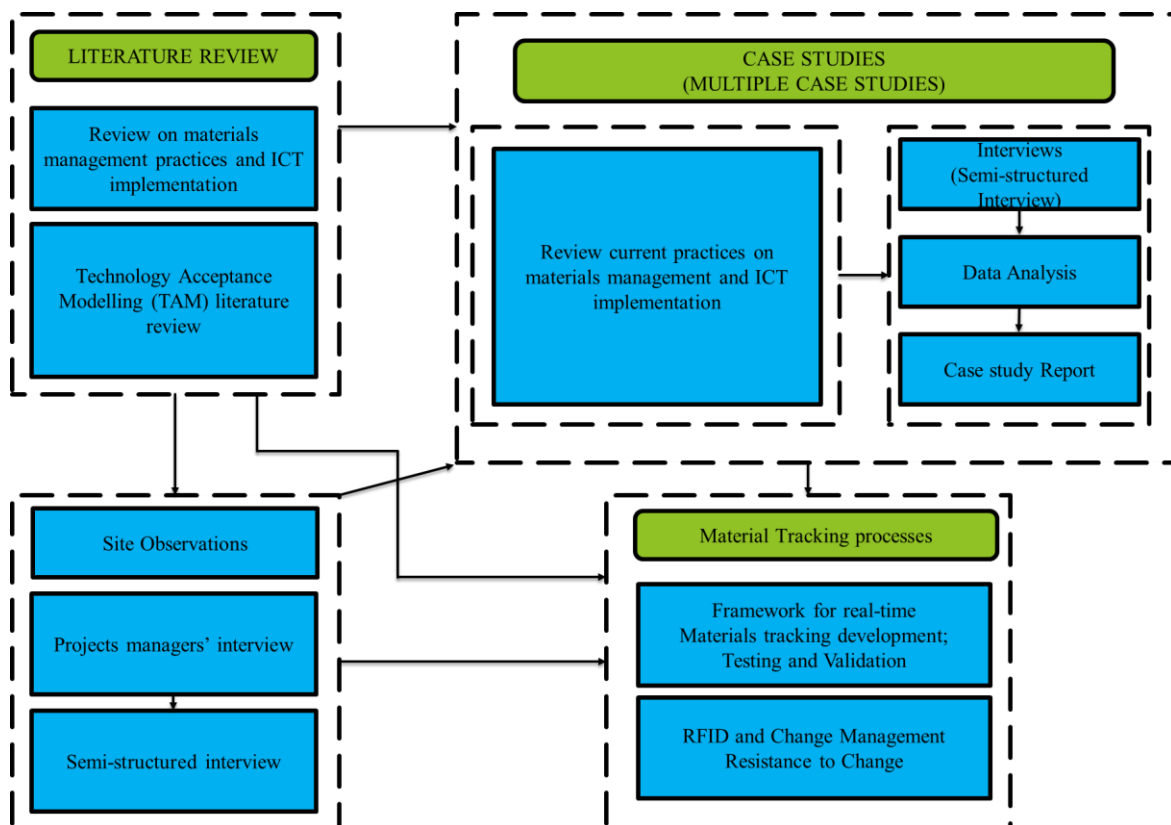
Figure 4.9: Overall conceptual framework of the research process

The research methodology used on this research were briefly described and presented in chapter 4 section 4.3; further details of this method is provided in the following sections below.

4.6.1   A Review of Literature

According to Neuman (2006), there are five main processes of the systematic literature search. These include: design and refine the search; design a search; research reports location; research

articles evaluation and note-taking. Blumberg et al (2005), stated that a crucial part of every research project is the review of the current literature. According to Sekaran and Bougie (2016), the aim of undertaking a review of literature is to ensure that no essential variable is neglected that has in the past been found to be a problem to the research area. Hence, it is essential that relevant body of literature from the previous research should also be critically reviewed, not just simply finding and reviewing the literature (Fellows and Liu, 2015).

In this research a review of literature was conducted to explore/ investigate the existing literature on management of materials on construction projects. It also examined ICT implementation and emerging technologies that support practices in management of materials in construction projects (notably for projects that are complex). This enables the research to fulfil its first objective as expected by this research that was explained in chapter 1 section 1.6. A primary source can be classified as a full-text publication of empirical and theoretical studies; such that original works are represented. Moreover, the compilations of information either in digital or printed forms is termed secondary sources.

The relevant literature searches were carried out through the Emerald Insight (an integrated search engine that facilitates search across different electronic journals and databases); British Library E-Theses Online Services (EThOS), used to search for books, doctoral dissertations and referred journals; and internet search engines such as conference proceedings, Google Scholar and company reports. After finding the related literature, the literature review of either current or previous issues are undertaken as the next step.

The first objective of the research would be achieved by the review of two main topics that have been selected as illustrated in figure 4.9.

- To ascertain problems and which forms of practices in management of materials could be improved;

- To examine the emerging technologies and ICT implementation in materials management practices support, with focus on emerging technologies which are most viable (such as RFID, BIM, Robotics, industry 4.0) for use in management of materials practices on construction projects.

The review of literature is a continuous process and will simultaneously be carried out to apprehend new gaps and issues in the existing literature. Other related topics to be researched such as TAM development process and research methodology were also reviewed.

4.6.2 **Case Studies**

To achieve the second and third objectives in this study, the case study approach was adopted. Case studies were carried out to analyse the current industrial practice in management of materials and to establish elements of good practice and other main problem areas. Case studies were also vital in identifying the use of Information and Communication Technology to aid management of materials processes, and how these could enhance the inventory management on the construction site. This will enable the achievement of the identified second and third objectives by this study. This entails probing the current practices involved in Information and Communication Technology implementation and management of materials.

The multi-case studies approach has been adopted through this research in order to examine present-day phenomenon within six construction projects. The material management practices involved among these six construction projects were compared in order to establish elements of good practices key problem areas and to spot how information and communication technology can be utilised to enhance processes involved in material and inventory management on site. These multi-case studies of the construction project will also be used to investigate the integration requirement of materials management and technology acceptance modelling to develop a sustainable system. The case studies approach has the main advantage of allowing combination of several sources, when compared to other approaches.

The case study protocols used in this research are described as follows:

A. **The unit of analysis definition**: To achieve the research objective, the 'unit of analysis' is selected to help in achieving the study objective, which is to investigate the possibility for improving management of materials practices in the construction industry through the integration of materials tracking and technology acceptance. The unit of analysis is applied on each of the construction project through this study. The adopted 'case study unit of analysis' (i.e., embedded unit of analysis) for this study are as follows:

 i. Problems/ challenges of materials management: This investigates the most significant issue that occurs with management of materials practices;

 ii. Approaches adopted to resolving the problems/ challenges: The purpose of this is to identify strategies that site/ project managers adopt to solve problems with materials management on the construction site;

iii.   Implementation of ICT: The aim of this is to identify the ICT usage in managing materials on the construction site;

iv.   Emerging wireless technologies usage: The purpose of this unit of analysis is to investigate the potential usage of emerging technologies to facilitate management of materials practices; and

v.   Systems for materials tracking: This aims to identify methods currently in use by project/ site managers to facilitate tracking of materials on the construction site.

B.   **Selection of Case**: Creswell and Poth (2017), stated that a "case" is defined by the individual managing the project, the project setting, the events that occur, and the developmental processes over the project. The focus of this research is on the integration of materials tracking and technology acceptance, hence, the selected "case" was large as well as small construction project utilised for the case study. Identification of the construction organisations used for the case study are based on large and small projects, which tried to implement new technologies (such as RFID) for tracking of materials in real-time. The criteria for selection of the six construction projects were based of the following:

i.   How complex (i.e., the project size) the materials management (e. g. logistics) were on the large and small projects; and

ii.   Adequate access to investigate the relevant management of materials issues to be explored.

There is also the willingness of individual in the organisation to partake in the study and share their experience in materials management on the construction site.

C.   **Collection of data**: Semi-structured interviews have been utilized for collection of data with the site/ project managers in each of the construction site. A set of questions were drafted as a tool to conduct a semi-structured interview to obtain views and responses of project managers or site managers about current issues and aspects of material management that requires improvement on the construction projects. The organisation of the question was done under these broad headings: main issues in the management of materials practices; approaches adopted to deal with the issues; implementation of ICT, emerging wireless technology; and materials tracking frameworks. About two to eight hours were spent on each of the interviews, which included site visit, site

observations, interview sessions, telephone conversations and working on some of the projects. The collected data from the interviews were recorded and also transcribed verbatim.

D. **Data analysis:** The aim of this was to collect the data and analyse the data to gather information on the current problems in the management of materials practices, approaches currently utilised to addressing the problems/ issues, implementation of ICT, the Emerging wireless technologies usage, and current system for materials tracking. Further details will be described in chapter four on the findings from each interview.

The collected data was basically from semi-structured interviews with the individuals involved with material management in the construction organisation. A set of questions were designed for the semi-structured interview intended to gain opinions and responses from material management personnel with respect to current issues, and aspects of material management that require improvement and investigation of current ICT implementation in material management practices on the construction projects. Semi-structured interviews were selected to enable the interviewer the opportunity to investigate expert opinion or views of the interviewee while maintaining a level of similarity between interviewees.

There are three parts to the semi-structured interviews. The purpose of part one is to get general information about the project/ site managers such as site managers' roles, project type and their level of experience in management of construction project. The second part is aimed at getting information on the current problems and implementation of ICT in the materials management practices. The third part has the aim of investigating the requirement for materials management integration and technology acceptance. Key findings garnered from the case studies were utilised to make a judgement of the issues/ problems, aspects of material management that require improvement and identification of approach to be applied in solving the problems.

In addition, from the finding, this study attempts to identify the potential for RFID usage in tracking of materials and the technology acceptance project material management system. Further details will be described in chapter four on the findings from each interview.

4.6.3 Site Observation

The third and fourth objects of the research were achieved through site observations. The researcher having worked in many sites and done site visits, was able to use this as a means of information gathering. Observations are ways of gathering information about behaviours,

events, or physical features in their natural surroundings. Observations can be overt (everyone knows they are being observed) or covert (no one knows they are being observed and the observer is concealed). During covert observation, people tend to behave naturally since they don't know they are being observed. However, due to ethical concerns, participants were made aware of the research being conducted.

4.6.4 Real-Time Materials Tracking processes

To achieve the fourth objective of the research, process of tracking material in real-time to improve material inventory management in the construction industry, will be evaluated. The material tracking process is a system approach that aids an automatic tracking of materials on the construction site. It involves a description of the material tracking process in real-time; and a discussion of the key features of the processes to improve material inventory managements in UK construction industry. Real-time materials tracking system is composed of five main components. These include

- ❖ Delivery of Materials

- ❖ Storage of Materials

- ❖ Material Usage

- ❖ Centre for On-Site Material Control; and

- ❖ Transmission Report.

A brief description of components in the conceptual approach to material tracking in real-time at the construction site is given below:

- ❖ Delivery of Materials: Tracking of the materials delivery and the material delivery status is done at this stage of the tracking process at the construction site. The portable RFID reader dictates the RFID tags attached to the purchased materials being delivered at the construction site entrance. Information about the material delivery and the delivery status will be inputted in the tags and recorded in the integrated database. Integration of the tracking system with the work programme is done at this stage such that the information can be assessed for each specific material to check their usage status.

- ❖ Storage of Materials: The material tracking and checking of material availability at the storage area are done at this stage at the construction site. Material inventory

utilisation is verified and recorded at this stage during the movement of materials in and out of the storage area. These are integrated with the work programme such that related work tasks can be identified with their specific materials.

❖ Material Usage: The tracking of material usage at the construction site, is done at this stage. The status of materials to be installed for a particular work task is provided by the work programme during this stage.

❖ Centre for On-Site Material Control: The centre for on-site material control can be set up at the site office and entails collection and analysis of all information about the construction materials in the database system; and

❖ Transmission Report: Information required to produce real-time material tracking reports are generated at the main office from all the materials information received from the site office.

A summary of the research methods adopted to achieve the objectives of this research is tabulated in Table 4.5.

Table 4.5: Summary of Research Methods Used

	RESEARCH METHODS			
RESEARCH OBJECTIVES	**Literature Review**	**Case studies**	**Real-Time Materials Tracking Development**	**Site Observations**
(1). To analyse the key different approaches to material inventory management that are being adopted in the construction industry worldwide	**X**			
(2). To analyse the approaches to material inventory management				

practices used in the UK construction industry	X	X	X	
(3). To identify the current challenges in the UK construction industry with regards to material inventory management	X	X	X	X
(4). To formulate a process for real-time material tracking that will improve material inventory management approaches in the UK construction sector				X

4.7 ETHICAL ISSUES

It is vital that research is conducted not only with expertise and diligence, but also in honesty and integrity. The cornerstone in conducting an efficient and meaningful research is the research ethics (Trimble and Fisher, 2006). Ethical issues are essential so that human right aspects of the study is protected and recognised. For the research to be rendered ethical, there should be rights of confidentiality, anonymity, informed consent and self-determination.

McNamara (2008) laid down five ethical issues to be considered when conducting survey research. These guidelines include:

1. **Voluntary participation (self-determination)**: The researcher should ensure that participation of respondents is completely voluntary (self-determination) for the research to be carried out. This need for voluntary participation creates a bias conflict especially when the need for high rate of respondents ends with low return rate.

2. **Avoid possible harm to the participants/ respondents**: There is need to avoid harming the participants/ respondents with questions that may cause embarrassment or uncomfortable feeling.

3. **Protect respondents' identity**: Protection of the identity of respondents is important especially when there want to exercise their confidentiality and anonymity.

Respondents can be regarded as anonymous if they cannot be identified. A confidential survey is also when respondents is identified by his/ her response. To ensure confidentiality, the email cover needs to state if the respondents need their identity to be confidential as regard to making report on the result.

4. **Make known identity of sponsor and purpose of research**: The fourth guideline is to make known the purpose of the research and the sponsors to the prospective respondents

5. **Accuracy of reporting**: There is need to ensure accurate reporting in the methods to be applied as well as survey results done with honesty and openness to professionals in the educational environment. There is need for research to be honest and open about problems and weaknesses experienced, and positive results on the study. This helps to advance the field of academics.

4.8   SUMMARY

The research methods that have been adopted for use in this thesis, was discussed in this chapter. The chapter presented the "nested" research methodology, which methodology according to Cooper et al. (2005), is a type of research grouped into three main key themes: research techniques; research philosophy and research approaches. There was discussion on the quantitative, qualitative and mixed methods (i.e., a combination of quantitative and qualitative) research. Research methodology selection in this chapter discussed the multiple case studies and interview techniques selected for this research. The chapter finally discussed the mixed methods adopted for this research through three main sections: a review of literature, case studies and real-time materials tracking processes. This chapter also discussed ethical issue in research which observed in the cause of writing the thesis. The next chapter focuses on case studies used to investigate current material inventory management processes, ICT implementation, challenges, the potential of using new wireless technologies (such as RFID) for materials tracking practices improvement.

5   CHAPTER FIVE

CASE STUDIES ON THE APPROACHES TO MATERIAL INVENTORY MANAGEMENT IN THE UK CONSTRUCTION INDUSTRY

5.1   INTRODUCTION

In this chapter, six construction projects were selected as case studies to investigate current material inventory management processes, Information and Communication Technology implementation, challenges, the potential of using new wireless technologies (e.g., Radio Frequency Identification) for tracking of materials practices improvement, and to integrate requirements of managing materials as well as technology acceptance. These involved semi-structured face-to-face interviews with individuals responsible for managing materials, site logistics and project management to establish the current situation regarding material inventory managements on projects site and to analyse the identified problems. These case studies are individually presented and analysed. The main findings derived from the case studies about current challenges; approaches on how these identified problems can be addressed and the potential implementation of emerging technologies to enhance tracking of materials are presented and analysed.

5.2   OBJECTIVES OF THE CASE STUDIES

The follows are the key objectives of the case studies undertaken:

- to analyse the current approaches and problems related to the management of materials in the UK construction projects.
- to investigate the ICT implementation in management of materials processes and the possibility of using emerging wireless technologies (such as RFID) to overcome difficulties in the logistics associated with management of material on complex and large construction projects.

The case study approach chosen for this research and the multiple case studies design adopted for this research has been detailed in Chapter 4 (section 4.5.1.1). The undertaken case studies cover the management of materials management approaches on six construction projects. They incorporate qualitative comparators and observations from the six cases chosen (Case A- Case F). Semi-structured interviews with individual in the materials management and site logistics (such as project managers or logistics managers) were used to collect data for analysis. The designed questions for the semi-structured interviews were in three parts (see Appendix B). The part 1 (confidential) of the semi-structured interviews was designed to capture general

background details about the interviewee such as their name, position, years of experience, company details, date of interview, role, type of project and experience involved in construction project management. Part 2 of the semi-structured interview is composed of five sections that examine the management of material processes, current approaches, materials' management problems and use of ICT in management of materials. The part 3 of the semi-structured interviews was aimed at investigating possibility of RFID usage in tracking of materials and requirements of materials management integration and technology acceptance modelling (TAM).

The 'unit of analysis' in this research purpose, is geared towards attaining the objective the research, which is to investigate the possibility of improving on-site tracking of materials and inventory management processes on construction projects through implementation of emerging technologies. The five 'case study units of analysis' (i.e., embedded unit of analysis) for this study is based on the six construction projects chosen for the purpose of this research and they are noted as follows:

- Problems/ challenges of materials management: The most significant problems that are encountered in the management of materials are explored;
- Approaches adopted to resolving the problems/ challenges: The purpose of this is to identify strategies adopted by individual (managers) to address the problems in materials management on the construction site;
- Implementation of ICT: This aims to identify the usage of ICT in material management on the construction site;
- Emerging wireless technologies usage: This examines the possibility of using emerging technologies to assist in the management of materials approaches; and
- Systems for materials tracking: The aim of this unit of analysis is to identify current approaches being used by to enhance tracking of materials on the construction site.

