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REDUCING CONSTRUCTION WASTE IN HEALTHCARE PROJECTS: A PROJECT LIFECYCLE APPROACH

by

D.D.A.Niluka Dulashinie Domingo

B.Sc.QS. (Hons.)

Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of Loughborough University

Civil and Building Engineering Department
Loughborough University

NOVEMBER 2011

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This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgements or in footnotes, and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a degree.

…… (Signed)

…… (Date)

DEDICATION

Dedicated to my parents and my loving husband Duminda Wijayasinghe…..

ACKNOWLEDGEMENTS

I would like to express my gratitude to those who have given so much devotion and dedication in numerous ways to complete this thesis.

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ABSTRACT

Construction waste generation is a global issue in the sustainable construction context and several studies have been performed in different parts of the world to develop methods and tools for waste prevention, reduction, reuse and recycling. Most of these studies adopted a linear approach by focussing on a specific project phase, such as design, procurement or construction. However, there is a consensus in the literature that factors causing construction waste span across the project life cycle and recent researchers emphasised the need for a more integrated lifecycle approach to holistically assess and evaluate causes of waste to suggest recommendations to reduce lifecycle construction waste generation.

Over recent years, the UK government has been investing billions of pounds in new and refurbished healthcare projects, where the healthcare buildings are often referred to, in literature, as complex buildings. This large investment has created a number of sustainability issues including water consumption, CO2 emissions, energy consumption, and more significantly construction waste generation. However, no significant research has been undertaken to propose a systematic construction waste minimisation mechanism for healthcare construction projects. Therefore, this research aims to develop a lifecycle construction waste minimisation framework for healthcare projects (HC-WMF).

In order to identify the research problem and construction waste generation issues peculiar to healthcare projects, nine preliminary interviews were conducted with healthcare clients (N=3), architects (N=3), and contractors (N=3). The findings revealed that healthcare projects generate high rates of waste compared to other building projects throughout the project lifecycle, identified complex features that have an effect on waste generation, and identified particular causes of construction waste in healthcare projects. A further in-depth study based on four case studies was undertaken to understand the impact of waste generation due to the causes of waste, the relationship between complex features in healthcare projects and the causes of waste, and best waste minimisation practices to be implemented throughout a healthcare project lifecycle to address construction waste causes. Three interviews (client, architect, and contractor) from each case study were undertaken during the data collection stage.

A Healthcare Construction Waste Minimisation Framework (HC-WMF) and Self-Assessment Tool (SAT) were then developed based on the findings of the literature review, preliminary data collection study and case studies, and adoption of the key concepts of problem solving methodology. This HC-WMF comprised six waste minimisation strategies (project documents management, stakeholders' waste awareness, communication and coordination, buildability, materials selection and procurement, and change management) to be followed throughout the lifecycle stages of a healthcare project. SAT provides a means to assess the effectiveness in implementing HC-WMF and to obtain feedback and learning outcomes for continuous further improvements. In order to validate the developed HC-WMF and SAT a validation questionnaire (N=26) and validation interviews (N=4) were conducted. The validation results showed that the HC-WMF and SAT would be very useful in reducing construction waste generation from healthcare projects.

The research contributes to construction waste minimisation research introducing a novel approach to lifecycle waste reduction. Also, the research revealed the complex features in healthcare projects that affect construction waste generation, causes and origins of waste peculiar to healthcare projects, and best waste minimisation strategies to implement to reduce construction waste generation from healthcare projects. Most importantly, through HC-WMF, this research produced a set of guidelines to be followed throughout the healthcare project lifecycle to reduce construction waste generation. The study has made recommendations which, if adopted, will lead to significant improvements in sustainable healthcare construction due to construction waste minimisation. The content should be of interest to clients, designers, and contractors dealing with construction waste minimisation and sustainable construction in healthcare projects.

Key words: Construction waste, Healthcare, Causes of waste, Healthcare complexities, Waste minimisation, UK.

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ABBREVIATIONS

AEDET	Achieving Excellence Design Evaluation Toolkit
BRE	Building Research Establishment
BREEAM	Building Research Establishment's Environmental Assessment Method
C & D	Construction and demolition
CD&E	Construction, Demolition, and Excavation
CIRIA	Construction Industry Research and Information Association
CPIM	Construction Process Improvement Methodology
DEFRA	Department for Environment, Food and Rural Affairs
DETR	Department of the Environment, Transport and the Regions
DH	Department of Health
DRP	Design Review Panel
DTI	Department of Trade and Industry
EPSRC	Engineering and Physical Sciences Research Council
EU	European Union
GCCP	The Government Construction Clients' Panel
GDP	Gross Domestic Product
HaCIRIC	Health and Care Infrastructure Research and Innovation Centre
HBN	Health Building Notes
HC-WMF	Healthcare Construction Waste Minimisation Framework
HTM	Health Technical Memorandum
ISO	International Standardisation Organisation
LIFT	Local Investment Finance Trust
M&E	Mechanical and Electrical
NAO	National Audit Office
NEAT	NHS Environmental Assessment Tool
NHS	National Health Service
OGC	Office of Government Commerce
P21	Procure 21
PFI	Private Finance Initiatives
RIBA	Royal Institute of British Architects
SAT	Self-Assessment Tool
SC	Sustainable Construction
SD	Sustainable Development
SHINE	Learning Network of Sustainable Healthcare

SOGE	Sustainable Operations for the Government Estate
UK	United Kingdom
UNCHS	United Nations Centre for Human Settlements
USA	United States of America
WHO	World Health Organisation
WRAP	Waste Resources Action Programme

1

INTRODUCTION

1.1 Background

Sustainable development (SD) is not a novel concept since numerous civilisations in the past recognised the correlation between environment, society and economy in the local and regional context. The last few decades emphasised further these needs in the context of a national and global level because of the rapid growth in the world especially in the developing world. SD helps to deliver economic, environmental, and social objectives simultaneously (DETR, 2000; NAO, 2007). It is most commonly defined as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). The construction industry plays a vital role in the development of a country, and in most developing and industrialised economies, the construction industry constitutes approximately 8-12% of Gross Domestic Product (GDP) (UNCHS, 1993). In the United Kingdom (UK) this accounts for some 7% of GDP (Cabinet Office, 2011). These statistics highlight the significance of the construction industry in a country's economy where the concept of sustainable construction (SC) reflects an important component in the SD context.

SC builds upon the principles of SD (DTI, 2006), which can be simply defined as the application of SD principles to the construction industry (WRAP, 2010a). SC helps to deliver built assets while securing natural and social environments, and it offers enhanced quality of life, customer satisfaction, and potential to cater for future changes through flexibility (Chen and Chambers, 1999; GCCP, 2000; ISO, 2005). The construction industry is using various indicators to measure the performance of SC and therefore, the UK government published in 2008 its Sustainable Construction Strategy (HM Government, 2008) specifying targets to mitigate and adapt to climate changes, reduce water and materials consumption, enhance biodiversity, and reduce construction waste generation.

A number of past researchers revealed a positive correlation between construction waste minimisation and SC, since it allows securing natural resources while obtaining expected economic, social and environmental benefits (Faniran and Caban, 1998; Shen and Tam, 2002; Dainty and Brooke, 2004). However, in the past two decades alarming figures have been reported from different parts of the world with regard to the amount of total waste generation in construction. In countries like the USA, Australia, Brazil, Hong Kong, and the Netherlands, these figures accounts for approximately one third of the total waste sent to landfill sites (Rogoff and Williams, 1994; Ferguson et al., 1995; and EPA, 1998; Tam et al., 2007a). Moreover, recent figures published by the UK government revealed that construction, demolition, and excavation (CD&E) activities produce around 120 million tonnes of waste every year (WRAP, 2007) which is approximately 32% of the total waste generated in the UK and is three times the waste produced by all households combined (DEFRA, 2007a). Furthermore, 10% of all materials delivered to construction sites are wasted due to damage, loss and over-ordering (Guthrie et al., 1998) and approximately 13% of building materials delivered to sites are directly sent to landfills without being used (DEFRA, 2007b). As such, the 'Waste Strategy for England 2007' has identified the construction industry as a major waste generator (DEFRA, 2007a).

Construction waste impacts on economic competitiveness in the construction industry are substantial since it creates lot of extra costs (i.e. overhead costs; extra work on cleaning; lower productivity; land fill taxes) for contractors where the ultimate burden of such costs is borne by clients (Skoyles and Skoyles, 1987; Ekanayake and Ofori, 2000). Moreover, a company generating large amounts of construction waste is often at a disadvantage in the competitive environment, where Teo and Loosemore (2001) estimated that companies producing higher levels of waste are at a 10% disadvantage in the tendering procedure.

Additionally, construction waste creates a number of environmental problems at both national and global levels since it consumes a large proportion of landfill volumes, superfluously uses non-renewable natural resources and contributes to environmental pollution through air and water pollution (Bossink and Brouwers, 1996; Ekanayake and Ofofri, 2000; Chan and Fong, 2002; Esin and Cosgun, 2007). Moreover, construction waste creates a number of social problems due to health and safety issues. These environmental, economic and social issues put significant pressure onto the construction industry to reduce construction waste generation.