Analysis of data involving the single case and cross-case analysis is shown in the figure below (Fig 5.1)

Figure 5.1: Single-case and Cross-case analysis (Source: Yin, 2009)
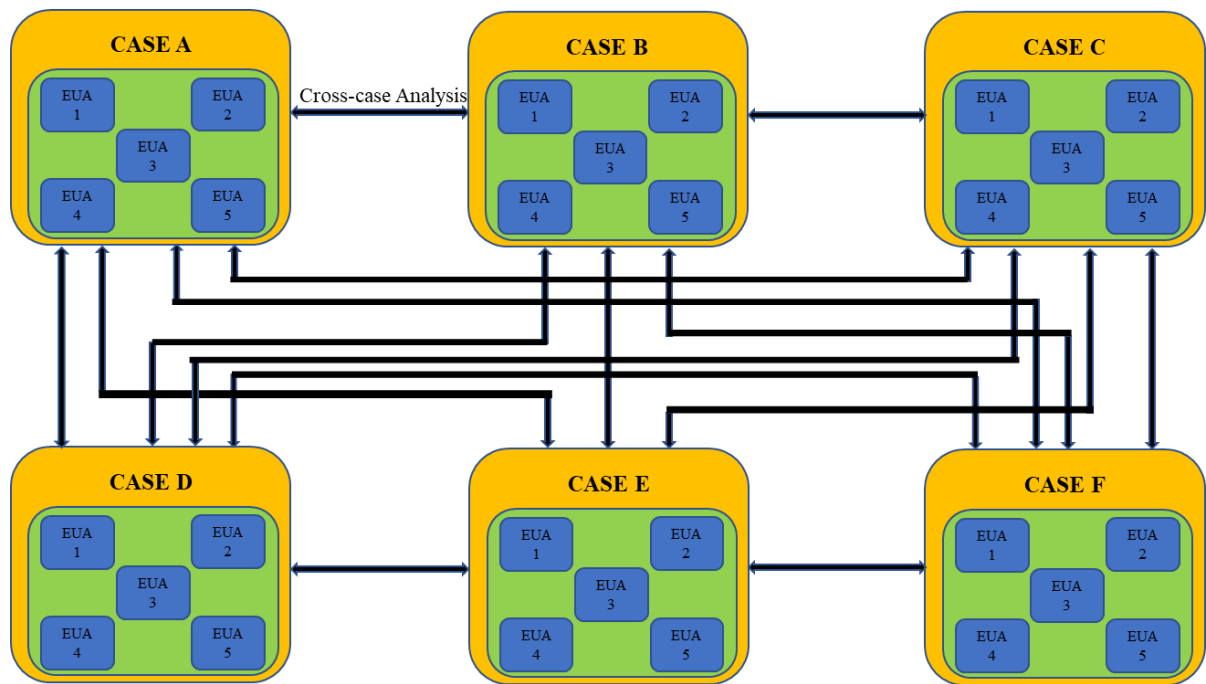
Note:

- EUA1   Case Study Unit of Analysis 1: Problems/ challenges of materials management

- EUA2   Case Study Unit of Analysis 2: Approaches adopted to resolving the problems/ challenges

- EUA3   Case Study Unit of Analysis 3: Implementation of ICT

- EUA4   Case Study Unit of Analysis 4: Emerging wireless technologies usage

- EUA5   Case Study Unit of Analysis 5: Systems for materials tracking

The essence of using single case analysis is to produce reports for the individual cases such that information can be garnered on current materials management practices, Implementation of ICT and problems of material management (refer Chapter 4 section 4.5.1.1). Stjelja (2013) suggested that this enables the case unique patterns of each case to emerge before generalised patterns are pushed across cases. The use of cross-case analysis is to allow a comparison of the 'case study units of analysis' (i.e., embedded unit of analysis) across all the different case studies (Yin, 2009). The cross-case analysis involved the examination of the five units of analysis between each case that is studied, such that key findings can be provided from an argumentative interpretation.

A summary of the key findings and the details of the undertaken case studies which were grouped according to the five main unit of analysis, are discussed in the succeeding chapter.

5.3   Case Study Projects

Six construction projects were undertaken in the case studies to explore current practices and problems faced in the management of materials and to identify the ICT implementation such that processes in the management of management will be enhanced. Useful information relating to materials tracking and the potential use of emerging wireless technologies such as RFID will also be obtained from the case studies. The first two case studies (Cases A and B) will involve identification and conducting interviews on two small projects from two different construction companies. The remaining four more case studies (Cases C, D, E and F), which will focus on larger and more complex projects. A combination of small and large projects was used in order to capture the similarity and dissimilarity of issues in materials management and the implementation of ICT and other emerging wireless technologies.

This study is based on six cases (construction organisations). The research involved the identification of construction organisations that are most appropriate for the study. The case studies were carefully and deliberately selected based on these main criteria; cost of the project (/size of the project), strive by the organisations to implement new wireless technologies (Such as RFID) for real-time tracking of materials, and the willingness of persons within the organisations to participate in the interview and share their material management experience on the construction projects. The variance in the costs of the projects give an avenue to explore differences in the issues of management of materials involving small and large-scale projects. The participant for the research interview were all experienced professionals in the construction projects with a range of 8 to 30 years of experience, while the project's cost ranged from £1.8 million to £0.5 billion. Table 5.1 presented the background information on the six construction projects involved in the case studies.

Table 5.1: List of Cases Studied

CASE	TYPE OF PROJECT	PERSON INTERVIEWED	CONSTRUCTION EXPERIENCE	COST (£)
A	Training Centre Building Project	Logistics manager	15 years	1.8 million
B	Laboratory Fit-out and Refurbishment Project	Site manager	17 years	2.6 million
C	Hospital Building Project	Project manager	30 years	380 million
D	Airport Terminals and Airfield Modification Project	Logistics manager	12 years	0.45 billion
E	Commercial office building Project	Materials manager	10	275 million
F	Residential Development Project	Site manager	20	133 million

To gain useful information for the research, visits were made to these construction sites were the projects are undergoing, and semi-structured interviews were conducted with the project managers, site managers, and/or other personnel involved in materials management on construction projects. The interviews lasted for about 2 hours, which included an interview session, site visit and working on these projects to have a feel of how materials are managed on these construction sites. The data collected from the interviews were recorded and transcribed. Supplementary data were collected from the projects plans and documents on the nature of management of materials approaches on these construction sites.

5.3.1   Case A: Building project centre for training

Project A consists of a training centre with a project cost of about £1.8 million involving the construction of three lecture theatres. Although this is not a large project, it is technically complex in nature. The logistic manager of the main contractor involved in this project was interviewed so as to capture the material management practices and current issues that relate to management of materials at the construction project.

5.3.1.1   Problems/ Challenges of Materials Management

In general, the logistic manager responsible to this project noted that there were several problems/ challenges facing management of materials for this project. These include:

- Incorrect delivery: Some of the materials delivered do not comply with the required standard (i.e., are of poor quality, incorrect product sent, goods not in good condition etc.).

- Late Delivery: due to inadequate logistics or stock and other problems involved with transportation, there may often be a delay in the supply of materials to the construction site.

- Incomplete Delivery: this occurs when there is insufficient or damage to the materials delivered.

- Storage Constraints: this involves problems with storage inadequacies or insufficient site storage space (compound space).

5.3.1.2 Approaches adopted to resolving the problems/ challenges

The logistic manager noted that there were several approaches being adopted so as to address materials' management problems on this project. He said that "all the activities involved in purchasing materials were monitored carefully to ensure that supply of materials was done correctly, there is complete compliance with required standard and delivery." Secondly, "there is constant evaluation of suppliers involved in the delivery of materials to the site to ensure timely arrival of materials and as when needed". Lastly, to deal with inadequate site storage, "the contractors are required to ensure that the materials delivered do not stay for long period at the site so as to avoid damage/ theft of materials due to unprotected and/or unsafe storage area".

5.3.1.3 Implementation of ICT

This project generally made use of the ICT tools such as

- An email system
- Microsoft Excel Spreadsheet and Project
- Fax system

Microsoft Excel Spreadsheet was employed to facilitate materials information storage and as recording system; the fax machine was utilized for the purchasing activities and the Microsoft project is used for the project planning. The emailing system employed in this project was mainly for the purpose of communication between contractors and suppliers.

5.3.1.4 Emerging wireless technologies usage

This project did not utilize any emerging wireless technologies (such as RFID) to support tracking of materials on the construction site. However, the interviewee was aware of the use

of bar-coding technologies for product tagging and use of other emerging technologies for material tracking.

5.3.1.5 Systems for materials tracking

This project currently makes use of manual practises for checking material delivery and tracking and also for stock inventory, but according to the interviewee, "there is no specific technique or two being utilised to assist in material handling on site".

5.3.2 Case B: Laboratory Refurbishment and Fit-out Project

In case B, termed 'Project B', it has a total cost of about £2.6 million and involved the fit-out and refurbishment works for a laboratory building. Though, this project was not a large-scale one, it was technically complex due to the various suppliers involved. This is a fit-out work project and is composed of two categories: Group A and Group B. 'Group A' involved a fit-out work for suspended ceilings, electrical services, air conditioning, decorations and carpet while 'Group B' involved fit-out work for furniture and demountable partitioning. The interview was done with the site manager and their duties on the project covered the overall refurbishment and fit-out works.

5.3.2.1 Problems/ Challenges of Materials Management

The site manager, in managing this site, identified various challenges/ problems in relation to management of materials as follows:

- Damages to materials: there are sometimes material damages to when they are being delivered to site;
- Late delivery: supply of materials to construction site sometimes experiences delays;
- Lack of materials: This problem happened when supplier's requirement was not met by the contractors, such situation include late payment of purchased materials. Materials delivery and storage level at the construction site are affected.
- Materials logistics: these problems are encountered while moving of materials by labour to the places they are need; and
- Improper handling: this is due to poor materials' handling by labourer on site.

5.3.2.2 Approaches adopted to resolving the problems/ challenges

The site manager noted that: "Firstly, when there are any problems with the delivery of materials (such as shortages, late delivery or damages to materials) the suppliers were immediately advised. The second strategy in use involved referral of any problems on the

project to the Quality Officer, who assist in resolving problems that relate to the material quality. And the last strategy which is applied when dealing with the logistics within the work place, is that all work by labour is carefully monitored and controlled; to avoid double handling and having to make same mistake by labour force, the site manager makes clear directive and delegates certain work processes to the workers".

5.3.2.3   Implementation of ICT

This project generally made use of the ICT tools such as

- An email system
- Microsoft Excel Spreadsheet and Project
- Fax system

The emailing system employed in this project was mainly for the purpose of communication between contractors and suppliers. Microsoft Excel Spreadsheet was employed to facilitate materials information storage and as recording system; the fax machine system was utilized for the purchasing activities, for storing all materials information and to send hard copy documents; and the Microsoft project is used for the project planning.

5.3.2.4   Emerging wireless technologies usage

The usage of emerging technology was not utilised on this project to assist in tracking of materials on the construction site, but the site manager was aware of the need automated tracking of materials using some emerging technologies.

5.3.2.5   Systems for materials tracking

This project still made use of the manual methods to facilitate materials tracking for the aim of inventory checking/management and delivery confirmation.

5.3.3   **Case C: Hospital Building Project**

In case C, the project termed 'Project C', has a total cost of about £330 million involving the construction of a hospital building. Project C was a complex and large construction work that involved many sub-contractors and various work tasks. The sub-contractor was interviewed. The main contractor duty was the construction of the main building which had seven levels with a rooftop mounted plant room and basement. From the interview, the approach generally adopted for management of materials was identified, but to have better insight into materials supply information, another interview was organised with another sub-contractor involved on the project. The sub-contractor's site manager was interviewed, and their duties included

plasterboard works and installation of pipes in the Acute building consisting of 8 operating theatres and 110 bedrooms.

5.3.3.1 Problems/ Challenges of Materials Management

The following problems, were what the project manager that was interviewed, identified as some of several problems encountered in the management of materials at the construction site:

- Inadequate storage space: The construction site does not have sufficient space for storage of materials;

- Problems with Tower crane distribution: Due to the high demand for tower crane operations, it has been difficult to move materials that need tower crane lifting to be done when required;

- Materials logistics problems: The construction site has logistics problems with the storage constraints (such as storage of materials in a separate location);

- Small loading area: There are constraints in the materials loading and unloading of materials because of the small areas available for loading; and

- Access problems at site: Due to the single site access point there were usually traffic congestion especially when there were numerous vehicles entering into the construction site within same period.

5.3.3.2 Approaches adopted to resolving the problems/ challenges

'Project C' being such a complex and large project, there was a necessity to have a good strategy that will enable the problems to be handled properly. The project manager noted that: "to overcome the problems faced with the distribution and logistics of tower crane, there is regular coordination meetings and discussions with all sub-contractors. Provisions were also made for the activities of the tower cranes to be proper scheduled and a record of all the operations within the construction site done. The construction site employed the services of traffic marshals, security guards and banksmen to deal with the single access problems and for the traffic flow management in and out of the construction site. It is also the responsibility of the security guard to ensure the safety of equipment, construction materials, and many other valuables in use at the site with the aid of the CCTV mounted at strategic area of the project site. The project implemented Just-in-Time (JIT) techniques were implemented to deal with site storage space inadequacies and the small loading area challenges for the material delivery at the project site:".

5.3.3.3   Implementation of ICT

The project used all the basic information and communication technology tools for material inventory managements in the construction project. Such ICT tools include:

- Microsoft Excel Spreadsheet and project;
- Fax system; and
- An e-mail system.

The project used the fax machine for purchasing activities; the e-mail system for the purpose of communication; the MS project is used for project planning, while Microsoft Excel Spreadsheet was used for collating information on materials and as a database recording system.

5.3.3.4   Emerging wireless technologies usage

This project did not utilise emerging technologies to facilitate tracking of materials practices. However, the interviewee was conversant with the potential of emerging technologies in enhanced tracking of material, speed up of ordering, paperwork reduction, and improved checking and efficient control of materials.

5.3.3.5   Systems for materials tracking

Tracking of materials on this project were manually done, but the interviewee was aware material tracking using tagging technologies (such as RFID and bar-coding).

5.3.4   **Case D: Airfield Modification and Airport Terminals project**

Airfield Modification and Airport Terminals project ('Project D') has a total cost of about £450 million involving the modification of the airfield and airport terminal. This covered the development of a new aircraft pier stands and the demolition of an old pier. This also allowed for an arrival corridor construction, to enable improvement of the security and segregation for the passenger's arrival and departure. Furthermore, it involved the building of a new retail stores and multi-storey car park. To research the consolidation centre operation and functional implementation, an interview was conducted with the logistics manager. Their company provided logistics services to counter the limited space challenges encountered with the storage of materials at the construction site.

5.3.4.1   Problems/ Challenges of Materials Management

The following are the most significant challenges the project manager faced on 'project D':

- Insufficient site space: the storage area has inadequate space for materials storage at the construction site;

- Late material delivery: the construction sometimes experiences late delivery (within aircraft lay down boundary) for materials into the project sites. This time constraints are most times affected by delays due to aircraft operation;

- Regulatory consideration: because of the security regulations, there are difficulties with the materials supply activities into the construction site. There are also time permission constraints on the sub-contractors to exit the construction site within airport lay down boundary;

- Insufficient loading area: there are inadequate area provided for loading and unloading operation at the consolidation centre; and

- Congestion time: during the peak hours, the consolidation centre experience challenges when there many vehicles delivering materials in and out of the centre.

5.3.4.2 Approaches adopted to resolving the problems/ challenges

To deal with all the problems mentioned above, the project case adopted several approaches. The consolidation centre was implemented into this project to ensure that the construction materials were correctly and efficiently delivered at the required time and to the right construction site. The consolidation centre acts as an assembly point for collection of all materials transported into the site before they are distributed to their points of need in the construction site. This method helps to avoid the materials congestion at the loading area of the site. The consolidation centre implementation also helps to resolve the lack of storage space problems on the site. Moreover, the consolidation centre also proffered solutions to other challenges encountered, like the safety and security improvement of site; congestion reduction from traffic within the perimeter of airport; delivery reliability and improvement; materials loss reduction; enhanced efficiency of workforce; and other related environmental benefit. The airport security department provides regulations and night-time operation permission that must be followed for materials transportation (within laid down aircraft boundary) into the construction site.

5.3.4.3 Implementation of ICT

The project used all the basic information and communication technology tools for material inventory managements in the construction project. Such ICT tools include:

- Microsoft Excel Spreadsheet and Project

- A Faxing system;

- Bar-coding;

- E-mailing system; and

- RFID system.

The project used the fax machine for purchasing activities; the e-mail system for the purpose of communication; the MS project is used for project planning, while Microsoft Excel Spreadsheet was used for collating information on materials and as a database recording system. To facilitate material delivery identification and validation, Bar-coding was used. There was limited use of the RFID systems by one of the sub-contractors.

5.3.4.4   Emerging wireless technologies usage

The project manager that was interviewed noted the vital need for utilizing emerging technologies in advancing material tracking and other materials management practices. The interviewee said, "The implementation of emerging technologies in advancing material tracking and other materials management practices help to speed up ordering, tracking of materials, reduction in paperwork, and enhance more efficient materials checking and control."

5.3.4.5   Systems for materials tracking

This project used bar-coding and manual practices in its activities to facilitate material tracking operations. To facilitate material delivery identification and validation, Bar-coding was used in the consolidation centre operation and to provide effective materials management. There was limited use of the RFID systems by one of the sub-contractors for specific operation that were not disclosed by the project manager.

5.3.5   Case E: Commercial office building project

In this case E, the project termed 'Project E', has a total cost of about £275 million and involved the construction of a new Commercial office building project. This project has over 150 sub-projects and consisted of 18 main projects on a 300-hectare site. The project covered a huge and extensive complex programme of operations. It encompassed a vast civil engineering works including tunnelling, excavation, concrete sub-structures, reinforcement, paving concrete, curtain walling and roofing. Other works included a network of new roads, car parking, waste management, retail and other facilities. Interviews were undertaken with the business improvement personnel and the material logistics manager of the main client, to gather the information on the management of material practices and perspectives of main contractor.

5.3.5.1 Problems/ Challenges of Materials Management

The following problems, were what the interviewees identified as some of several problems encountered in the management of materials at the construction site:

- Inadequate storage space: The construction site does not have sufficient space for storage of materials;

- Supply chain constraint: due to the huge and various number of suppliers and materials, there is a vast challenge created with managing contractors' as well as suppliers' commitment to carries out their duties effectively;

- Project size problem: due to the physical access problems and the project scale/size, there is challenges with the traffic overflow and effect on surrounding local roads around the construction site;

- Late material delivery: the construction sometimes experiences late delivery for materials into the project sits. This material supply constraints are most times due to the huge amount of materials and dealing with various suppliers. Suppliers from outside the country also cause these delays because they require more time to clear goods and deliver to site; and

- Incorrect delivery: some of the materials delivered on site do not comply with specific standard requirements, in which case, needed to be returned to suppliers. This problem affected the materials delivery processes into the construction site.

5.3.5.2 Approaches adopted to resolving the problems/ challenges

According to the material logistics manager of the main client, "a Project Flow System was developed on this project to allow workflow management system that is transparent and coordinates project team member's team better; identify efforts to improve performance; and share resources." The materials manager also noted that a Logistics Centre (LC) was implemented to ease the vast number of materials was employed in this project activities. Within the construction site, the Logistics Centre was used to control materials logistics while the LC acted as a buffer for vehicles loaded with materials before were supplied into the project site. This project also applied the Just-In-Time (JIT) technique to allow delivery of the right materials at the right time and to the right required place. The application of this arrangement was to avert vehicles and materials congestion traffic approaching the project site. Furthermore, the application of the JIT and LC techniques were also to resolve many challenges that relate to handling of materials on the project site, such as loss of material, late delivery, materials not

meeting up with requirement standards, congestions on site, site storage constraints, overflow of traffic in the surrounding local roads and into the construction site.