The National Health Service (NHS) is one of the largest public sector client in the UK government having a considerable property portfolio (Holmes et al., 2006). With the aim of delivering better health for people in the country, the NHS has started a significant capital investment programme including modernisations to its existing buildings whilst also constructing new healthcare buildings. This capital investment accounted for around £5.5 billion in 2007/08, in real terms almost four times the amount for 1997 (DH, 2007a). This capital investment programme is expected to continue in the future since the NHS plans to spend over £4.4 billion on healthcare buildings from 2010/11 to 2014/15 (DH, 2010). With this capital investment programme a number of sustainability issues have arisen including: excessive consumption of energy and water; carbon emission, and large volumes of waste generation (SHINE, 2006). Therefore, healthcare industry stakeholders are placing more emphasis on SC while delivering healthcare facilities to reduce overall building impacts (Brannen, 2007). The Department of Health (DH) sets SC targets for operational energy, water consumption, transport, sustainable procurement and waste minimisation and recycling (DH, 2007b). In the construction of healthcare buildings, construction companies are required to meet the UK Sustainable Construction Strategy target to reduce CD&E waste to landfill sites by 50% of 2008 figures by 2012, and to achieve zero net waste at construction site level by 2015, and zero waste landfill by 2020 (HM Government, 2008).

Many authors argue that source reduction is the best way of minimising construction waste and eliminating waste disposal problems to landfill sites (Cohen and Allen, 1992; McDonald and Smithers, 1998; Begum et al., 2007). Additionally, past research studies identified causes and origins of waste using different classifications such as: project level activities (Gavilan and Bernold, 1994; Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000); waste to material types (Soibeiman et al., 1994; Pinto and Agopayan, 1994); and project lifecycle stages (Graham and Smithers, 1996; Osmani et al, 2008).

Waste minimisation approaches suggested by most research studies propose onsite waste minimisation and management practices (McDonald and Smithers, 1998; Poon et al., 2001; Chen and Wong, 2002). A few research studies investigated waste minimisation at design stage (Keys et al., 2000; Jaques, 2000; Osmani et al., 2006; Osmani et al., 2008). Despite the fact that past research studies indicated that waste can arise at any stage of the construction process from inception, through the design stages and construction and operation stages (Spivey, 1974; Gavilan and Bernold, 1994; Craven et al., 1994; Faniran and Caban, 1998; Ekanayake and Ofori, 2000),

many of the research studies focused only a specific project phase, such as design, procurement or construction. However, there is a small but growing body of literature that highlighted the need for a more integrated lifecycle approach to minimise construction waste effectively while achieving SC targets (Dainty and Brooke, 2004; Shen et al., 2004; Begum et al., 2007).

1.2 Research Justification

With the huge capital investment programme currently underway in the NHS including new construction; refurbishment/renovation; and extensions to existing buildings; large numbers of SC issues became apparent including construction waste generation. However, the NHS as a good corporate citizen of the UK government has a considerable level of responsibility to support the government during its capital investment programme to achieve the SC targets specified by the UK Sustainable Construction Strategy. As construction waste generation is identified as a significant sustainability issue in the healthcare capital investment programme, it is useful to investigate an appropriate waste minimisation mechanism for healthcare construction projects.

Literature reveals a large number of waste causes related to different lifecycle stages, which can be broadly categorised into four main lifecycle stages of construction projects: pre-design; design; contract agreement; and construction/renovation. For instance, most of the pre design phase causes of waste mentioned in the literature are related to lack of project planning (Tam et al., 2007b); lack of identification of client's needs (Kulathunga et al, 2006); and incomplete briefing (Osmani et al., 2006). In the design phase most of the causes of waste are either related to drawings or materials selection and specifications (Gavailan and Bernold, 1994; Bossink and Brouwers,1996; Ekanayake and Ofori, 2000; Poon et al., 2004a; Kulathunga et al., 2006; Osmani et al., 2006; Tam et al., 2007b; Osmani et al., 2008). In the contract agreement phase causes of waste are specified in the literature as errors in contract/tender documents (Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000; Osmani et al., 2008); incomplete contract documents (Ekanayake and Ofori, 2000; Kulathunga et al., 2006; Osmani et al., 2008); contract type and method of tendering (Skoyles and Skoyles, 1987; Baldwin et al., 1998). The construction phase causes of waste can be categorised into material procurement, material storage, material handling, on-site management and planning, site operation, transportation and residual waste (Gavilan and Bernold, 1994; Bossink

and Brouwers, 1996; Ekanayake and Ofori, 2000; Kulathunga et al., 2006; Osmani et al., 2008).