5.3.5.3 Implementation of ICT

The project ('Project E') used all the basic information and communication technology tools for material inventory managements in the construction project. Such ICT tools include

- A project flow system;
- A faxing system;
- MS Excel spreadsheet;
- An e-mail system;
- Microsoft Excel Spreadsheet;
- Bar-coding; and
- RFID system
- MS Project

'Project E' was a big project but combined the use of high-end technologies (such as RFID, barcoding, Project Flow System) with basic ICT tools (such as Microsoft Excel spreadsheet, e-mailing system, fax system) to assist with the management of materials on the project site. To support management of materials in the project site, the basic ICT tools such as Microsoft Excel spreadsheet and fax machine were utilised, and for the purpose of communication only, e-mail was utilised. The bar-coding system was used on this project to track re-bar materials during delivery of the materials. The Project Flow System was developed on this project to allow workflow management system that is transparent and coordinates project team member's team better; identify efforts to improve performance; and share resources. The Project Flow System drives the materials flow more effectively and collects work activities related to the team's demand. In line with actual construction methodology, the project developed assembly packages to enable break down of project activities into units of production that are more manageable. The developed assembly packages allowed for procurement, fabrication and delivery of all assembly parts to site and ready for installation.

5.3.5.4 Emerging wireless technologies usage

RFID and PDA were the emerging technologies being used on this project; their application was only used for the specific tasks, such as the utilization of PDA to aid monitoring of daily construction activities and the use of RFID to track precast columns.

5.3.5.5 Systems for materials tracking

'Project E' applied the use of tagging technologies such as RFID and bar-coding supported by manual practices of material tracking materials. The project used bar-coding to monitor the re-bars materials delivery, and at the LC for controlling and tracking practices. The utilisation of the RFID was for precast column tracking at the different stages of their construction processes.

5.3.6 Case F: Residential Development Building Project

The last case to be considered is 'Project F', involving the construction of a residential development building and having a total cost of about £133 million. The building project is composed of a total of 298 apartments building comprising of 249 private apartments and 49 affordable housing units. Interviews were undertaken with the site manager of the main client.

5.3.6.1 Problems/ Challenges of Materials Management

The site manager identified several problems in relation to materials management, such as:

- Location of the project: the project location is a problem because of the busy nature of the area which has affected the material delivery activities at the project site;

- Material logistics problems: There were logistics problems at the construction site due to surrounding public infrastructure such as local roads, schools and railways. This made it very hard for the transportation of concrete and large construction material in and out of the construction site;

- Congestion time: Due to the public schools, school operations (school run) time was created in which were no delivery of material during such time. This created more challenges during the peak delivery time because of the huge number of vehicular traffic in and out of the site; and increased the waiting time of delivery vehicles for unloading materials at specific storage area;

- Site access constraints: Access permission was required from the local authority on this project for material transportation and delivery into the construction site during school operations (school run);

- Regulation consideration: The contractor observed regulatory considerations by seeking permission from local authority to manage delivery of materials into the project site.

5.3.6.2 Approaches adopted to resolving the problems/ challenges

To address the problems, interviewee stated that, "the main contractor co-ordinates the sub-contractor's daily operations by conducting meetings on a daily basis …". Because of the

surrounding public infrastructure/facilities such as railways and schools, the movement of concrete and large construction materials into the site is the biggest concern with regards to material logistics at the project site. Empty buildings and car park areas were utilised for storage purposes. Moreover, lockable storage facilities were use to store valuable materials and small items. The implementation of the project flow system to integrate work programme with the resources planning to enable proper management of all the resource information and activities.

5.3.6.3 Implementation of ICT

Generally, the materials management on this project was supported by several ICT tools, including:

- Fax system was used to carry out purchasing activities;
- E-mail system was utilised for purpose of communication;
- Materials information storage was done on the MS Excel Spreadsheet; and
- The project used the Project Flow System for project management and resource planning.

5.3.6.4 Emerging wireless technologies usage

The use and implementation of emerging technologies was not supported in project, though, the interviewee was well informed of the RFID importance in providing efficient material controls and automatic tracking of materials at the project site. The main contractor's site manager noted there were many things to be considered for RFID to be implemented such as construction workers (skill requirement needs) and for suppliers/ manufacturers' collaboration (for tagging purposes) and standardised materials labelling.

5.3.6.5 Systems for materials tracking

Manual methods of tracking materials were utilised on this project to facilitate materials management at the project site. The site manager that was interviewed was well informed of RFID use and supported potential use of tagging technologies like the bar-coding and RFID to enhance material tracking on the construction site.

5.4 CHAPTER SUMMARY

This chapter undertook an analysis of six case studies to investigate current material inventory management processes, ICT implementation, challenges, the potential of using new wireless technologies (such as RFID) for materials tracking practices improvement, and integration requirements of materials management. The undertaken case studies cover the management of

materials management in construction sector and to aid achieving the research objectives. From the analysis carried out, findings have revealed that each of these projects has related problems of storage area inadequacy at the project sites. There was general use of manual methods in all cases studied in tracking of delivery materials, controlling material damage and material identification at storage units. These material management activities result in massive use of paperwork and several human errors due to use of manual methods on the project site. The succeeding chapter will make an analysis on key findings in more details of the undertaken case studies.

6 CHAPTER SIX

ANALYSIS ON KEY FINDINGS FROM CASE STUDIES

6.1 INTRODUCTION

This chapter discusses a summary of the key findings and the details of the undertaken case studies, which were grouped according to the five main case study unit of analysis (i.e., embedded unit of analysis). The units of analysis will enable analysis on the key findings from the cases studied.

6.2 KEY FINDINGS FROM CASE STUDIES

The case studies of the different projects that have been studied, have revealed that each of these projects has related problems of storage area inadequacy at the project sites. The problems of material management, approaches to resolving materials management challenges, implementation of Information and Communication Technology (ICT), emerging wireless technologies usage, and systems for materials tracking are summarised in Table 6.1 and discussed below. The cross-case analysis was used to discuss the six cases studied using five 'case study units of analysis' (i.e., embedded unit of analysis), and the these are as follows:

- Case Study Unit of Analysis 1: Problems/ challenges of materials management;
- Case Study Unit of Analysis 2: Approaches adopted to resolving the problems/ challenges;
- Case Study Unit of Analysis 3: Implementation of Information and Communication Technology (ICT);
- Case Study Unit of Analysis 4: Emerging wireless technologies usage; and
- Case Study Unit of Analysis 5: Systems for materials tracking.

Table 6.1: Cross-Case Analysis of the Cases

ELEMENT OF ANALYSIS	CASE A	CASE B	CASE C	CASE D	CASE E	CASE F
Materials Management Problems	•Incorrect delivery •Late Delivery	•Damages to materials •Late delivery	•Inadequate storage space •Problems with Tower	•Insufficient site space •Late material delivery	•Inadequate storage space •Supply chain constraint	•Location of the project

	•Incomplete Delivery •Storage Constraints	•Lack of materials •Materials logistics •Improper handling	•crane distribution •Materials logistics problems •Small loading area •Access problems at site	•Regulatory consideration •Insufficient loading area •Congestion time	•Project size problem •Late material delivery •Incorrect delivery	•Material logistics problems •Congestion time •Site access constraints •Regulation consideration
Approaches adopted to resolving the problems/ challenges	•Constant and careful evaluation and monitoring •Standardization compliance •Minimal storage control	•Quick response to problems •Referral of problems to quality officer •Carefully monitoring and control. •Clear directive and work delegation	•Regular coordinated meetings and discussions with stakeholders •Proper scheduling and recording of all the operations •Implementation of Just-In-Time (JIT) •Provision of enough storage •Regular and scheduled stock checking	•Implementation of consolidation centre to resolve problems/ challenges •Mandating airport security department to provide regulations and permission for operations on the project site	•Development of project flow system •Implementation of Logistics Centre (LC) •Implementation of Just-In-Time (JIT)	•Development of project flow system •Regulation compliance •Daily meeting
Implementation of ICT	•E-mail system •Microsoft Excel	•E-mail system •Microsoft Excel	•Microsoft Excel Spreadsheet and Project	•Microsoft Excel Spreadsheet and Project	•Fax system •E-mail system	•Fax system •E-mail system

	Spreadsheet and Project •Fax system	Spreadsheet and Project •Fax system	•Fax system •E-mail system	•Fax system •E-mail system •Bar-coding	•Microsoft Excel Spreadsheet •Bar-coding •Project Flow System	•MS Excel Spreadsheet •Project Flow System
Emerging wireless technologies usage	•No	•No	•No	•Yes (RFID)	•Yes (RFID, PDA)	•No
Systems for materials tracking	•Manual	•Manual	•Manual	•Manual •Bar-coding •RFID	•PDA •RFID •Manual •Bar-coding	•Manual

6.2.1 Problems/ challenges of materials management

In general, the revelations from the case study findings show that the main challenges/ problems encountered in the management of material operations relate to site storage constraints; materials handling and distribution logistics on the project sites; and construction site material ordering and delivery as shown on table 6.2. Moreover, the findings also showed that the most commonly occurring problems on the cases studied had to do with site storage constraints and late delivery of material problems. As can be evident from the findings, late delivery of materials was suffered more on four case studies (i.e., Case A, B, D, E) while site storage constraints were suffered more on another four case studies (i.e., Case A, C, D, E). The second most occurring challenges has to do with the material logistics problems which was suffered on three cases that were studied (i.e., Case B, C, F). Similar management of material issues were highlighted by previous researchers in their study such as improper material storage (Hore and West, 2004), large material storage capacity requirement (Bankvall et al., 2010), increased cost of inventory due to early delivery of materials (Mehr and Omran, 2013), difficulties in material transportation (Abdul Kadir et al., 2006), and late material delivery (Hwang et al., 2013; Rosenfeld, 2013).

Furthermore, some of other problems that were suffered by at least two cases were inadequate area for loading, incorrect delivery, problems due to site access, regulatory consideration, and congestion time problems. Incorrect delivery occurred in Case A and E; inadequate area for loading was suffered in Case C and D; problems due to site access occurred in Case C and F; while regulatory consideration and congestion time problems were suffered in Case D and F. Problems that were evident in a single case study each occurred were as follows: constraints due to lack of storage compound and incomplete delivery which affected Case A; Case B suffered improper handling, lack of material and materials damage problems; Case C suffered problems of tower crane distribution; project size and supply chain problems occurred in Case E; and Case F had project location problems.

Previous research indicated that the shortage or lack of materials can result in delay and loss of productivity in construction activities (Sweis et at., 2008; Aibinu and Odeyinka, 2006; Sambasivan and Soon, 2007; Abdul-Rahman et al., 2006; Le-Hoai et al., 2008). Some of the other problems that were indirectly highlighted on the cases that were studied, but remain challenges faced in the case studies, include non-compliance with specifications and use of manual processes (i.e., excessive paperwork usage). Previous researchers identified these indicated problems in their research which they suggested to influencing management of material processes in construction sites (Abdul Kadir et al., 2006; Aibinu and Odeyinka, 2006; Mehr and Omran, 2013).

Table 6.2: Problems/ Challenges of Materials Management from the Case Studies

Problems/ Challenges of Materials Management	CASE A	CASE B	CASE C	CASE D	CASE E	CASE F
Late delivery of materials	*	*		*	*	
Site storage constraints	*		*	*	*	
Material logistics problems		*	*			*
Incorrect material delivery	*				*	
Inadequate area for loading			*	*		
Problems due to site access			*			*

Regulatory consideration issues				*		*
Congestion time problems				*		*
Others: **Incomplete delivery**	*					
Constraints due to lack of storage compound	*					
Materials damage problems		*				
Lack of Materials problems		*				
Improper material handling		*				
Problems of tower crane distribution			*			
Supply chain problems					*	
Challenges due to project size					*	
Project location problems						*

6.2.2 Approaches adopted to resolving the problems/ challenges

The feedback from the studies showed that many of the construction companies have encountered the challenges of late delivery on the project site. Different approaches have been adopted by different projects to address the problems of late delivery and each case solution differed from another case solution of dealing with the late delivery problems. Case A approach to dealing with the challenges of late delivery was through constant evaluation and monitoring approaches, while quick response was utilised by Case B to enable notify suppliers when they experienced any unexpected event like late delivery. The Consolidation Centre (CC) was implemented by Case D to deal with any late delivery of material problems and they also adhere to the airport security requirements. Furthermore, the Logistics Centre (LC) was implemented on Case E to enable delivery of materials to be stored in a temporary storage compound, and

Just-In-Time (JIT) technique was also adopted to overcome the problems of late delivery. To overcome the problems of material delivery and to achieve better management of delivery of materials to project sites, they noted the need for collaboration between contractors and suppliers.

All the construction companies that were interviewed experienced the problems of inadequate storage on-site that would enable them to store materials on site and both large as well as the projects (Case A, C, D, E) that were studies, was affected. Moreover, more consideration was needed by large scale projects to tackle the problems because of the projects' size, and the vast amount and the variety of materials used for the construction activities. In dealing with the problems of inadequate storage site, the cases that were studied had adopted some approaches that will enable them to overcome these problems and these included: Case A had to undertake minimum stock control on site; Cases D and E had to implement the Just-In-Time (JIT) techniques; while the Consolidation Centre (CC) was implemented by Case D to tackle the problems. The problems of materials logistics were caused by constraints on the material transportation activities to the project sites because of the single access, congestion of materials at peak time and public regulations constraints. Furthermore, the cases that were studied had to overcome these challenges by implementing the various approaches such as: Case B provided clear instructions and monitor operations; Case C had to implement JIT techniques, undertake coordinate meetings and regular discussions, while Case F carried out daily meetings with stakeholders.

In addition, Case E implemented Just-In-Time (JIT) techniques to deal with the challenges of incorrect delivery, project size and supply chain problems; Case D used JIT techniques to deal with the problems of inadequate loading area; while JIT was used by Case C to manage site access problems. Other approaches adopted by the cases studied were the setting up of the Logistics Centre and Consolidation Centre to overcome: Congestion time problems and lack of adequate loading area by Case D; project size, supply chain and congestion challenges by Case E. Compliance with the local authority regulations is needed by most of the cases studied to: deal with regulations requirements and to overcome site access problems by Case C and D; and deal with issues of project location by Case F.

Case A had to overcome the challenges of storage constraints and incomplete delivery by adopting the approaches of regular monitoring of operations, constant evaluation and observing minimum stay control approach. A Quality Officer has been appointed by Case B to enhance

150

inspection of delivered materials to aid quick response to suppliers when on-site material level has gone down, deal with materials damages and to overcome the problems of improper material handling; while issuance of clear instruction and monitoring of construction workers was done by the contractor. The approaches adopted on the construction site to deal with the challenges of tower crane distribution operation by Case C was through proper record scheduling.

6.2.3 Implementation of Information and Communication Technology (ICT)

The use of basic Information and Communication Technology (ICT) tools were generally utilised in all the projects used in the case study, such as the use of the fax system for purchasing activities and the utilisation of Microsoft Excel spreadsheet to assist in all material information storage. These basic ICT tools were most common practices used in cases A and B, which were small scale projects materials management in construction works.

Moreover, current practices in large-scale construction projects still utilised these types of basic ICT tools as were seen in cases C, D, E and F. The e-mailing system was used in case B for the purpose of materials ordering and for communication, yet a fax system was still used to produce documents in hard copy. Cases A, C, D, E and F only utilised the e-mailing system for the purpose of communication.

In addition, a Project Flow system was implemented as a tool in Case E to organise project team members better, to provide a transparent system for workflow management, to identify the effort to performance improvement and for resources sharing. The materials management could be driven through the Project Flow system, to support the assessment of relation between the work activities and the team's requirements. The project flow was also implemented in the project operations in Case F to support resource planning integration with the work programme and to properly manage all activities and centralise resource information. Cases D and E project sites used the bar-coding system to enhance tracking of materials. Bar-coding system was also utilised in Case D to track materials and for the purpose of validating material delivery time to the site, date and its current location. Also, the bar-coding system was applied in Case E to assist in the rebar tracking and control.

6.2.4 Emerging wireless technologies usage

The cases that have been studied have revealed that use of emerging wireless technologies (such as Radio Frequency Identification (RFID) and Personal Digital Assistant (PDA)) were not adequately utilised. Of the six cases that were studied, it was only two the made use of them

in their project site, with most case study construction companies not utilising them in their operations. Notwithstanding, the people that were interviewed were aware of the importance of wireless technologies usage (such as RFID technologies) in their management of materials practices. The emerging wireless technologies implementation can facilitate efficient material control, speed up ordering, tracking of materials improvement, reduction in the use of paperwork and will assist in checking of materials. Cases D and E that implemented the use of emerging technologies such as RFID into their management of materials practices, have revealed the importance of its usage. At the consolidation centre and logistic centre in Cases D and E, Radio Frequency Identification (RFID) was utilised to facilitate control of materials delivery and to track precast column; and Personal Digital Assistant (PDA) was used in case E construction site to assist in checking daily construction activities.

Furthermore, some of the few requirements, which impacted on the construction workers among other things, were the adoption of RFID and PDA in the construction activities. The construction worker was affected because of the requirements to undergo new training to enhance their technical capability (such as information and communication technology knowhow; willingness to accept and learn new emerging wireless technologies; and to increase their work discipline. There is need for construction industry to educate construction workers by assisting in their training and retraining, and provision of adequate technical expertise in ICT. Through the adoption of such emerging wireless technologies, the organisations will benefit maximally, and the significant advantage of such implementation, is that there will be an overall improvement to the materials management processes. Emerging wireless technologies literature reviews (in chapters two and three) can proffer a better solution to the problems that are currently faced in material management such as: late delivery of materials, site storage constraints, material logistics problems, incorrect material delivery, inadequate area for loading, problems due to site access, regulatory consideration issues, congestion time problems, incomplete delivery, constraints due to lack of storage compound, materials damage problems, lack of materials problems, improper material handling, problems of tower crane distribution, supply chain problems, challenges due to project size, and project location problems.

6.2.5 Systems for materials tracking

In all of the cases studied (Case A, B, C, D, E and F), the use of manual operations is a commonplace in material handling and monitoring activities on construction and has led to the use of excessive paperwork and human error. In suggestion of good practices for the case

studies, RFID and bar-coding system usage (and other emerging technologies) have been recommended, to help overcome some of those problems faced on the construction site. The contractors are required to upgrade their current materials tracking practices through implementation of Radio Frequency Identification (RFID) and bar-coding (tagging technologies) to make material handling in the project site easier, quicker, more efficient and less of paperwork.