Notwithstanding, research studies that focused on identifying the related causes of waste in construction, a number of researchers have attempted to recognise best waste minimisation and management approaches. Most researchers recommended on-site waste minimisation practices such as: waste quantification and source evaluation (Gavilan and Bernold,1994; Bossink and Brouwers,1996; Faniran and Caban,1998; Ekanayake and Ofori, 2000; Poon et al., 2004a; Kulatunga et al., 2006; Guzman et al., 2009); on-site construction waste sorting methods and techniques (Poon et al., 2001; Wang et al. 2010); planning and organisation of site activities (Gavilan and Bernold, 1994; Faniran and caban, 1998; Poon et al., 2004b); onsite waste auditing and assessment (McGrath, 2001; Chen and Wong, 2002); and reuse and recycling (Lawson et al., 2001; Emmanuel, 2004). Although some research studies recommended improvement in the design brief (Keys et al., 2000; Greenwood, 2003; Osmani et al., 2008), to date no significant research has been conducted to identify waste minimisation and management practices to be implemented at the pre-design phase. Few recent research studies have outlined design out waste practices such as: early supply chain integration (Dainty and Brooke, 2004; Osmani et al., 2006; Guzman et al., 2009); use of pre-fabricated elements (Dainty and Brooke, 2004; Baldwin et al., 2006) and timely and effective communication (Faniran and Caban, 1998; Poon et al., 2004b). Similarly, few research studies emphasised the need for new contractual requirements targeting waste minimisation (Greenwood, 2003; Dainty and Brooke, 2004). However, no significant research has been conducted focusing on the lifecycle approach to reducing construction waste generation even though the causes of waste found in the literature span project lifecycle stages from inception to completion.

There is a consensus in the literature that healthcare buildings are “different” and “complex” due to complexities within functional and operational features (Akintoye and Chinyio, 2005). As a result, it is important to customise causes of waste, particular for healthcare construction projects, when proposing an appropriate waste minimisation procedure. Existing literature discusses causes of waste commonly for all the construction projects and knowledge related to healthcare construction projects is very limited. Also, literature failed to propose a systematic approach to select causes of waste relevant for each type of project depending on the project characteristics.

Furthermore, literature reveals that healthcare buildings need to be adaptable and flexible to facilitate future user and management requirements with the advancements in medical technology (Thomson et al.,1998). Therefore, it could be argued that healthcare construction projects generate comparatively high amounts of waste throughout the facility lifecycle due to frequent changes.

Literature findings also reveal that the current and future trend in delivering healthcare projects in the UK is most commonly through Private Finance Initiatives (PFI), Local Investment Finance Trust (LIFT) and Procure 21 (P21) schemes (DH, 2007a) (see Section 2.8.1). Previous studies in waste minimisation and management emphasised that different construction procurement systems may have a different effect on the generation of waste on-site as a result of the different interrelationships involved in alternative procurement processes, (McDonald and Smithers, 1998); individual responsibility and communication within procurement teams (Emmitt and Gorse, 1998); and the decision-making process in the projects (Ekanayake and Ofori, 2000). The above findings were further confirmed by Gamage et al. (2009) revealing the need for a further study to investigate the impacts of different procurements systems on construction waste generation. Since, healthcare projects also use specific procurement systems such as P21 and LIFT that were specifically introduced by the NHS to deliver healthcare projects, the impacts of waste generation due to different procurement systems could vary.

According to the above arguments based on the literature review findings, it is clear that healthcare construction projects differ from other building construction projects due to: the complex nature of functional and operation features; lifecycle requirements of being adaptable and flexible; and use of special procurement systems in the delivery of healthcare projects. However, to date, no significant research has been conducted to identify the effects of the above features in terms of waste generation in healthcare construction projects. Also, currently, there is no clear evidence in literature relating to waste minimisation methods, frameworks or models that directly consider healthcare waste minimisation. As construction waste minimisation from healthcare projects is an important requirement in the UK with the rapid growth in the healthcare sector, this context emphasises the need for a thorough investigation to identify a lifecycle waste minimisation approach for healthcare projects, which is the focus of this research.

1.3 Aim and Objectives

This research study aims to develop a lifecycle construction waste minimisation framework for healthcare projects (HC-WMF). The HC-WMF intends to assist healthcare stakeholders to reduce waste generation from healthcare construction projects across all lifecycle steps. In this pursuit, the following objectives are considered.

Objectives related to literature:

1. Explore the relationship between sustainable construction and waste minimisation.
2. Examine construction waste minimisation drivers, causes and origins of waste, and current and emerging waste minimisation approaches.
3. Examine current and future trends in the UK healthcare industry and assess the importance of construction waste minimisation in sustainable healthcare construction.

Objectives specific to current research:

4. Investigate causes of waste particularly for healthcare building projects in the pre-design and contract agreement, design and construction/renovation phases.
5. Identify specific functional and operational features of healthcare construction projects that affect waste generation.
6. Explore the most suitable waste minimisation strategies to be implemented in the healthcare project lifecycle stages to reduce construction waste generation in healthcare building projects.
7. Develop and validate a lifecycle construction waste minimisation framework for healthcare projects.

1.4 Research Methodology Overview

The research methodology for this research study was carefully selected to address the research problem and objectives. This research study was placed in the pragmatic knowledge claim position since it mainly focused on identifying solutions to comprehensive real life problems. This research study followed a combination of inductive and deductive reasoning approaches during the theory testing and theory building purposes, since the combination is often advantageous as it enables the researcher to gather benefits from both approaches (Yin, 2003; Gill and Johnson, 2002; Saunders et al., 2007). Preliminary data collection and in depth interviews from

holistic-multiple case studies based on the literature review findings were used to induce knowledge into this research. The research begins with a preliminary data collection study to address the identified knowledge gaps in the literature which are related to healthcare construction waste minimisation and to establish a firm base for the research study. Subsequently, the research study used a case study approach to explore construction waste generation and minimisation in healthcare construction projects with the help real life scenarios. The following sections outline the methodological approach used in this research study (Figure 1.1).

Literature review: A comprehensive literature review was conducted to ensure that the previous research findings have not been repeated or ignored in the research study. The literature review focussed on three main areas: sustainable construction; waste minimisation; and healthcare construction and waste generation. Additionally, a review of research methods was undertaken to identify the most suitable methodology to be adopted for this research. A literature search was undertaken using electronic and printed sources as illustrated in Figure 1.1. The search was carried out using the 'snowball' technique where the search was gradually extended through the references and key authors within the discovered literature. The key words used in searching literature were 'sustainable construction', 'construction waste' 'healthcare construction' and 'construction waste minimisation'. The literature also identified existing knowledge gaps in the areas of SC; construction waste minimisation; and healthcare construction and waste generation and established clear research objectives and methodology.

Preliminary data collection study: The literature review exposed a number of knowledge gaps related to: particular causes and origins of waste in healthcare construction; particular features in healthcare projects that affect waste generation; and suitable waste minimisation approaches to reduce construction waste from healthcare projects. Subsequently, a preliminary data collection study was undertaken, which consisted of a pre interview questionnaire and follow up interviews as stated in the Figure 1.1. Nine key healthcare stakeholders representing clients, architects and contractors participated in this study. The pre interview questionnaire and interview templates contained three sections: background information; lifecycle construction waste mapping; and construction waste minimisation practices.

Case Studies: The findings of the preliminary data collection study showed that healthcare construction projects generate considerably higher amounts of waste throughout the building lifecycle. Moreover, findings uncovered causes of waste and

healthcare building characteristics that increase waste generation in healthcare projects. In that pursuit, exploratory case studies were conducted with the aim of identifying highly impact causes of waste in terms of waste generation, relationships between causes of waste and healthcare project characteristics, and potential waste minimisation practices to be implemented throughout the building's lifecycle to reduce construction waste generation in healthcare projects. Four case studies which included: two acute care projects; and two primary care healthcare projects, were selected for this study. From each case study, three interviews were conducted among client representatives; architects; and contractors. The interview template contained four sections: background information; causes of construction waste and their relationship to functional/operational features in healthcare projects; construction waste minimisation strategies; and further thoughts.

Design and development of HC-WMF: The basic concept of the HC-WMF design followed the construction process improvement method (CPIM) adopted from traditional problem solving methodology (refer section 3.5.5). The HC-WMF was developed based on the findings of the literature review, preliminary data collection study and case studies. Founded on the current research study results, the HC-WMF proposed a set of waste minimisation activities to be implemented throughout the lifecycle of healthcare construction projects to reduce construction waste generation. These waste minimisation activities were broadly categorised into six waste minimisation strategies: project document management; stakeholder and waste awareness; communication and coordination; buildability; materials selection and procurement; and change management. The HC-WMF consists of three levels: high level, low level and SAT. The high level HC-WMF demonstrates the logical waste minimisation sequence proposed from the HC-WMF including six waste minimisation strategies and continuous learning processes with the use of SAT. The low level HC-WMF illustrates the most suitable actions to implement in each lifecycle phase under each waste minimisation strategy. A coding system (i.e. colour and numbering) was used to facilitate easy reference within the high level and low level framework components. A SAT was developed using Excel Macros to measure how effectively the proposed waste minimisation activities will be implemented in a particular project to obtain feedback and lessons learnt for future projects to reduce construction waste generation through continuous improvements.