The utilisation of bar-coding system in case D at the consolidation centre operations was to support effective management of materials. At the consolidation centre, the processes entail the validation and identification of materials delivery such that the material specific location, date and time can be known. However, the logistic centre implemented in Case E, used the bar-coding was to facilitate controlling and tracking of the rebar during delivery of the rebar to the construction site. In addition, Case D implementation of RFID was to facilitate control of materials delivery; while Case E implemented RFID to track precast column and PDA to assist in checking daily construction activities on the project site.

6.3   Synthesis of Good Practices

The analysis from the case studies has led to suggestion for solutions to the challenges faces by the project cases (i.e., cases A, B, C, D, E and F) and how to improve approaches to material inventory managements on construction site. These suggested solutions on how to improve the current material management practices in the cases studied in this research is presented in Table 6.3 below. The table recommends that the current practices for tracking of materials by all the cases, needed to be upgraded through implementation of emerging technologies (such as Radio Frequency Identification (RFID), BIM, and bar-coding (tagging technologies) etc.) to make material handling in the project site easier, quicker, more efficient and less of paperwork. The usage of ICT tools was suggested in Case E such that labour, materials and plant utilisation can be integrated into one system. In addition, provision of adequate storage areas was suggested in cases A, C and D to overcome site storage challenges on the construction site; and for better handling of materials on these cases' project sites, a proper storage compound was suggested. To enhance systems for materials tracking and improve the overall management of material processes in both large-scale and small-scale projects, there is need to make a switch to automated material delivery tracking from current practices that are manual, material control to reduce damage, cataloguing of materials/ identification at the storage location, and minimizing excessive paperwork.

Table 6.3: Solutions Recommended for the Cases Studied

CASE STUDIES	SOLUTIONS RECOMMENDED
CASE A	• Making provision for more site storage location. • Increasing investment on better storage facilities. • Increasing the amount of workforce that monitor materials. • ICT/ emerging technologies implementation to enable faster and easier materials activities. • Tracking and reducing paperwork usage through cloud-based solutions
CASE B	• Double handling should be avoided. • Avoiding familiar mistakes. • ICT/ emerging technologies implementation to enable faster and easier materials activities.
CASE C	• Making provision for more access to construction site. • Storage area should be increased. • Implementation of emerging technologies (such as Radio Frequency Identification (RFID) and bar-coding (tagging technologies)) for tracking of construction materials (such as steel).
CASE D	• More provision should be made at the Consolidation Centre for more loading area. • ICT/ emerging technologies implementation to enable faster, easier and efficient in material control and checking.
CASE E	• Instilling discipline and material standardisation construction site. • ICT/ other emerging technologies implementation that will integrate labour, materials and plant usage.

	• Improve standardization (of supplier's labelling of construction materials) and collaboration among suppliers, manufacturers and contractors/ sub-contractors to enhance the overall supply chain on the construction projects.
CASE F	• Implementation of emerging technologies (such as Radio Frequency Identification (RFID)0 to enable automatic material delivery tracking and efficient material control. • Improve standardization (of supplier's labelling of construction materials) and collaboration among suppliers, manufacturers and contractors/ sub-contractors to enhance the overall supply chain on the construction projects.

Furthermore, it was also suggested that to improve standardization and collaboration among suppliers, manufacturers and contractors/ sub-contractors to enhance the overall supply chain on the construction projects. These suggestions are recommended for Case E and F to enable standardisation the supplier's labelling of construction materials to enhance tracking of materials better; and also, to manage the supply chain effectively and allow collaboration across and within multiple supplier. To effectively manage handling of materials effectively in Case B, avoiding double handling was suggested so that same mistakes will not be repeated; and provision of more access at the project site was suggested on Case C to improve its materials logistics. These projects need to implement the Information and Communication Technology (ICT) tools that can integrate plant, labour and materials into one system.

6.4   Limitations of Current Practices on Material inventory management

From the case studies, there has been site storage area limitations at the project site, that has been experienced on all the construction projects. These limitations have affected both large- and small-scale projects they have been studied. The following are some other constraints that have been experienced: construction site single access constraints; public infrastructure surrounding the project sites (such as railways and schools); regulation considerations; and materials vehicles' congestion during peak time. The development of consolidation centre and Just-In-Time (JIT) techniques could proffer solution to the problems of material storage and logistics in the management of materials processes. The implementation of these techniques can proffer solution to congestion of materials resulting from lack of storage space at project

sites. Regardless, the use of these techniques to proffer solution to human error (such as paper-based reports and double handling) are not applicable, as these are used in information recording and exchange related within supply chain material components.

There was general use of manual methods in all cases studied in tracking of delivery materials, controlling material damage and material identification at storage units. These material management activities result in massive use of paperwork and several human errors due to use of manual methods on the project site. Moreover, the revelations from the cases studies undertaken have shown that the utilisation of basic information and communication technology tools (such as Microsoft excel spreadsheet and fax machine) to facilitate database systems and purchasing activities, is widespread. The use of modem information and communication technology tools such as RFID to support tracking of material and automatic material identification, is inadequate. The use of such modern ICT tools like RFID could have provided information on material usage in real-time. Also, the dearth of information and communication technology (ICT) tools that can integrate labour, materials and labour with scheduling technology and high-level programming, in one system.

6.5 Real-Time Materials Tracking Requirements

There is need for manual practices to be transformed to automatic practices to facilitate the overall improvement of practices in material handling materials such that material management can be more effective and efficient and enable real-time material usage information. It is expected that the usage of emerging wireless technologies system (such as RFID) will facilitate material tracking activities such that human error in identification of materials can be tackled and minimise congestion time due to site storage constraints. According to Moselhi and El-Omari (2006), there is need for efficiency and effectiveness in the material inventory management in large scale projects, and for such projects to have the potential to utilise RFID to support management of materials processes in projects that are complex (Golparvar-Fard et al., 2009). Consequently, there is scope to improve the material inventory management at the construction site using more computer-based systems (Jun and El-Rayes, 2011; Zwikael, 2009).

Nonetheless, the findings from the cases studied and literature review have shown that there is inadequate positive examples of effective usage of such emerging wireless technologies systems. Some aspects of implementation of ICT in the approaches to material inventory managements practices, have been identified from the case studies. In tackling material

management problems, there were many challenges faced by the site managers in using the current practices. The following were some of the key findings that were revealed from case studies: there is insufficient techniques available to overcome human error; and insufficient utilisation of modem information and communication technology (ICT) tools (such as RFID) to facilitate tracking of materials. Hence, there is requirement for an integrated framework for tracking of material in real-time, such that an intelligent management of materials system, can be provided on the project sites.

The process of real-time materials tracking development is intended to enhance tracking of construction materials and overall material inventory management process at the construction site. Th real-time material tracking process consists of: (1) Delivery of materials; (2) Storage of materials; (3) Usage of materials; (4) Centre for on-site material control; and (5) Transmission of report. The overall process of tracking of material in real-time is described as follow:

- **Delivery of materials:** There are two stages involved in this process and they are: order confirmation for delivery and delivery status. In the first stage, the RFID reader will detect the delivery of purchased materials having RFID tags from the main entrance of the project site, and this is followed by confirmation of the arrival of materials delivery. Information on the materials delivery (such as name of materials, material quantity, etc.) will be contained within the RFID tags and this information is saved in the MS access (i.e., the database). In the second stage, material delivery status is checked by the site managers/ subcontractor managers determined if the delivered materials are to be used immediately or to be stored until they are needed, and to also check if they meet the required specifications. Integrating this process with a project management system (such as Microsoft Project) can assist the site manager in determine the decision of use of delivered material, storage or to return such material back to the supplier within particular project task for each specific material.

- **Storage of materials:** In this process of material storage at the storage area, records the storage date of materials are done by the storekeeper into the attached RFID tags as well as the MS access (i.e. the database). There are also periodic checks at the storage area by the site manager on the availability of materials needed for installation. There is need for integrating the work programmes with the stored information in database such that materials installation dates can readily be retrieved for each specific material.

157

- **Usage of materials:** In this stage of real-time material tracking, needed information is checked by the site manager/ sub-contractor by integrating work programmes with the database. Records of the installation data for a particular material can be retrieved from the database and inputted into the attached RFID tags for each material. This integration can provide information about the actual start and finish date of each material in the storage and saved into the work programme. Reports can be generated in the MS Project to ensure that the required resources (personnel and materials) are available to undertake each specified task.

- **Centre for on-site material control:** This process entails the establishment of site office as a centre for on-site material control. The database will be used for gathering and analysis of the materials delivery, data use and storage.

- **Transmission of report:** This process involves sending, through email, of all the information on tracking of material in real-time to the main office.

6.6 SIGNIFICANCE OF CASE STUDY FINDINGS FOR THE OPERATIONS MANAGEMENT

Operations management involves a complex interplay of technological systems, people and organizational and physical processes, all of which are constantly changing over time. (Sadeghi et al., 2021). In the field of operations management, factors such as global competition, co-development, co-creation of products, innovation, technology integration, global supply networks, sustainability, and corporate social responsibility have created new challenges for managers (Narasimhan, 2014). Over time, the operations management discipline has evolved in response to these different forms of challenges. In view of the enduring and emerging challenges facing operations management scholars, it would be prudent to revisit mainstream approaches to operation management research. (Soltani et al., 2014).

On the other hand, examining ongoing business operations within an organization does not allow conditions to be controlled or variables to be manipulated to influence outcomes. The restriction prevents the use of controlled experiments and, with them, robust methods that form the basis of laboratory experiments and mathematical simulations (Sadeghi et al., 2021). As a result, the researcher must determine the conditions, in each case, that could influence the outcome of the phenomenon. It may be possible to conduct a quasi-experiment (Sadeghi et al., 2021) if there exist many cases and if it is known what conditions will affect the results (so that their possible impacts can be statistically accounted for). However, when faced with unfamiliar

situations or those that lack theoretical grounding, the researcher might not know what conditions are relevant or significant. In addition, it may be difficult to study many examples because of the number of conditions involved (Yin, 2017). The case study approach may be the only way to investigate a problem in these circumstances (Sadeghi et al., 2021).

In most cases studies within the operations management domain, several common themes emerge. The first pertains to the preference of qualitative research over other research paradigms to examine emerging research areas in operations management, especially regarding its interface with other functional areas. (Hines et al., 2002; Pagell, 2004). Furthermore, the qualitative research of operations management is often linked to a need to better understand contemporary phenomena in their real-world settings (Voss et al., 2002). Finally, it is important to note that there is generally no coherent theory for explaining, predicting, or mastering phenomena in many of the operations management areas (Soltani et al., 2014). Research in operations management has been heavily focused on analytic and quantitative methods, which puts it at a disadvantage with regards to theory-building efforts, especially at the grand theory level; thus, the theory that supports the development of case study research is derived from its strength in building and extending OM theories (Barratt et al., 2011).

A research strategy of building theory from case studies entails using one or more cases to come up with theoretical propositions, midrange theories, and/or theoretical constructs based upon empirical data (Yin, 2017). Therefore, emergence of new fields of research is particularly appropriate. The advantage of this approach is that it can address "Why?" and "How?" questions in previously unexplored areas of research particularly well (Seuring, 2005). Dai et al. (2020) pointed out that case studies are a valid method that generates new insights and builds new theories, since they link qualitative evidence with mainstream deductive research (Eisenhardt and Graebner, 2007). As noted earlier by Sadeghi et al. (2021), the field of operations management can be advance through the generation of ideas that leads to theories. By synthesizing and integrating past research to provide new conceptualizations (theories) of operations management issues, such ideas can be generated from observational data (Narasimhan, 2014).

It has been noted in many research types that operations management needs to pursue more empirical methods, especially the case study method. There have been several case study methods review recently, focusing on operations management topics (Stuart et al., 2002; Barratt et al., 2011). For example, Barratt et al. (2011) reviewed the research outcomes and its state from operations management field qualitative case studies, using inductive and deductive articles that were published in in operations management journals between 1992 and 2007. A

case study's significance lies in its capacity to enhance our understanding of a phenomenon by comparing different cases and what we can learn from such comparisons as students of science (Samaddar and Kadiyala, 2006). The use of case study in this research provides a general guideline in operations management research, especially in theory building.

6.6.1 Significance of Case Study findings for Construction Management

As a research strategy, case study has become an obvious choice for researchers who seek to undertake modest scale studies or conduct a comparison of a small number of organizations at a time (Rowley, 2002). Throughout the years, the strategy has evolved and gained reputation as a useful tool and effective methodology for examining and understanding trends and complex situations in a wide range of scientific disciplines (Franklin and Mills, 2017; Shuttleworth, 2008). Thus, case study has developed into a valid form of inquiry to explore a broad range of complex issues, particularly when human behaviour and social interaction are central to understanding topics of interest (Harrison et al, 2017). Furthermore, it is observed that case study allows investigators to capture the holistic and meaningful characteristics of real-life events and complex situations such as construction management. (Sutrisna and Barrett, 2007; Yin, 2017). Construction management refers to the practice of planning, coordinating, monitoring, and controlling construction projects with the purpose of delivering the asset on time, within budget, and to the predetermined quality (Miller, 2021). The case study method can be applied to projects such as housing production, which, like any other construction project, requires all the processes of project management. This method can be used to identify general and specific issues that arise during the execution of such projects. By utilizing case study strategy, for example, the potential risks of a housing development project can be identified to determine case-specific and general risks affecting the project.

Due to the contentious nature of case study strategy, research students select it without adequate knowledge of the subject and the factors that could affect their research (Rashi et al., 2019). This results in confusion and wasted time, which negatively impacts the overall research findings. As a result, if the strategy is erroneously applied to subjects that could have been investigated using another, more reliable methodology, results such as these can be unreliable and misleading. Considering this, it is imperative to broaden the understanding of upcoming researchers, especially in complex disciplines like construction management, regarding the basics of conducting case study research. Specifically, researchers seeking to investigate construction management projects (such as methods of housing production, causes of time and cost overruns in construction projects, risks associated with housing projects, costs and quality

of road projects) using case studies need to have an understanding of the basic knowledge of the strategy.

Case study strategy has been adopted by researchers in the field of construction management in proffering solutions to construction related problems. Cheng et al. (20076) explored case study in satisfaction levels of UK construction clients based on the performance of consultants. Case study strategy had been adopted in a study on developing sustainable supply chains in the UK construction industry (Dadhich, 2015). The strategy had also been used in investigating extreme weather resilience of construction SMEs in the UK (Wedawatta et al., 2011). Case study was also used to examine the diffusion of digital innovation of UK construction engineering firms (Shibeika and Harty, 2015). Several other studies in which the case study strategy was applied in construction abound in the literature.

While studies have demonstrated the benefits of adopting case study research strategies in construction management research, few have been written on the process and procedures involved in designing them or the steps researchers may use to conduct an effective case study. (Gagnon, 2010; Hancock and Algozzine, 2021). This study therefore seeks to fill this gap by formulating a process for construction management with the view to broaden the understanding of research students and professionals in the built environment on the subject. For the purpose of clarity, the research focused process formulation for real-time material tracking that will improve material inventory management approaches in the UK construction sector. Managing construction processes effectively is a complex phenomenon and crucial for the success of construction projects. In many fields of study, including construction management, case study research strategy has proven to be an effective way to investigate complex situations.

6.7   TECHNOLOGY ACCEPTANCE MODEL (TAM)

The modern era has seen advances in information technology have been significantly shaped the manners in which individuals live just as the manners in which associations deal with their organizations in their expert business areas. Actualizing different sorts of information systems (e.g., Decision Support Systems) has been perceived as a standout amongst the most urgent task for firms to keep on surviving or being competitive. Though extensive exertion has been dedicated to improving the execution of information system usage, organisations are still experiencing the disappointments of information system usage. Actualizing different sorts of information systems, for example, emerging technologies (such as BIM, Radio Frequency Identification (RFID), Enterprises Resource Planning (ERP) systems, Decision Support Systems (DSS), and Knowledge Management Systems (KMS)), has been recognized as one of the necessary tasks organizations have to perform in order to be competitive. The findings from

the case studies showed that acceptance of technology usage in the construction industry is highly welcomed by all the people interviewed (See interview appendices). User's acceptance of an information system and attitude toward it, are among all potential causes that might be responsible for the information system implementation success or the failure. Venkatesh et al. (2012) noted that they have been recognized as factors that have critical impacts on the information system implementation and performance. The interviewees were of the view that the use of emerging technologies will enhance their work, improve efficiency, save time and cost.

6.8   RFID and Change Management

The process of change management is often viewed as a set of separate activities that occurs during a project within an organization. For these activities to be fully integrated into an implementation plan, a more holistic view of change management must be adopted that involves both internal and external perspectives. (Stapleton and Razek, 2004).

In addition to the challenges faced by RFID implementations, change management shows the complexity of change implementations and often records high failure rates. (Lines *et al.*, 2015). Change management factors play a vital role in RFID user adoption in addition to those measured by technology adoption theories. Reports of failed RFID implementation usually accompany a change process and user resistance is one of the major reasons for RFID system change failure (Hunter et al., 2010).

Lines et al. (2015) defined resistance to change as any dissenting action that slow, oppose, or obstruct a change management effort. Change management issues are particularly present in multinational organizations where the parent sites are in different locations. This complexity can vary in different dimensions including business strategy, management execution, software configuration and technical platform. Management execution contributes to the greatest degree toward RFID implementation success (Chen et al., 2012). Managing a multi-site RFID implementation project can also be challenging due to different managerial reporting lines, languages, and national cultures. RFID implementation can help integration of departments and functions to achieve a true process focus. It has the potential to integrate data flows, databases and systems even across different companies, and to streamline operations and reporting (Finkenzeller, 2010).

However, implementation of RFID is a huge commitment for any organisation (Hunter et al., 2010). The process of RFID implementation begins with planning. Finkenzeller, (2010) suggest that after planning is completed, a project team should embark on a few discrete phases. There may be a post-implementation review, after the system is up and running, leading to a

stabilization phase. Whilst these different phases are crucial to a successful implementation, a successful adoption of the system is not guaranteed. The change management phase must continue throughout the implementation process. A careful communication management is crucial for change as well as key stakeholders' involvement such as employee's involvement in the decision making and implementation process (Buono and Subbiah, 2014). Furthermore, user involvement and training are vital to the success of RFID systems implemetation (Hunter et al., 2010).

Top management is therefore a primary change agent responsible for identifying factors in the organization's culture and environment (Martin and Huq, 2007). Additionally, insufficient actions by top management have been cited as barriers to RFID implementation, and the use and understanding of RFID systems by employees. (Hunter et al., 2010).