HC-WMF validation: The aim of the validation process was to refine and examine the appropriateness of the proposed HC-WMF. The validation study further explored the

potential implementation strategies for the proposed HC-WMF. The HC-WMF validation process consisted of three stages: pre validation discussions with four construction management researchers at Loughborough University; an electronic questionnaire was sent to twenty-six respondents who participated in this research study during the data collection stage; and semi structured interviews conducted with project managers with experience in healthcare construction. The combination of both qualitative and quantitative studies were conducted to validate the developed HC-WMF in terms of their clarity and appropriateness of the proposed contents to minimise construction waste generation in healthcare construction projects.

Data analysis: The data collected in this research study was mostly qualitative, based on semi structured interviews conducted during the preliminary data collection study, case studies and HC-WMF validation interviews. Constant Comparative Method was used to analyse the data collected from the aforesaid studies (refer section 3.6.2). The entire data analysis process was carried out manually without using qualitative data analysis software. Microsoft Word (2007) and Microsoft excel 2007 were used for data storage and manipulation purposes. Additionally, the quantitative data collected from the pre interview questionnaire (preliminary data collection study) and validation questionnaire were analysed using descriptive statistics where counts (numbers or frequency) and proportions (percentages); were mainly used to present the results (3.6.1).

Research Steps	Research Methodology	Research outcomes
Literature Review	• **Topics:** sustainable construction; construction waste; healthcare construction and waste generation; and research methodology • **Sources of information:** journal articles; conference papers, web publications, government reports, books, and thesis	• Identify knowledge gaps in the literature • Identify and refined research aim, objectives • Identify a suitable research methodology to follow including data collection and analysis methods
Preliminary data collections study	• **Data collection techniques:** (1)Pre interview Questionnaire: (2) Preliminary interviews: Semi structured, face- to- face interviews • **Respondents:** client representatives (N=3); architects (N=3); contractor representatives (N=3) with healthcare experience • **Data analysis techniques:** Quantitative data analysis: descriptive statistics Qualitative data analysis: constant comparison method	• Discuss and evaluate waste generation severity in healthcare projects compared to other buildings. • Identify causes of waste in healthcare projects. • Identify complexities in healthcare projects effect on waste generation. • Discuss and assess the most effective waste minimisation practices currently used in healthcare project lifecycle.
Case studies	• **Data collection technique:** Interviews: Semi structured, face-to- face interviews • **Respondents:** client representatives, architects; contractor representatives from case studies (N=4; two acute care projects and two primary care projects) • **Data analysis technique:** Qualitative data analysis: constant comparison method	• Identify impacts of causes of waste on construction waste generation in healthcare projects. • Identify relationships between causes of waste and complexities in healthcare buildings. • Investigate and assess good waste minimisation practices to address causes of waste in healthcare project lifecycle. • Identified complexities in healthcare facilities effect on waste generation.
Design and Development of HC-WMF	• Compile and structure findings form the literature review, preliminary data collection study and case studies. • Followed steps in the construction process improvement method.	• HC-WMF: comprising of high level (waste minimisation strategies), low level (waste minimisation activities to implement in each lifecycle stage) and , SAT(guide project team to assess the effectiveness in implementing waste minimisation activities proposed in the HC-WMF)
Validation of HC-WMF	• **Data collection techniques:** (1)Validation questionnaire (2)Validation interviews • **Respondents:** (1) Questionnaire**:** N=26 (all the participants involved to the preliminary study and case studies) (2) Interviews: N=4 (contractor representatives) • **Data analysis techniques:** Quantitative data analysis: descriptive statistics Qualitative data analysis: constant comparison method	• Refine HC-WMF. • Future improvement measures to the HC-WMF. • Potential implementation strategies for the proposed HC-WMF.

Figure 1.1: Research process: research steps, methodology, and outcomes

1.5 Contribution to Knowledge

The current research study has explored construction waste generation in the context of UK healthcare construction sector. The outcomes of the research study demonstrate a detailed lifecycle approach to reduce construction waste generation in healthcare projects and to introduce a self-assessment system to obtain feedback and lessons learnt from projects to achieve continuous improvement. The specific contribution of this research falls into two categories: contribution to literature and lifecycle construction waste minimisation framework for healthcare projects.