6.8.1 Resistance to change

Definition of Resistance – This is defined as a phenomenon that can hinder the overall process of change, either by delaying or slowing down its beginning, obstructing or hindering its implementation, and increase its costs (Ahmed et al., 2006)

User resistance is an important issue in RFID implementations and has been attributed as the root cause of many project failures (Hunter et al., 2010). For example, Mabad et al., (2021) found a significant amount of user resistance even after nine months of RFID integration testing, partly due to the many interfaces with existing systems. Jones and Chung (2010) find that the reason for low RFID system return on investments is user resistance. Furthermore, a report on implemented the commercial package, RFID solution, found that resistance is the second most important contributor to budget and time overruns and is the fourth most important hindrance to RFID implementation (Hunt, 2007).

Additional studies also reveal how users' resistance causes technology implementation failures (Roper et al., 2015). The goal of managers in RFID system implemetation is to achieve the desired level of use of the system. Organizations are realizing that user satisfaction with information systems is an important factor in determining the success of those systems. Practitioners have thus, developed many models and theories to further explore user acceptance of information systems. Kazmi (2008) emphasized the role executive and managerial commitment, of strategic IT planning, business process skills, IT skills, RFID learning and training to the success of RFID systems implementation. Successful training for employees is vital to bridge the gap between RFID systems users experience and skills. Organizational performance depends on individuals' task completion.

The rapid growth in the use of computing in organizations makes practitioners obligated to study the effects of ICT acceptance on people's performance (Attaran, 2012). During a change process, resistance may surface for a variety of reasons. According to Ahmed *et al.* (2006), six fundamental reasons for user resistance to change are described as:

- There is no clear communication on the nature of the change to the users
- Improper articulation of the change or quantifiable objectives
- The potential users feel strong forces dissuading them from changing
- The users are made to undergo the change without an input to the direction or nature of change
- The change appears to be subjective i.e., made on personal grounds
- The change is drastic and ignores current institutions in the organization

Other causes of resistance from literature are user myopia i.e. the user not understanding the long term benefit or the vision of the change, denial, subjective norms, lack of necessary capabilities, deep rooted values, reactive mindset resignation and emotional loyalty (Venkatesh et al., 2012).

In general, three sources of user resistance can be identified. The resistance can either be system oriented, people oriented, or interaction oriented (Ali *et al.,* 2016). During an RFID implementation, when these sources of user resistance are not addressed, resistance could manifest in the form of under-utilization of the system or sabotage, which works against the aim for the RFID system implementation.

6.9   Chapter Summary

For this research, a total of six cases were studied and this analysed the findings that have been revealed from the case studies. The undertaken case studies carried out investigated the current problems and challenges of materials management; approaches they adopted to resolving the problems/ challenges; implementation of Information and Communication Technology (ICT) tools the cases; and the potential usage of emerging wireless technologies on the cases' construction sites in tackling the difficulties with material logistics. Revelations from the analyses of findings show that most of the cases have familiar problems with material storage difficulties. On-site material monitoring and handling activities (such as tracking of materials) uses manual operations to facilitate such activities in most of the case studied which leads to the possibility of excessive paperwork use and human errors. The synthesis of good practices that were suggested entail implementation of Radio Frequency Identification (RFID) and bar-coding (tagging technologies) to make material handling in the project site easier, quicker,

more efficient and less of paperwork and upgrade current practices in materials tracking. This requires the implementation of an RFID-facilitated construction management of materials tracking system. To enhance systems for materials tracking and improve the overall management of material processes in both large-scale and small-scale projects, there were recommendations to make a switch to automated material delivery tracking from current practices that are manual, material control to reduce damage, cataloguing of materials/ identification at the storage location, and minimizing excessive paperwork. There was also recommendation to implement the Information and Communication Technology (ICT)/ emerging technology tools that can integrate plant, labour and materials into one system.

Regarding the above findings, this research will focus on the evaluation of real-time materials tracking process system to integrate RFID based approaches to material inventory managements with project management, and to enhance tracking of material on-site and improve material inventory management practices. The significance of case study findings provides guidelines in operations management and an effective way of investigating complex situations in construction management. The processes involved in real-time materials tracking using RFID will be formulated in the next chapter.

7 CHAPTER SEVEN

FORMULATION OF THE PROCESS FOR REAL-TIME MATERIALS TRACKING

7.1 INTRODUCTION

This chapter discusses the process of tracking material in real-time to improve material inventory managements in the construction industry. The material tracking process is a system approach that aids an automatic tracking of materials on the construction site. In this chapter, an introduction to material tracking components in real-time will be discussed; these include delivery of materials, storage of materials, materials usage, centre for on-site material control, and transmission report. This is then followed by a description of the material tracking process in real-time; and a discussion of the key features of the processes to improve material inventory managements in UK construction industry. Testing and validation of the process will also be carried out to decide whether to accept or reject the process proffered.

7.2 Components for real-time material tracking

The findings from the cases studied and the literature review will be used to implement a process for real-time material tracking. This will show that it is possible to change to automatic processes from the manual processes and show the possibility of employing RFID to support management of materials at the construction site. This proposes an integrated approach for tracking of materials in real-time to aid an intelligent system that improves material inventory managements in the UK Construction Industry. Figure 7.1 depicts the components for tracking of materials in real-time which depends on the use of emerging wireless technologies (such as RFID).

Real-time materials tracking system is composed of five main components. These include

- Delivery of Materials

- Storage of Materials

- Material Usage

- Centre for On-Site Material Control; and

- Transmission Report
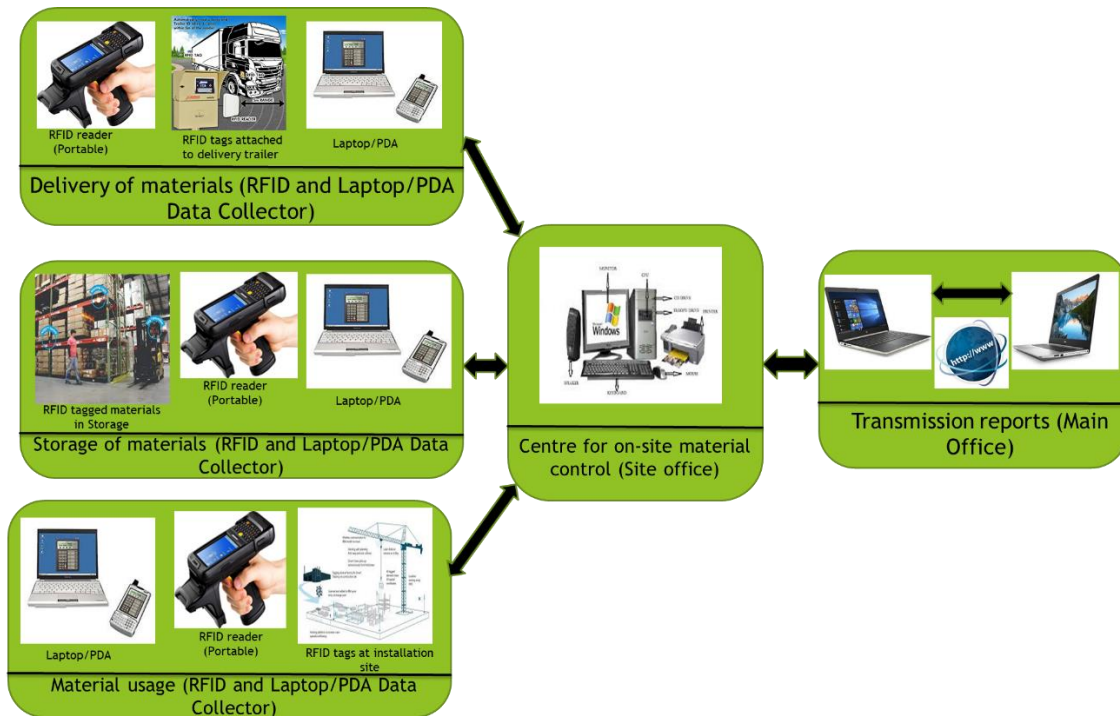
Figure 7.1: Components of Material Tracking in Real-Time

The conceptual approach to material tracking in real-time is represented by the main components of tracking of materials in real-time at the construction site. These components are described fully in section 6.5 and briefly below:

- Delivery of Materials: Tracking of the materials delivery and the material delivery status is done at this stage of the tracking process at the construction site.

- Storage of Materials: The material tracking and checking of material availability at the storage area are done at this stage at the construction site.

- Material Usage: The tracking of material usage at the construction site, is done at this stage.

- Centre for On-Site Material Control: The centre for on-site material control can be set up at the site office and entails collection and analysis of all information about the construction materials in the database system; and

- Transmission Report: Information required to produce real-time material tracking reports are generated at the main office from all the materials information received from the site office.

7.3   The process for real-time materials tracking

The intention of the real-time materials tracking process is to improve tracking of materials and the overall material inventory management processes in the construction industry. Radio Frequency Identification (RFID) is used to collect automated data for material tracking with the aid of a reader (i.e., an interrogator) and a tag (i.e., a transponder). Such example of RFID reader is the portable 'Hopeland CL7202K1', 'NFC RFID Reader SL600', 'Denso BHT-1281 RFID Handheld Terminal', 'M3 RFID 7510S' etc; and RFID tag are 'Alien H3 9662', 'YARONGTECH UHF RFID Inlay tag', 'NTAG215' etc; which forms the components of an RFID system. The portable RFID readers can be fixed to a laptop or a PDA to help in data collection and transmission to the site office from the construction site.

The findings from the cases studied showed that there was insufficient approach/ technique used to tackle double handling due to human errors; excessive use of paper-based reports to track materials at the project site; and insufficient usage of emerging technology tools such as RFID to support automatic material tracking identification. The process of tracking of materials in real-time supports a structured approach that enables integration of work programmes with RFID based materials management in a project management system. The main stages of material tracking process in real-time is shown in Figure 7.2, showing the five main components involved in real-time material tracking process including: delivery of materials (for automated tracking of materials); storage of materials (for inventory materials tracking); material usage (for tracking usage of materials); centre for on-site control (for materials data collection and analysis); and transmission report (for producing real-time material tracking reports).
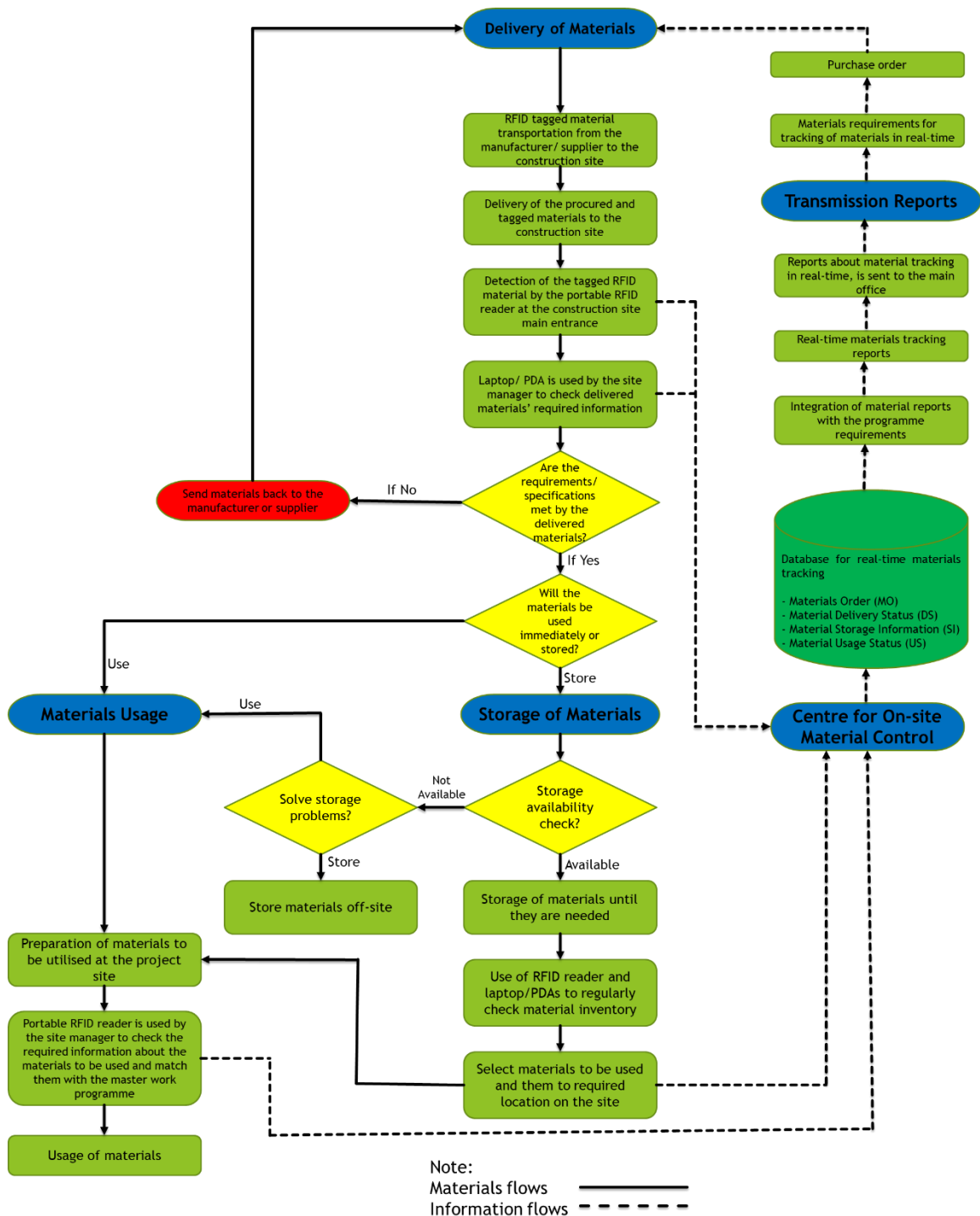
Figure 7.2: The Process for Tracking of Materials in Real-Time

7.4   Material Tracking Processes

The processes for tracking materials in real-time is made up of five key components which are described in the following subheadings.

7.4.1   Delivery of Materials Process

The process of delivery of materials illustrates how materials can be delivered into the construction site using automated materials tracking and materials delivery status identification at the construction site entrance. Manufacturers and suppliers of the delivered materials are required to attach RFID tags to the purchased materials before such materials are transported for onward delivery to the construction site. Hence there is need for collaboration between contractors, suppliers as well as manufacturers such that a standardised type of RFID tag is affixed to each of the supplied materials. It is important for all suppliers to have a standardised RFID tags so that suitable RFID readers can be used in RFID tag detection of delivered materials at the entrance of the construction site. It is expected that site managers at the construction site will track high value material delivery to their site to avoid money and time wastage. Figure 7.3 illustrates the scenario for delivery of materials at the construction site.
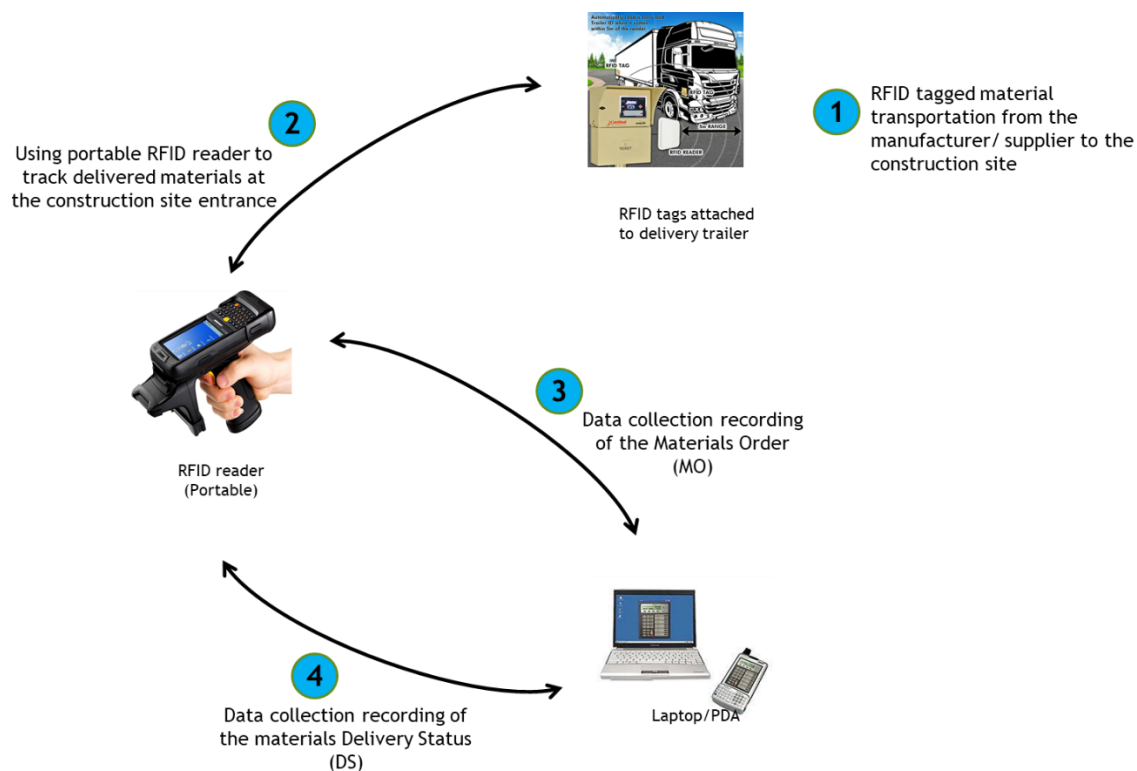
Figure 7.3: Delivery of Materials Process (RFID and Laptop/PDA Data Collector)

This process undertakes a new approach for material tracking during the material delivery into the construction site through RFID and PDA implementation. The description of the delivery of material process that was illustrated in Figure 7.3 is given as follows.

1. Material Transportation: this involves acceptance and preparation of delivery material by the supplier or the manufacturer for purchase orders of specific materials requested from the construction main office. A system for tracking of materials in real-time

requires that RFID tags are attached to the materials by the manufacturers or suppliers. Also, there is need of collaboration between suppliers or manufacturers and contractors to ensure that when RFID is implemented that RFID tags are standardised. The type of RFID tag to be used is required to transmit and receive data from a handheld device (such as RFID reader/ interrogator) at a sufficient distance. After the material to the delivered are attached with the RFID tag, the material will be ready to be transported to the construction site from the manufacturer's storage site.

2. Tracking of Material Delivered: Using portable RFID readers, the tagged materials being delivered can be tracked on arrival at the entrance of the construction site. The personnel in charge (i.e., the site manager) can readily detect the delivery of the tagged material using a portable RFID reader at the entrance of the construction site. Portable RFID readers such as i-CARD 3 (which can transmit and receive data at 100 metres), can be used to detect the tagged delivered material on arrival. This i-CARD 3 RFID reader can be attached to a PDA or laptop to read and write data from the RFID tags.

3. Data collection recording of the Materials Order (MO): Some more information about the purchased material can inputted into the RFID tags at this stage, by the personnel in charge (i.e., the site manager). The database of the PDA or the laptop will also be used to save the materials order data for onward transmission into the site office main computer. The data saved can be accessed later to get information about the materials delivery. The data can be transmitted by direct connection or through a wireless network or by direct connection between the site office main computer and the PDA or laptop having the RFID reader. The following are the data from the Materials Order (MO that can be recorded and stored in the process of material order data collection:

   - Materials ID;

   - Materials Name;

   - Suppliers ID;

   - Supplier's Name;

   - Unit Price (GBP);

   - Quantity (unit); and

   - Invoice No.

4. Data collection on material Delivery Status (DS): This stage involves the inputation of delivery status into the delivered material RFID tags after recording all the materials order data. The site manager, at this stage, is required to decide on the whether the materials delivered to the construction site are to be utilised immediately or that they need to be stored at the storage area. The manager also need that assess the quality of delivered material to ensure that they meet the required standard requested. For record purposes, confirmation of material order delivery will be communicated to the supplier or manufacturer and the site office. The RFID tags will store information on the material Delivery Status (DS) and are also saved to the database in the site office. Such Delivery Status information are as follows:

- Delivery Date;

- Delivery Status (i.e. material received, accepted and used, material received, accepted and store, material received, damaged and rejected);

- Materials Status (e. g. Used, Stored, damaged and returned to Manufacturer/ Supplier); and

- Remarks (e. g. Store material, use immediately, Re-order material and Next Delivery on 23/10/2018).

7.4.2 Storage of Materials Process

The site manager or sub-contractor, in this case of material storage process, is required to regularly check material availability using either the computer system at the storage area or a portable RFID attached to the PDA. This periodic check process is needed to ensure that purchased materials are available at the storage area when they are needed for use/ installation purposes. The materials storage process is illustrated Figure 7.4 and shown below.
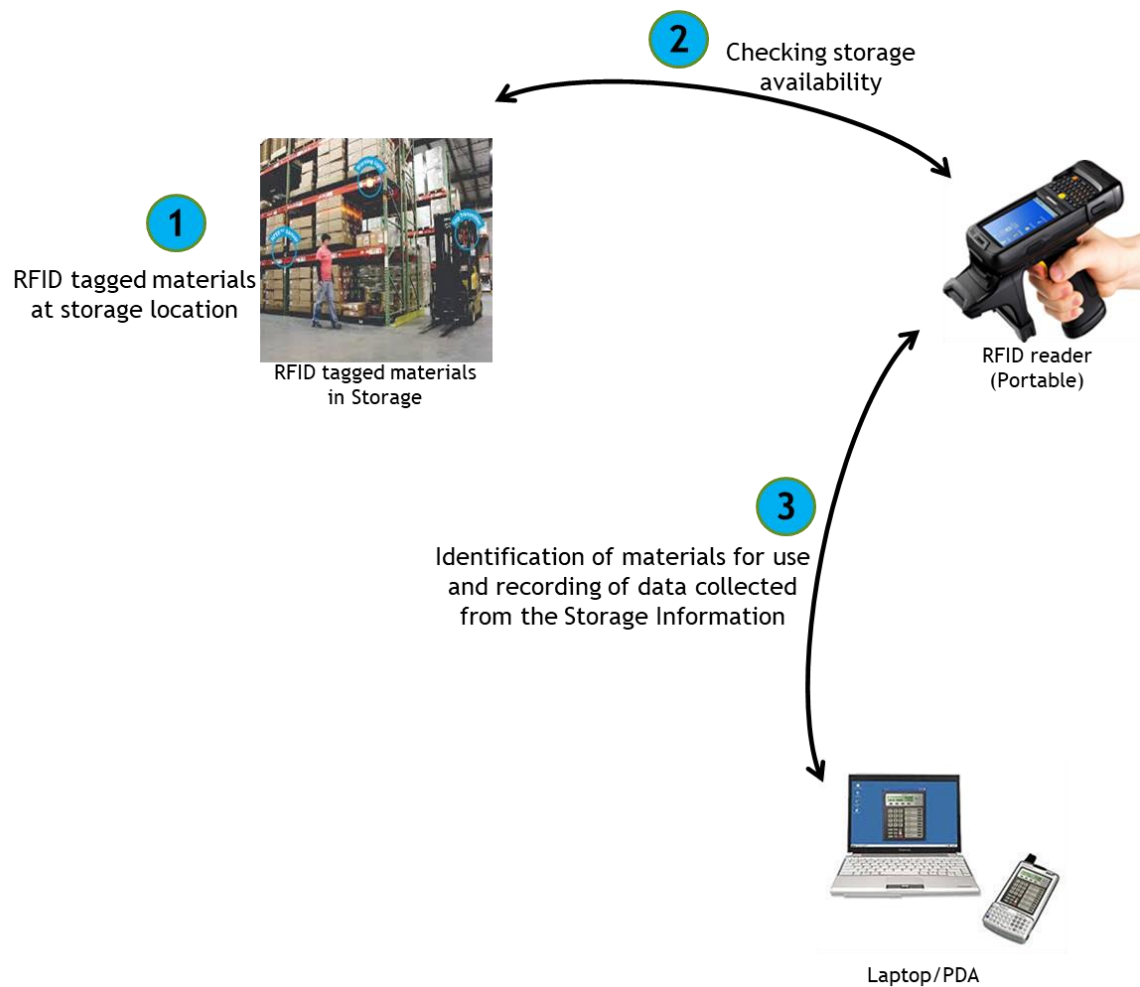
Figure 7.4: Storage of Materials Process (RFID and Laptop/PDA Data Collector)

The three-stage process of material storage is described below:

1. Tagged materials at storage location: At this stage, when the material is delivered into the construction site and a decision is made by the site manager for the purchased material to be used if they required immediately for installation or to for it to be stored in the storage area and used later. Also, the site manager or subcontractor checks for availability of storage space in the storage area on-site and decide to either store the materials on-site or off-site (if there is limited storage space). Depending on the work programme schedule, the site also required to identify materials required for use immediately. The RFID tagged materials are stored temporarily in the storage area until there is a demand for them to be used.

2. Checking storage availability: The materials inventory status at the storage area needs to be regularly checked by the site manager (or the personnel in charge) using the

portable RFID reader to establish quantity of materials and their availability when they are required.

3. Identification of materials for use and recording of data collected from the Storage Information (SI): To check the use of materials, the project programmes need to be examined to determine which of the materials that need to be utilised for a given task or need to be installed on a specific date. With this, the RFID reader can be used to track materials and identify the materials from the storage area that needed to be used or installed and record the data collected from the Storage Information (SI). Transportation of the required materials are arranged when the specific tagged materials are ready to be used or installed and are moved to the required location where they are needed in the construction site. Storage information is needed to be inputted into the RFID tags of the materials such as the store man's name and the date the material is taken out from the storage (specific storage-out date). This storage information needs to be stored in the tagged RFID material and saved in the site office database. The storage information that will be stored in the RFID tags include:

- specific storage-out date

- specific name of storeman

7.4.3 Materials Usage Process:

The person in charge (i.e., the site manager) needs to regularly check the materials usage information throughout the materials use process. This process involves checking for information by the site manager about the usage schedule of the supplied materials from the work programme. Figure 7.5 illustrates the materials used process and it is shown below.
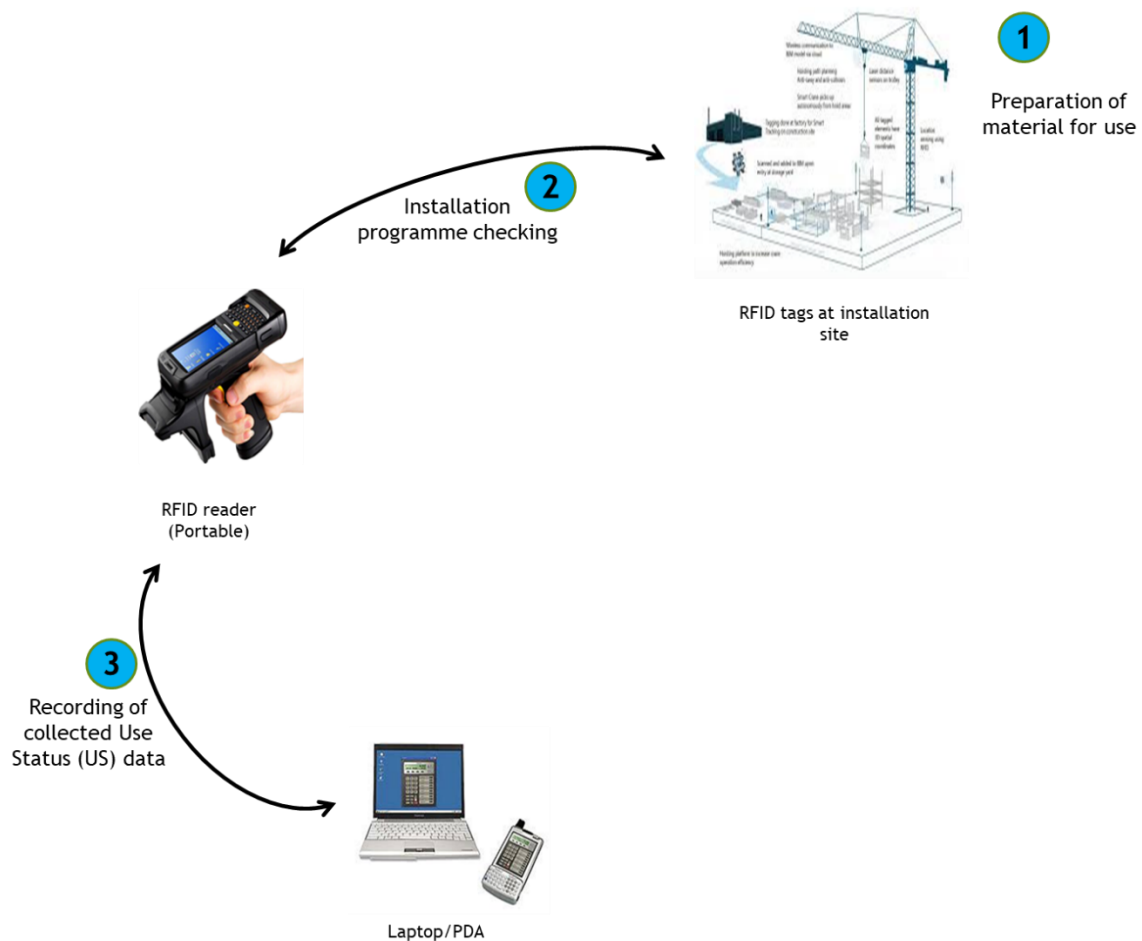
Figure 7.5: Material usage (RFID and Laptop/PDA Data Collector)

The description of the materials usage process is given below.

1. Preparation of Material for Use: This involves identification of the information about the materials from the master work programme such as the specific use date, quantity to be used or installed and which part of the building or work the material will be used. The information is checked and provided from the work programme, for each specific material as and when they are required for use.

2. Installation programme checking: At this stage, portable RFID reader used by personnel in charge (i.e., the site manager) to check required information from the RFID attached to materials that need to be used/ installed. The checking of the installation programme at this stage, enables the right materials to be provided for the specific task and for use requirements.

3. Recording of collected Use Status (US) data: The collected use status data needs to be inputted into the RFID tags of the material and saved in the site office database.

Information about the specific start date and finish date for the particular material that needs to be used/ installed, is also provided at this stage. The information that are recorded from the collected Use Status (US) data are as follows:

- Task name

- Duration of installation (in days)

- Start date

- Finish date

7.4.4 Centre for On-Site Material Control Process

This process entails the establishment of an on-site control centre at the site office with the purpose of gathering information about delivery of materials, material storage and usage of of materials at the construction site. The process involved at this level of on-site control centre, is illustrated in Figure 7.6.

1. Exchange of materials tracking data in real-time: At this stage, all data collected at the construction site are exchanged. Such material data collected that will be exchanged at the on-site control centre include Material delivery status, Materials order, Material storage information and material usage status. The exchange can be transmitted through the portable computer system/ PDA or wireless network that is connected to the main office and site office computer.

2. Record of materials tracking database in real-time: The materials demands or requirements for materials tracking in real-time is provided by the on-site database. This provides an up-to-date information to the site manager on the materials order such as the material quantity that will arrive in a specific day, material allocation for either immediate use or storage etc. Other information that are also updated are the material delivery status data (such as the material Delivery Status, material delivery date, materials storage and Usage Status); and material storage information (about the movement of materials from one storage area to another, specific date of materials of movement and the storekeeper's name. Furthermore, other additional information that may be updated includes the duration of installation (in days), task name, start date and finish date. The updating needs to be integrated with project tools (such as ERP and Microsoft Project) so that the actual start and finish date can be amended immediately when the material is utilised/ installed for the specific task.

177
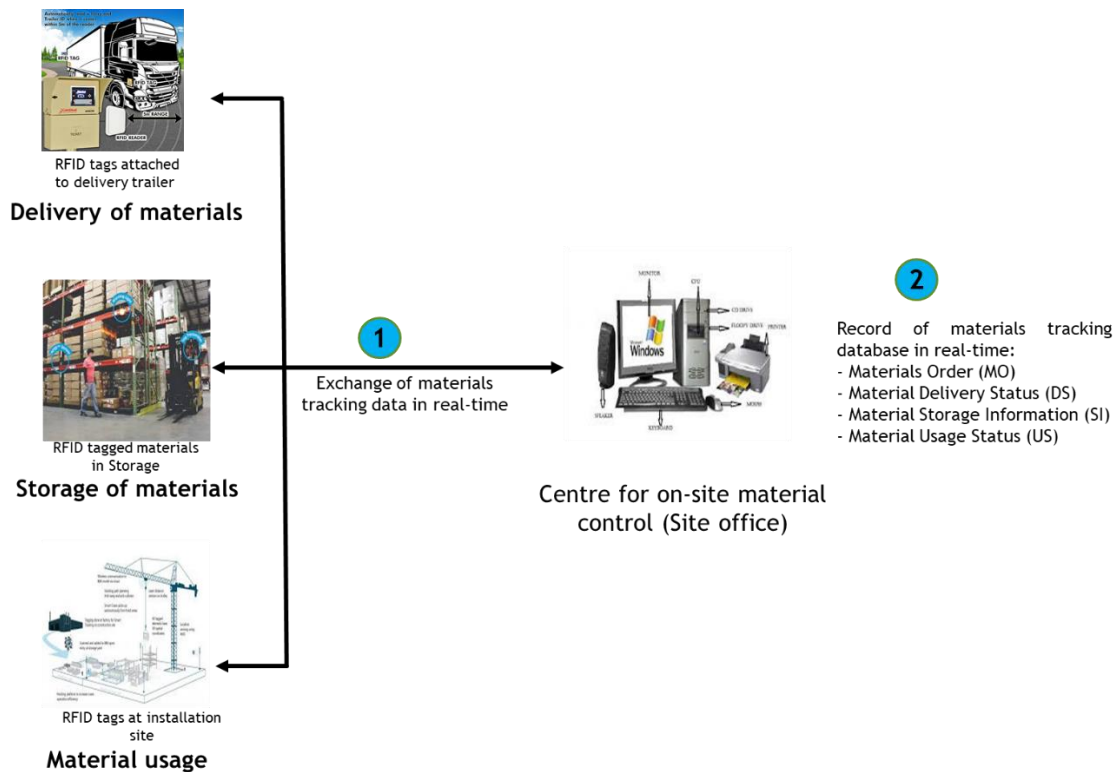
Figure 7.6: Centre for On-Site Material Control Process

7.4.5 Transmission Report Process

The transmission report process is illustrated in Figure 7.7 which shows how material tracking reports are transmitted to the main office from site office.
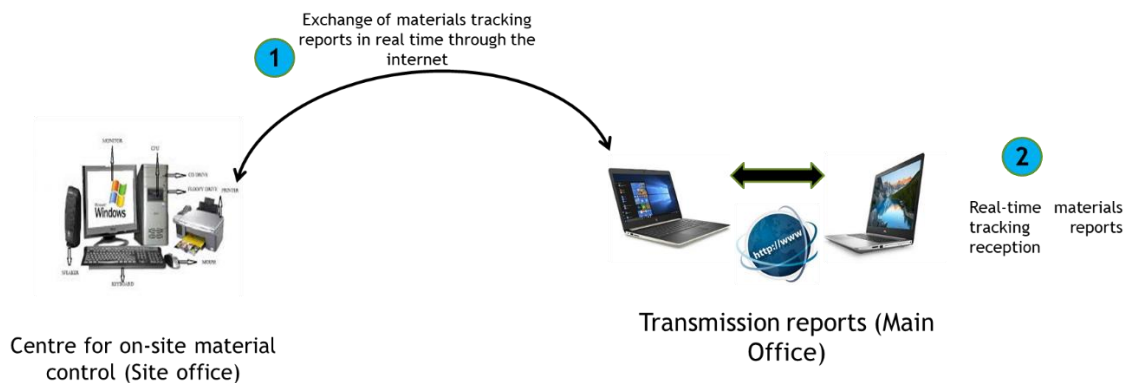
Figure 7.7: Transmission Report Process

Description of real-time transmission of material tracking reports is given below:

1. Exchange of materials tracking reports in real time: This involves real-time material tracking report preparation at the site office and onward transmission, through email, to the main office. Through this, information required for materials utilisation, are gathered and produced for use at the main office.

2. Real-time materials tracking reports reception: Information received from the site office, is received in the main office and used to produce progress report for specific construction projects. Such information received from the site office are material delivery status, materials order, material storage information and material usage status. All the materials information is kept in the main office administration for record purposes and for use to plan for materials purchases in future.

7.5   Testing and validation

This section is concerned with contacts made during the process of formulating the process for real-time material tracking that will improve material inventory management approaches in the UK construction sector, testing and validating the viability of the process. These contacts in tab 7.1 were made to discuss the formulation process for viability. They agreed on the potential for such a process aiding material inventory and assisted the formulation process. The testing done were integration testing, ergonomic testing and acceptance testing. This is to enable future users to examine the usefulness and acceptance of the formulated process. The integration testing is to verify the different process can work together and integrated into construction project. Ergonomic testing was done to ensure process efficiency and comfort in the working site environment. And acceptance testing for performed for the future users of the process with the aim of validating the process formulation. This helps to decide whether to keep or reject the process formulation. They expressed their views on the functionalities, usefulness, acceptability and possible system's development approaches. There were some concerns in the initial formulated process in functionality and usefulness. Suggestions were also made in the areas of concern which helped in the final process formulation.