1. The findings of the study that contribute to the literature on construction waste minimisation and healthcare SC are to:
   - Provide a novel lifecycle approach to reduce construction waste generation from healthcare projects from the planning/pre design phase to completion of construction/renovation stages;
   - Identify causes and origins of waste that are particular to healthcare projects throughout their lifecycle;
   - Identify complex functional and operational features in healthcare projects that affect construction waste generation and their relationship to causes of waste in the healthcare project lifecycle; and
   - Propose several measures to address causes of waste in the healthcare project lifecycle.

2. The research study has proposed a HC-WMF for healthcare projects which provides the basis for healthcare projects to implement construction waste minimisation activities throughout the project lifecycle. The HC-WMF guides the project team in a healthcare construction project in implementing waste minimisation activities from the beginning to completion of a project. Additionally, the SAT provides the basis to assess the effectiveness in implementing waste minimisation activities in healthcare construction projects facilitating opportunities to obtain feedback and lessons learnt for continuous improvement.

1.6 Structure of the Thesis

As displayed in the Figure 1.2, this thesis contains eight chapters.

Chapter 1: This chapter presents an overview to the thesis. It begins with an introduction to the context of the research and states research aim and objectives. It also reveals the research justification, an overview of the research methodology and key contribution of the research. The last section of this chapter gives a guide to the thesis.

Chapter 2: This chapter presents a critical review of literature that provides the foundation to the research. The chapter consists of three sections: sustainable construction; waste minimisation; and healthcare construction and waste generation.

Chapter 3: This chapter provides an overview to the research methodology. It describes research philosophies, research approaches, research designs and research methods while providing emphasis on adapted research methodology. Additionally, this chapter explains the research process in detail including initial impetus, literature review, preliminary data collection, and case studies. Consequently, this chapter illustrates data ordering and analysis procedures while giving insights about the data validity and reliability measures. Finally the chapter describes the HC-WMF and SAT design and development procedure.

Chapter 4: This chapter presents the findings from the preliminary interviews. The chapter covers background to the study and interviewees, waste generation in healthcare, the effect of complex features in healthcare projects on waste generation and causes of waste in healthcare projects. Additionally, the chapter reports potential waste minimisation practices for healthcare projects based on the research study findings.

Chapter 5: This chapter reports the findings from the main data collection study in the research which is case studies. It presents interview results and provides analysis of findings including background information, causes of construction waste in healthcare projects, features in healthcare projects which affect construction waste generation, and waste minimisation strategies.

Chapter 6: This chapter discusses the HC-WMF design, development and validation process. The chapter describes the key components in the HC-WMF. Also, the chapter presents the findings from the HC-WMF validation questionnaire and semi structured

interviews outlining key actions taken to refine the proposed HC-WMF. Additionally, the chapter illustrates the potential implementation strategies for proposed HC-WMF.

Chapter 7: This chapter presents a discussion of the main themes derived from the study specifying where the research findings fit into the literature.

Chapter 8: This chapter presents the conclusions and recommendations of this study. The chapter consist of a summary of research findings, contribution to knowledge, recommendations, limitations of the research and further research.