NAME	SUBJECT	LOCATION
Site manager	Validation	Orchard Group, Liverpool
IT developer	Testing	CinTech IT Solutions, UK
Project manager	Testing and Validation	Wilson James Construction, London
Assistant project manager	Validation	Allenbuild Construction Ltd, London
Project manager	Testing and Validation	Allenbuild construction Ltd, London

| Academics | Testing | Anglian Ruskian University, Chelmsford |
| Project manager | Testing and Validation | Dhesi Group, UK |

Table 7.1: Contacts during Testing and Validation

7.6   Chapter Summary

This chapter has presented the evaluation of the process of tracking material in real-time to improve material inventory managements in the construction industry. The process of tracking material in real-time is made up of five main components which were derived from the evidence review of literatures. The suggested processes were aimed at promoting the implementation of Radio Frequency Identification (RFID) to track materials automatically and integrating it with other available technologies such as the computer systems and Personal Digital Assistant (PDA). It is expected that the move to automatic practices of tracking material in real-time from the manual practices of tracking materials currently used by many construction companies, could improve material inventory management on construction projects. Linking of the materials tracking process in real-time with the project management work system is also considered to ensure that certain project tasks are associated with the required tagged material components. To assist with the uptake of associated wireless technologies for materials tracking system (like Radio Frequency Identification (RFID)), there is need to provide the requirements necessary to determine its applicability in improving approaches to inventory management of construction materials practices. Such requirements include reasonable computer literacy level; knowledge of innovative and emerging wireless technologies; basic materials management knowledge; and planning skills. Testing and validation undertaken assisted in formulating a process that can be useful, functional and acceptable for a possible process system's development. The next chapter presents the conclusion and recommendation on improving approaches to material inventory management in the UK construction industry.

8   CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

8.1   Introduction

This chapter draws a conclusion to the thesis. The chapter begins with a concise run-through of the research and establishes the how the aims and objectives of the research were accomplished. Highlights of the main conclusions gathered from the research work are also presented. Other accomplishments of the research in contribution to knowledge are stated. Finally, the main limitations of the research were presented in this chapter, with some further research recommendations, suggested at the concluding sections.

8.2   Thesis summary

The key aim of this thesis research was to propose approaches on improving material inventory managements in construction industry in the UK. This was achieved through suggesting a process of tracking of material in real-time and integrating it with the construction project work programme, to ensure optimisation of project time, finance and material management. The justification for conducting this research was the necessity to have a well-defined system for tracking of materials in real-time such that tracking of materials tracking and material inventory management processes can be improved on the project site. Furthermore, to achieve the set aims of this research, several specific objectives were used, which included:

- To review key different approaches to material inventory managements that are being adopted in the construction industry worldwide.

- To analyse the approaches to material inventory managements practices used in the UK construction industry.

- To identify the current challenges/ problems in the UK construction industry with regards to material inventory management.

- To formulate a process for real-time material inventory tracking that will improve material inventory managements approaches in the UK construction sector.

The objectives of this research are summarised below with respect to specific tasks and actions undertaken such that the set research objectives can be achieved.

Objective One: To review key different approaches to material inventory managements that are being adopted in the construction industry worldwide

The evidence reviews of existing literatures on management of material practices found various challenges in material management on construction projects which includes supply delays, shortages, fluctuation in price, wastage and damage, and insufficient space for storage. The material supply delays and inadequate areas of storage were established as the main issues in the management of materials. Various approaches were being applied in resolving these problems of material management. These approaches included the utilisation of Information and Communication Technology (ICT) system (such as barcoding and RFID), proper logistics planning of materials and Just-In-Time (JIT) techniques. In general, there is limited use of technologies to tackle the problems of double handling (i.e., human error) in material tracking that is experienced in many construction projects. Exchange of information and recording relating to material management are still mostly paper-based reports within the logistics supply chain. This has led to material management being inefficient, problematic and error prone.

Chapter two presented the key findings on implementation of technologies and the processes of material management in the construction site. The implementation of ICT to facilitate material management practices currently used on the construction project was acknowledged to be more effective in material management on the construction site. A variety of emerging technologies, such as Radio Frequency Identification (RFID), have been identified to have the possibility of improving management of materials (particularly tracking of materials).

Objective Two: To analyse the approaches to material inventory managements practices used in the UK construction industry.

Six construction projects were selected as exploratory case studies to be used to investigate approaches to material inventory managements practices used in the UK construction industry; implementation of ICT issues, and the potential of utilising emerging wireless technologies usage and systems for materials tracking (such as RFID) to enhance practices currently used. This research chose the use of case study research to enable the acquisition of more insight into the material management. Details of this each case study was done in chapter four of this research. The case studies principally involved structured face-to-face interviews conducted with individuals that have the responsibility of managing materials on construction projects, site logistics and project management (from each of the six project cases) to identify the current situation regarding material inventory managements on construction projects. The choice of various kinds of construction projects gave an opportunity to analyse the material management situations on construction projects and allow identification of challenges. The main findings

were derived from the case studies based on five 'case study units of analysis' (i.e., embedded unit of analysis) which relates to: current challenges; approaches on how these identified problems can be addressed and the potential implementation of emerging technologies to enhance tracking of materials, are presented and analysed.

The 'unit of analysis' in this research purpose, is tailored towards attaining the objective of the research, which is to investigate the possibility of enhancing tracking of materials on the site and inventory management processes on construction projects through implementation of emerging technologies. The five 'case study units of analysis' (i.e., embedded unit of analysis) in this study is applied on the six project cases chosen for the purpose of this research and they are given as follows:

- Problems/ challenges of materials management: The most significant problems that are encountered in the management of materials are explored;

- Approaches adopted to resolving the problems/ challenges: The purpose of this is to identify strategies adopted by individual (managers) to address the problems in materials management on the construction site;

- Implementation of ICT: This aim to identify the usage of ICT in material management on the construction site;

- Emerging wireless technologies usage: This examines the possibility of using emerging technologies to assist in the management of materials approaches; and

- Systems for materials tracking: The aim of this unit of analysis is to identify current approaches being used by to enhance tracking of materials on the construction site.

The essence of using single case analysis is to produce reports for the individual cases such that information can be garnered on current materials management practices, Implementation of ICT and problems of material management.

Objective Three: To identify the current challenges/ problems in the UK construction industry with regards to material inventory management.

To identify the current challenges/ problems in the UK construction industry with regards to material inventory management, six case studies of different construction projects were studied and have revealed that each of these projects has related problems of storage area inadequacy and logistics at the project sites. The problems of material management, approaches to

resolving materials management challenges, implementation of Information and Communication Technology (ICT), emerging wireless technologies usage, and systems for materials tracking were analysed using cross-case analysis (see chapter five). The use of cross-case analysis is to allow a correlation of the 'case study units of analysis' (i.e., embedded unit of analysis) among all the different cases studied (Yin, 2009). The cross-case analysis entailed the investigation of the five unit of analysis across each case that is studied, such that key findings can be provided from an argumentative interpretation.

The findings identified from the cases studied showed that there are similar issues of storage constraints and logistics with most of the construction projects. In most of the cases, manual operations were used to facilitate monitoring and handling activities at the project sites (such as tracking of materials), with the possibility of excessive paperwork utilisation and human errors. The synthesis of good practices that were suggested entail implementation of Radio Frequency Identification (RFID) and bar-coding (tagging technologies) to make material handling in the project site easier, quicker, more efficient and less of paperwork and upgrade tracking of materials currently being practiced. This requires the implementation of an RFID-facilitated construction management of materials tracking system. To enhance systems for materials tracking and improve the overall management of material processes in both large-scale and small-scale projects, there were recommendations to make a switch to automated material delivery tracking from current practices that are manual, material control to reduce damage, cataloguing of materials/ identification at the storage location, and minimizing excessive paperwork. There was also recommendation to implement the Information and Communication Technology (ICT) tools that can integrate plant, labour and materials into one system.

To improve tracking of materials and overall management of materials processes, it is essential for each construction company to move from current manual approaches to automatic material tracking to facilitate material delivery tracking, easier material identification at the storage location and ensure material control to reduce excessive paperwork utilisation and damage.

Objective Four: To formulate a process for real-time material inventory tracking that will improve material inventory management approaches in the UK construction sector.

To formulate a process for real-time material inventory tracking that will improve material inventory managements, an evaluation of the process for real-time materials tracking was discussed in chapter six. The findings from the cases studied and the literature review were

used to apply a process for real-time material tracking. This showed that it is possible to change to automatic processes from the manual processes, and show the possibility of employing RFID to support management of materials at the construction site. This proposed an integrated approach for tracking of materials in real-time to aid an intelligent system that improves material inventory managements in the UK Construction Industry.

The findings from the evidence review of literature revealed that there are insufficient positive examples of RFID usage to effectively support tracking of materials at the construction site. Also, the findings from the cases studied showed that there was insufficient approach/ technique used to tackle double handling due to human errors; excessive use of paper-based reports to track materials at the project site; and insufficient usage of emerging technology tools such as RFID to support automatic material tracking identification. The process of tracking of materials in real-time supports a structured approach that enables integration of work programmes with RFID-based management of materials in a project management system. The main stages of material tracking process in real-time showed the five main components involved in real-time material tracking process including: delivery of materials (for automated tracking of materials); storage of materials (for inventory materials tracking); material usage (for tracking usage of materials); centre for on-site control (for materials data collection and analysis); and transmission report (for producing real-time material tracking reports).

It is expected that the move to automatic practices of tracking material in real-time from the manual practices of tracking materials currently used by many construction companies, could improve material inventory management on construction projects. Linking of the materials tracking process in real-time with the project management work system is also considered to ensure that certain project tasks are associated with the required tagged material components. To assist with the uptake of associated wireless technologies for materials tracking system (like Radio Frequency Identification (RFID), there is need to provide the requirements necessary to determine its applicability in improving approaches to material inventory management construction practices. Such requirements include reasonable computer literacy level; knowledge of innovative and emerging wireless technologies; basic materials management knowledge; and planning skills.

8.3   Research Conclusions

The improvement of material management practices was investigated in this research through the use of case studies. The research went on to suggest a process of tracking materials in real-

time to ensure optimisation of project time, cost and materials. From the research, the conclusions that were drawn are as follows:

- System for material tracking in real-time enables an innovative and robust approach to address material inventory management problems and tracking of materials on-site by integrating project management system with RFID-based material management.

- Integrating Microsoft projects with work programme supports the database system with resource information about certain project tasks in real-time (such as usage of RFID tagged material components).

- The provision of RFID-based system can help to tackle the problems of manual handling practices (such as excessive paperwork usage, human error, inefficiency) of materials tracking that may be experienced while managing materials on the project site. Other tracking technologies such as Personal Digital Assistant (PDA) can also facilitate the effective tracking of materials by supporting data capturing in real-time and easy information transfers within the project site.

- Automatic identification technologies, such as RFID, have the possibility of improving processes for material tracking, particularly, the overall material management practices on the project site. The reducing costs of employing the RFID system has added to the advantages of implementing them in material management. Another advantage is that there are not easily damaged in harsh weather conditions. However, installing RFID system on large-scale projects will require thousands of RFID tags being used, which may be tedious.

- The use of fax machine and MS Excel are commonly used in construction projects to aid procurement processes in the management if materials. They also provide connection between the site office, main office and suppliers/ manufacturers.

- The switch from manual to automatic materials management processes improve the overall material handling for enhanced effectiveness and efficiency on the construction project. The use of manual practices is error-prone which affects the overall optimisation of construction management in terms of productivity, quality of work, cost of operation and project duration. The switch minimises wastage of materials and reduces profit loss.

Furthermore, there is a trade-off between technical (engineering) efficiency and private cost efficiency when the cases studied, were analysed. Technical efficiency aims to minimize inputs, but private cost efficiency aims to minimize costs, which might or might not require fewer inputs. In other words, the small construction companies (for example, Case A) aim to lower costs as much as possible while still trying to hit a production goal.

The study clearly shows the importance to manage all materials used in the construction sector. The systematic literature review shows that processes in materials management require a transformation to improve the overall process in handling of materials for more efficiency and effectiveness on the construction site. It also identifies that poor handling of construction materials affects the overall performance of construction projects in terms of cost (budget), quality, time and productivity.

From this research, we can conclude that materials for the project, which is a very important resource if properly managed and handled, can vary the cost of the project to a large extent. If the measures to handle the materials properly for a construction project is strictly followed, it can reduce the total material cost of the project.

8.4 Contribution to Knowledge

The research main contribution to knowledge is based on four definite areas, each of which affords a basis to follow up work on, to further facilitate management of materials practices and the use of RFID-based technologies:

- Formulation of RFID-based material tracking in UK construction projects: The aim of this research is to show how the use of wireless technologies for materials tracking system (such as Radio Frequency Identification (RFID)), can improve overall material management practices on the construction project site. The findings from the cases studied have shown that there is still limited use of RFID-based systems for material tracking and management in the UK construction projects, especially in small-scale projects. The research has demonstrated that the application of RFID-based material tracking system in UK construction projects can improve the overall optimisation of construction management in terms of productivity, quality of work, cost of operation and project duration.

- Project management system integration to the RFID-based management of materials: This research has shown how integrating project management system with RFID-based material management can enhance processes for tracking of materials and inventory

management. The research has proved the need for use of RFID in construction projects to support approaches to managing materials inventory. The finding from the cases studied revealed lack of RFID-based integration of material tracking to project management system; inadequate site storage location (affecting both large and small construction projects). However, the use of Consolidation Centre (CC) techniques which was employed to tackle storage and logistics challenges did not address double handling due to human errors and excessive use of paper-based reports. Integrating project management system with RFID-based material management shown the connection assists in proper material usage, timely materials delivery, efficient and effective monitoring, and managing material inventory on construction site.

- Integrating work programme with the information from real-time materials tracking database: Findings from the cases studied, has shown that there is limited use of RFID technology to facilitate tracking and automatic identification of materials in construction project operations. There are likewise inadequate instruments that can relate materials, work and machinery into one framework. Applying the process of material tracking can serve as a useful tool to provide information material logistics management (such as materials arrival into the project site and the type of materials delivered. For instance, RFID reader can automatically track tagged material from the point of arrival into the site until the materials has been utilised. Considering this, the research has contributed to knowledge of how linking work programme to the database can enhance approaches to materials tracking on construction sites.

- The use of capable mobile device to support the process of tracking materials on the project site: This research identified other technologies (such as PDA), that enabled RFID reader to be incorporated to facilitate effective materials tracking on project site. This incorporation of mobile capability enables capturing of data in real-time and makes information transfer easier in the site. The incorporation of the PDA also has the advantages of enabling the site manager to move independently within the construction site and with the PDA at hand, and have easier access to information about materials delivery, storage and usage.

- This study seeks to fill this gap in case study research of construction management by formulating a process for construction management with the view to broaden the

understanding of research students and professionals in the built environment on the subject.

8.5 Limitations of the Research

The following are the main limitations of this research:

- The real-time material tracking process was only limited to tagged materials components of the construction project. It is important that all other construction materials are fitted with tags to allow identification and availability for any specific task done with the construction site.

- It is also essential to test the material tracking process suggested, in a real situation, involving delivery of materials, material storage and usage. This is to see how effective the process is.

- Larger number of case studies are also needed to help improve the richness of the information captured for this research. This will enable more cases to be studied and extensive interviews conducted to enable a more comprehensive work on RFID usage on construction projects.

- The recommended formulation for effective tracking of material in real-time, requires technology know-how/ training for construction workers. Such requirements can be explored further to enable effectiveness of the process.

8.6 Recommendations for Further Research

This research has explored the integration RFID based approaches to material inventory managements with project management to enhance tracking of material on-site and improve material inventory management practices. To further build on the work carried out in this thesis, there is scope for others to explore. Hence, the recommendations derived from this research, which has been suggested below for others research derived further research on.

8.6.1 Recommendations for Researchers

The following are the scope to be considered for further research.

- Integration of the project management system with other systems (such as web-based systems, Computer Aided Design (CAD), etc.), can be researched further. This would facilitate material management in the construction industry.

- Further approaches can be researched on the application of real-time material tracking processes, to further enhance real-time material tracking in different types of construction projects.

- PDA data collection techniques can be researched further such that update of relevant information can be inputted into the work programme database. This will enable data on material tracking in real-time to be automatically captured and transferred within the construction site boundary.

- Further research can be extended in providing wireless connection within the construction site to facilitate easier data transfer within departments, offices and storage locations.

8.6.2 Recommendations for Industry Practitioners

The recommendations given below can be applied to material management tracking practices on the construction projects by industry practitioners:

- It is vital to assess the capability of the site manager when implementing system for tracking of material in real-time on the construction projects. It is necessary to evaluation the current technological know-how of the site manager and provide relevant training need by the manager to enable effective application of potential emerging wireless technologies (such as RFID) into material tracking and handling practices on construction site.

- There is need for industry practitioners to conduct further research on the best approaches to implement the process of material tracking and the impact of integrating RFID-based materials management with project management systems. This will enable the most effective approach to improving inventory management and tracking on the construction site.

- Industry Practitioners can apply the suggested recommendations and benefits, shown by this research's application of RFID and PDA into material management practices, to improve approaches to material inventory managements and material tracking in the UK construction industry.

8.7 Concluding Remark

The scope for improving approaches to material inventory managements in construction industry in the UK, was established through a proposed integrated approach for RFID-based

materials management tracking in real-time. Through this integration, construction industries in UK can take advantage of optimising cost, resources and time on construction projects.

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STUDENT NO: 1504290

RESEARCH TOPIC: Improving Approaches to Material inventory managements in Construction Industry in the UK.

(A Doctoral Thesis in Partial Fulfilment of the Requirements for the Award of Doctor of Business Administration of the University of Wales Trinity Saint David)

PART 1

BACKGROUND/CONTACT DETAILS

Name	
Position	
Year Experience	
Company Details:	
a) Name	
b) Address	
c) Contact:	
i) Office	
ii) Fax	
iii) Mobile	
iv) E-mail	
Date of Interview	

PART 2

A. EXPERIENCE and ROLE

1. In your recent or current job/project, what are your functions and responsibilities on the project?

2. How long have you been involved in managing materials on construction sites?

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B. MATERIALS MANAGEMENT PROCESSES

1. Do you have a specific department (procurement division or others) for managing materials on your projects?

2. Do you have a specific materials procurement system (e.g., such as purchasing procedures, delivery procedures, follow-up procedures, etc.)?

3. Do you have a specific approach to materials management (e.g., such a s recording system, target inventory level, materials tracking, delivery frequency, access and routing, etc.)?

4. How do you manage material handling in terms of transportation and materials tracking on site?

5. How do you undertake inventory management (in terms of storage and site space)?

6. How do you manage logistics (movement or routing) of materials during site activities?

7. How do you manage waste materials on site?

C. MATERIALS MANAGEMENT PROBLEMS

1. What problems do you have in materials management?

2. How do you address these problems? (e.g., using previous experience, consulting, colleagues or seniors, refer to an experts, specific tools and techniques e.tc.)

3. How can your materials management processes be improved in the future?

D. USE OF ICT IN MATERIALS MANAGEMENT

1. What technologies do you use to facilitate materials management on your sites?

2. Do you use emerging technologies (such as wireless technologies, Bar-coding, Radio Frequency Identification (RFID), tagging technologies etc) in your materials management? (If NO, answer Q3 and If YES, answer Q4, Q5, Q6, Q7).

IF NO:

3. What factors hinder the introduction of such ICT in materials management processes in your organisation?

IF YES:

4. What benefit has your organisation experienced from the implementation of such ICT tools?

5. How can such ICT tools be used to support current materials management practices on large and complex construction projects?

6. How could the use of emerging technologies improve on-site logistics and tracking of materials?

7. What are the implications for construction workers in the adoption of these emerging technologies? (e.g., such as upskilling. training, organisational/human factors, etc)

E. THE FUTURE OF MATERIALS MANAGEMENT

1. What tools/techniques do you wish you had to improve your materials management practices?

2. Which of the emerging ICT tools (such as wireless technologies bar-coding, RFID, etc) has the most potential to improve your materials management practices?

PART 3

A. MATERIALS TRACKING PRACTICES

1. What is your specific approach to tracking materials on site?

2. How do you address particular problems in managing tracking of materials on site?

3. What methods of reporting are used for tracking of materials in inventory management on site?

4. How do you undertake problems on safety of materials at storage area?

B. ICT IMPLEMENTATION IN TRACKING SYTEM

1. What technologies do you use to facilitate tracking of materials on site?

2. How does the current ICT tools support tracking of materials on site?

3. What are the potential impact of the emerging ICT tools (such as Wireless Technologies, bar coding, RFID) on logistics and tracking of materials on site?

4. What is your comments regarding the implementation of the emerging ICT tools (such as wireless technologies, bar coding, RFID) to improve materials tracking practices.

(Q = Interviewer question; A = Interviewee answer)

Q1: In your recent or current project, what are your functions and responsibilities on the project.

A1: Yea, the project we are handling at the moment is, as you can see, is a commercial building, so my primary duty as the logistics manager is to direct a smooth and effective 24-hour operation of the plant, equipment and materials in the construction site. And also, to ensure that the tools and equipment that are needed, are supplied when required. So, are just trying to ensure that the management of material flows in and out of the construction site. Basically, that is what my main job is on the site.

Q2: Okay, thank you so much. How long have you been involved in managing materials in the construction site?

A2: I have been working in construction for the past 15 years but in management of materials, a narrowed part of my work to management of materials, for the past 10 years now, I have been in the management of …... logistics management of materials in the construction site.

Q3: Okay. Do you have a specific department for management of materials on this project?

A3: The department for management of materials is the department I am in now, which is the logistics management department, so that is the one (department) that does it.

Q4: Okay, thank you for the answer. I think my next question would now be …... if you have a specific material procurement system? Maybe, something like the follow-up procedures, purchasing procedures or delivery procedures…. something like that.

A4: Well, I think that the one we make use of is the delivery procedures as well as the purchasing procedures. So, there is a way we handle the whole thing so as to ensure that the materials that we need are in constant supply.

Q5: Yes, the next question will now be…... if you have a specific approach to materials management. Maybe in terms of recording systems, you know, target inventory level, material tracking, delivery frequency etc?

A5: Well, what we make use of is …….... we make use of …. the recording system. We also try to target our inventory levels to make sure that …… the materials we need are in constant supply and we also track our materials. We don't really do the tracking aspect of it. It is more

to do with the delivery companies. The company in charge will do the delivery aspect for us and we take it from there. But basically, that's the ……... major thing we normally do.

Q6: The next question is, do you have …… how do you manage material handling, in terms of transportation and material tracking on site?

A6: …... In that regard, what we do is……. we try to ensure that …... for most of the goods that come in, we have enough equipment that enable movement of the goods into the storage spaces or required area of use. We also use the Marshals and banksmen who ensure that some of the goods coming in are being directed to the right storage spaces or area of requirement. And the safety of the workers is also our concern. So, try to make use of the traffic marshals to ensure that things are done properly. The banksmen and other things, …. put in place. The safety procedures are also in place to ensure that when the goods come in, they are safely distributed to the necessary storage facilities that we have on ground.

Q7: Ok. Thank you very much. I think the next question will be on …... what challenges or problems do you face in the management of materials on the site?

A7: Generally, there are several problems we encounter in material management…… we face a whole lot of challenges, you know, some of them involves: (i) late delivery, you know, especially…... when there is delay in the supply of the materials to the construction site, some of the sub-contractors won't be comfortable with the delay… that we are the ones holding back from completing their jobs and you know the main contractors have a completion target. So, they try to make sure that some of these problems in terms of late deliveries are taken care of, but its not really in our hands. Its from the supplier and also the delivery company, so at the end of the day, we always have the issue of that kind of thing. (ii) sometimes, the delivered materials are not correct. Sometime, you order some goods, some of the will not be as what we requested for. Some of them, we order for something, we end up receiving something else. So, it's another concern. (iii) some of the suppliers, we the quantity that we requested, they will not deliver up to the quantity that we need. So, it's a concern to us sometimes, but some of these challenges do not happen often. So, we try to know how to deal with them. (iv) and sometimes, we have the challenge of the storage spaces, maybe, there is not enough storage space to store some of the materials we that we have, so, we are trying to make do with the limited spaces that we have already allocated for the storage of materials. So…., that's it.

Q8: Ok, …... what technologies do you use to facilitate materials management on your site?

A8: in that regard, we make use of some of the equipment and devices we have already in place. Some of the equipment that we have help…... we have the cranes, we have the

machineries you know that facilitate the movement of such goods from the delivery van or lorry into a particular location where they are needed. So, I think we have enough facilities that we use to facilitate the free movement of materials on site.

Q9: Ok, thank you. Do you have any emerging technologies, something like wireless technologies that you make use of, in your material management?

A9: well, think basically some of them are…. We make use of software systems, tagging technologies like bar-coding to specify the details on delivered item. I think that the much we do on that.

Q10: Ok, what benefits have your organisation or company experienced from the implementation of such ICT facilities like the tagging bar-coding that you make use of?

A10: ok, I think it makes work easier for everyone. It allows speedy delivery of goods, easier access to goods that need. So, there are so many benefits that we gain from them. We benefit a whole lot.

Q11: what tools or techniques do you wish that you had, to improve your material management practices?

A11: I think we are looking at any techniques that make work easier, that's what we are looking at. There are so many advances in technologies these days which makes works easier, so any of those tools.

Q12: So, do you mean something like Radio Frequency Identification (RFID) or things like that…. Do you think they can help?

A12: Yes, I think …yea, so long as it makes works easier for us, we are more than happy to work with it.

Ok, thank you very much. I really appreciate your time.

(Q = Interviewer question; A = Interviewee answer)

Q1: In your recent project, what were your responsibilities on the project.

A1: Ok, the project we handled recently was for a fit-out and refurbishment of building complex. I was part of the project management team. Our duties on the project involves overall refurbishment and fit-out work on the project site.

Q2: Okay, thank you. How long have you been managing projects in the construction industry?

A2: I have been working in construction for the past 17 years and I have been involved in the management of many projects within those years.

Q3: Okay. Did you have a specific department for management of materials on those several projects that you have handled?

A3: In some of those projects, there is department that deals with the logistics and material management while on others, the project management team handles it.

Q4: Ok, thank you for the answer. If I may ask …... do you make use of a specific material procurement system? Thing like the follow-up procedures, purchasing procedures or delivery procedures…. something like that.

A4: Yes, I think that the one we make use of are the standard purchasing procedures and delivery procedures.

Q5: Thank you, my next question is…... On the projects that you have handled, do you have a specific approach to materials management, in terms of recording systems, you know, target inventory level, material tracking, delivery frequency etc?

A5: Well, what we make use of is the recording system and the target inventory levels to enable supply and also track the material level.

Q6: Ok. Thank you for the answer. I think the next question will be on …... what challenges or problems do you face in the management of materials on the site?

A6: There are several challenges encountered in material management on the construction site……some of the material supplied damage during delivery or due to improper storage or handling; we sometimes encounter delays in supplying materials to the construction site as a result of delay in payment of purchased material which affects the delivery of materials and lowers the storage level on the construction site; there problem of material logistics especially

in the movement of materials by machines and workers to where the materials are required; and other challenges.

Q7: Ok, …... what technologies do you use to facilitate materials management on your site?

A7: We make use of various equipment and devices to assist movement of materials on the site. Some of these equipment include the forklift, cherry picker …... we use the cranes and other machineries to assist the movement of such materials in areas where they are needed.

Q8: Ok, thank you. Do you have any emerging technologies, something like RFID technologies that you make use of, in your material management?

A8: In terms of the RFID use, we are yet to start implementing its use to facilitate material management on the projects I have handled.

interviewer……... but you're aware of RFID use in material management

interviewee…………yes

Q9: So, what ICT tools or techniques do you use to improve your material management practices?

A9: We make of the Microsoft tools like the Excel Spreadsheet, e-mailing systems, fax system and other software.

Q10: how do to deal with some of the challenges you face in the management of materials on the construction projects?

A10: Firstly, if there are any problems relating to material damage, late delivery, or shortages, the suppliers are advised immediately. There is a second strategy, which involves referral of any problems to the Project's Quality team, who solves problems relating to the material's quality. Lastly, there is careful control and monitoring of logistics within the workplace to ensure safety of worker, proper handling and easy movement of materials by the work force.

Ok, thank you very much for your time. I really appreciate.

(Q = Interviewer question; A = Interviewee answer)

Q1: What are your functions and responsibilities on this project.

A1: It is my duty as the construction manager, to ensure the smooth running of operations on the site.

Q2: Thank you. How long have you been involved in construction management?

A2: I have been working in construction for the past 30 years now, dealing with different aspect of projects from small to complex ones.

Q3: Do you have a specific department for management of materials on this project?

A3: We have lots of sub-contractors handling different aspects of the project. Company A (name withheld) is responsible for the general logistic on this project.

Q4: Okay, thank you for the answer. Do you have a specific material procurement system, like the follow-up procedures, purchasing procedures or delivery procedures …? something like that.

A4: The logistic company deals with that aspect of material management

Q5: Ok, the next question will now be…... do you have a specific approach to materials management? In terms of recording systems, you know, target inventory level, material tracking, delivery frequency etc

A5: That also is handled by the logistic company on this site but I think they make use of tracking materials from the supplier to time of delivery which they keep record of.

Q6: The next question is…. how do you manage material handling, in terms of transportation and material movement on site?

A6: We make of machineries and labour for easy movement of materials to areas of need…. Two cranes are mounted on the site as you can see, and other machineries like the fork lift are used too.

Q7: Ok. Thank you very much. Another question is …... what challenges or problems do you face in the management of materials on the site?

A7: We've experienced several challenges since the projects started regarding materials management …… there is the problem of insufficient storage space for materials …. and other storage constraints on the construction site; we also have high degree demand for tower crane operations making it difficult to move materials that required lifting by crane; other problems

involve the constraints in the loading and unloading of materials; and site access problems … there is single site access point which causes traffic congestion when many vehicles come to the construction site at the same time.

Q8: How do to deal with some of the challenges you face in the management of materials on the construction projects?

A8: To overcome the logistics and distribution challenge of tower crane problems, regular discussions and coordination meetings with all subcontractors is undertaken. Provision is made for proper schedule of the tower crane activities to record all the operations within the construction site. The traffic banksmen are employed on the site to deal with the single access problems and to manage the traffic flow in and out of the construction site. Just-In-Time (JIT) techniques are implemented in this project to deal with inadequate site storage space and the small loading area for the delivery of materials to the construction site.

Q9: Ok, thank you. Do you have any emerging technologies, something like wireless technologies that you make use of, in your material management?

A9: The material that are supplied on the site are coded which makes it easy to record the detail about the materials.

Q10: Ok, what benefits have your organisation or company experienced from the implementation of ICT facilities like the technologies that you make use of?

A10: They assist in the smooth handling of the materials in and around the construction site.

Q11: what tools or techniques do you wish that you had, to improve your material management practices?

A11: Any technologies that assist with smooth handling of material on site.

Q12: How about something like Radio Frequency Identification (RFID) or things like that…. Do you think they can help?

A12: Yes, that will help…. For sure

Ok, thank you. I really appreciate your time.

(Q = Interviewer question; A = Interviewee answer)

Q1: In your recent or current project, what are your functions and responsibilities on the project.

A1: My responsibilities as the logistics manager, is to manage all the logistics activities involved in this project, and to engage all the stakeholders in dealing with construction material coming in and out of the site.

Q2: Okay, thank you so much. How long have you been involved in logistics management of materials in the construction site?

A2: I have been in the construction management for about 12 years.

Q3: Okay. Do you have a specific department for management of materials on this project?

A3: The consolidation centre manages the materials for the project

Q4: Okay, thank you for the answer. I think my next question would now be …... if you have a specific material procurement system? Maybe, something like the follow-up procedures, purchasing procedures or delivery procedures…. something like that.

A4: We have a set down delivery procedures that we follow

Q5: Yeah, the next question will now be…... if you have a specific approach to materials management. Maybe in terms of recording systems, you know, target inventory level, material tracking, delivery frequency etc?

A5: The consolidation centre was implemented into this project to ensure that the construction materials were correctly and efficiently delivered at the required time and to the right construction site.

Q6: The next question is, do you have …… how do you manage material handling, in terms of transportation and material tracking on site?

A6: The project uses bar-coding, RFID and manual practices in its activities to facilitate material tracking operations. Bar-coding is used in the consolidation centre operation to facilitate material delivery identification and validation.

Q7: Ok. Thank you very much. I think the next question will be on …... what challenges or problems do you face in the management of materials on the site?

A7: The challenges we face in this project are inadequate space for materials storage at the construction site; late material delivery of materials into the project sites due to time constraints

in aircraft operations; the security regulations make it difficult with the materials supply activities into the construction site. There are also time permission constraints on the sub-contractors to exit the construction site within airport lay down boundary; and there are inadequate areas provided for loading and unloading operation at the consolidation centre.

Q8: Ok, …... what technologies do you use to facilitate materials management on your site?

A8: We use the Microsoft Excel Spreadsheet and Project, Fax system, e-mailing system, Bar-coding; and RFID system.

Q9: Ok, thank you. Do you have any emerging technologies, something like wireless technologies that you make use of, in your material management?

A9: RFID systems are used by the sub-contractors for specific operations.

Q10: Ok, what benefits have your organisation or company experienced from the implementation of such ICT facilities like the tagging bar-coding that you make use of?

A10: The implementation of emerging technologies in advancing material tracking and other materials management practices help to speed up ordering, tracking of materials, reduction in paper work, and enhance more efficient materials checking and control.

Ok, thank you very much. I really appreciate your time.

(Q = Interviewer question; A = Interviewee answer)

Q1: In your recent or current project, what are your functions and responsibilities on the project.

A1: I am the materials manager for this project.

Q2: Okay, thank you so much. How long have you been involved in managing materials in the construction site?

A2: About 10 years now.

Q3: Okay. Do you have a specific department for management of materials on this project?

A3: The department for managing materials on this project is the Logistics Centre.

Q4: Okay, thank you for the answer. I think my next question would now be …... if you have a specific material procurement system? Maybe, something like the follow-up procedures, purchasing procedures or delivery procedures…. something like that.

A4: The Logistics Centre (LC) was implemented to ease the vast number of materials is employed in this project activities.

Q5: The next question will now be…... if you have a specific approach to materials management. Maybe in terms of recording systems, you know, target inventory level, material tracking, delivery frequency etc?

A5: The project management developed a Project Flow System to allow workflow management system that is transparent and coordinates project team member's team better; identify efforts to improve performance; and share resources. This project also applied the Just-In-Time (JIT) technique to allow delivery of the right material on time and to the required place. The application of this arrangement was to avert vehicles and materials congestion traffic approaching the project site.

Q6: The next question is, do you have …… how do you manage material handling, in terms of transportation and material tracking on site?

A6: The application of the JIT and LC techniques are to resolve many challenges that relate to handling of materials on the project site, such as loss of material, late delivery, materials not meeting up with requirement standards, congestions on site, site storage constraints, overflow of traffic in the surrounding local roads and into the construction site.

Q7: Ok, …... what technologies do you use to facilitate materials management on your site?

A7: We use the Project Flow System, Bar-coding and RFID system.

Q8: Ok, thank you. Do you have any emerging technologies, something like wireless technologies that you make use of, in your material management?

A8: We use the PDA and RFID on this project for the specific tasks, such as to help monitor daily construction activities using the PDA and the use of RFID to track precast columns.

Q9: Ok, what benefits have your organisation or company experienced from the implementation of such ICT facilities like the tagging bar-coding that you make use of?

A9: It has eased the workload for the project.

Q10: what tools or techniques do you wish that you had, to improve your material management practices?

A10: Any technology that ease the workload is much appreciated.

Ok, thank you very much. I really appreciate your time.

(Q = Interviewer question; A = Interviewee answer)

Q1: In your recent or current project, what are your functions and responsibilities on the project.

A1: I am the site manager.

Q2: Okay, thank you so much. How long have you been involved in managing materials in the construction site?

A2: I have been in construction for about 20 years now.

Q3: Okay. Do you have a specific department for management of materials on this project?

A3: The logistics department manages the materials for the project.

Q4: Okay, thank you for the answer. My next question is …... if you have a specific material procurement system? Maybe, something like the follow-up procedures, purchasing procedures or delivery procedures…. something like that.

A4: The company has material management procedures it follows to manage materials for the project.

Q5: Do you have a specific approach to materials management. Maybe in terms of recording systems, you know, target inventory level, material tracking, delivery frequency etc?

A5: This project uses the Project Flow System for project management and resource planning.

Q6: The next question is…... how do you manage material handling, in terms of transportation and material tracking on site?

A6: We use the available material handling equipment to move materials around the site…. Purchasing activities and communication is done using fax and email.

Q7: Ok. Thank you very much. the next question will be…... what challenges or problems do you face in the management of materials on the site?

A7: The project location is a problem because of the busy nature of the area This affects the material delivery activities into the project site; Due to the public schools, school operations time was created …... so, there is no delivery of materials during such time…. this creates more challenges during the peak delivery time because of the huge number of vehicular traffic in and out of the site; and increase the waiting time of delivery vehicles for unloading materials at specific storage area; we need access permission from the local authority on this project for material transportation and delivery into the construction site during school operations (school run)

Q8: Ok, …... what technologies do you use to facilitate materials management on your site?

A8: We use the Project Flow System manage material resources

Q9: Ok, thank you. Do you have any emerging technologies, like RFID, in your material management?

A9: We don't use RFID in this project.

Q10: Are you aware of its use in material management.

A10: Yes, I am aware of RFID importance in providing efficient material management and tracking but there are other things to consider like training of workers, supplier support and standardised material labelling.

Ok, thank you very much. I really appreciate your time.