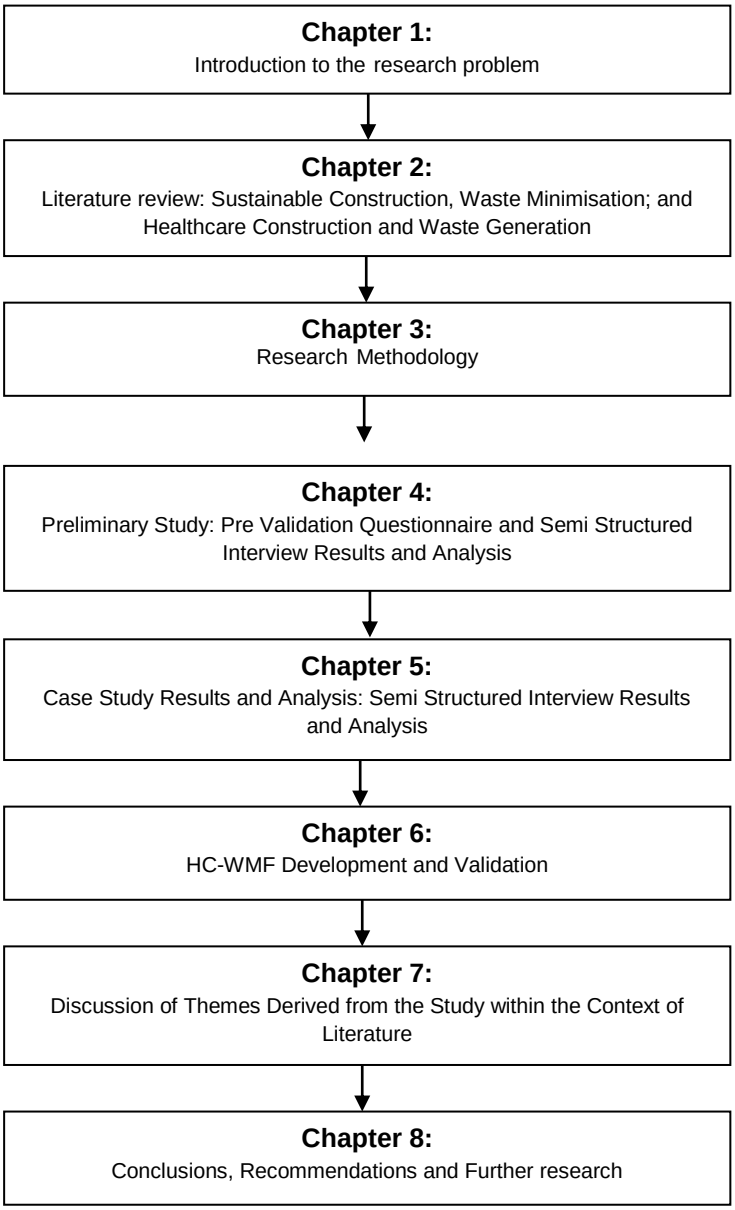


Figure 1.2: Structure of the Thesis

2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature review which seeks to examine healthcare construction waste generation issues and identify gaps in the knowledge. This chapter covers three main sections: sustainable construction; construction waste; and construction waste generation and minimisation in healthcare.

The first section of the chapter defines sustainable development and describes the UK's sustainable development strategy. Subsequently, the chapter examines sustainable construction and its relationship to waste minimisation with specific reference to the UK.

The second section reviews different definitions of construction waste and establishes the adopted definition for construction waste in the study; assesses construction waste classifications and quantifications; evaluates the best practicable options to address construction waste related issues (e.g. waste hierarchy). Subsequently, construction waste minimisation drivers and origins and causes of construction waste throughout the building lifecycle are examined at length, followed by insights into current construction waste minimisation approaches.

The third section reviews the current and future trends in healthcare construction; discusses the impact of waste minimisation on sustainable healthcare construction; describes healthcare construction waste origins throughout the project lifecycle; and explores existing knowledge gaps in the literature. Finally, the chapter examines current waste minimisation practices in healthcare construction.

2.2 Sustainable Development

The most common definition for Sustainable Development (SD) was presented in the Brundtland report 'Our Common Future', at the World Commission on the Environment and Development (WCED) in 1987 as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The International Council for Local Environmental Initiatives (1996) defined SD as the "development that delivers basic environmental, social and economic services to all residences of a community without threatening the viability of natural, built and social systems upon which the delivery of those systems depends". According to Sage (1998), SD is the "fulfilment of human needs through simultaneous socio-economic and technological progress and conservation of the earth's natural systems". These definitions confirm that the final aspiration of SD is to satisfy the present whilst ensuring the social, economic and environmental needs of future generations and recognising new ways of meeting people's needs, expectations and aspirations.

Over the last two decades there has been a growing understanding of the world and its inhabitants as a single system (Spence and Mulligan, 1995). With the rapid developments in the world, the environment is struggling to cater for the resources to satisfy the current consumption. Hence, there is a widespread recognition that if this rate of consumption continues it will create a huge environmental problem in the near future (DETR, 2000). This motivated world leaders and decision makers towards the concept of the SD in all developments.

2.2.1 The UK Strategy for Sustainable Development

At the Rio Summit in 1992, nearly 180 countries in the world discussed the importance of SD and agreed on a plan of action known as Agenda 21 and recommended that all countries should produce their own national sustainable strategies. As a result, in 1999, the UK government produced an outline proposal for delivering SD called 'A Better Quality of Life' which defines SD to ensure "a better quality of life for everyone, now and for generations to come" (DEFRA, 1999). This strategy set out a vision of simultaneously delivering economic, social and environmental outcomes as measured by a series of indicators, while meeting four objectives:

- social progress which recognises the needs of everyone;
- effective protection of the environment;
- prudent use of natural resources; and

- maintenance of high and stable levels of economic growth and employment.

In 2005, DEFRA reviewed the initial SD strategy and introduced a revised strategy entitled 'Securing the Future' to better suit future developments. In this document, SD is conceptualised around five key principles (refer figure 2.1) with a more explicit focus on environmental limits (HM Government, 2005).

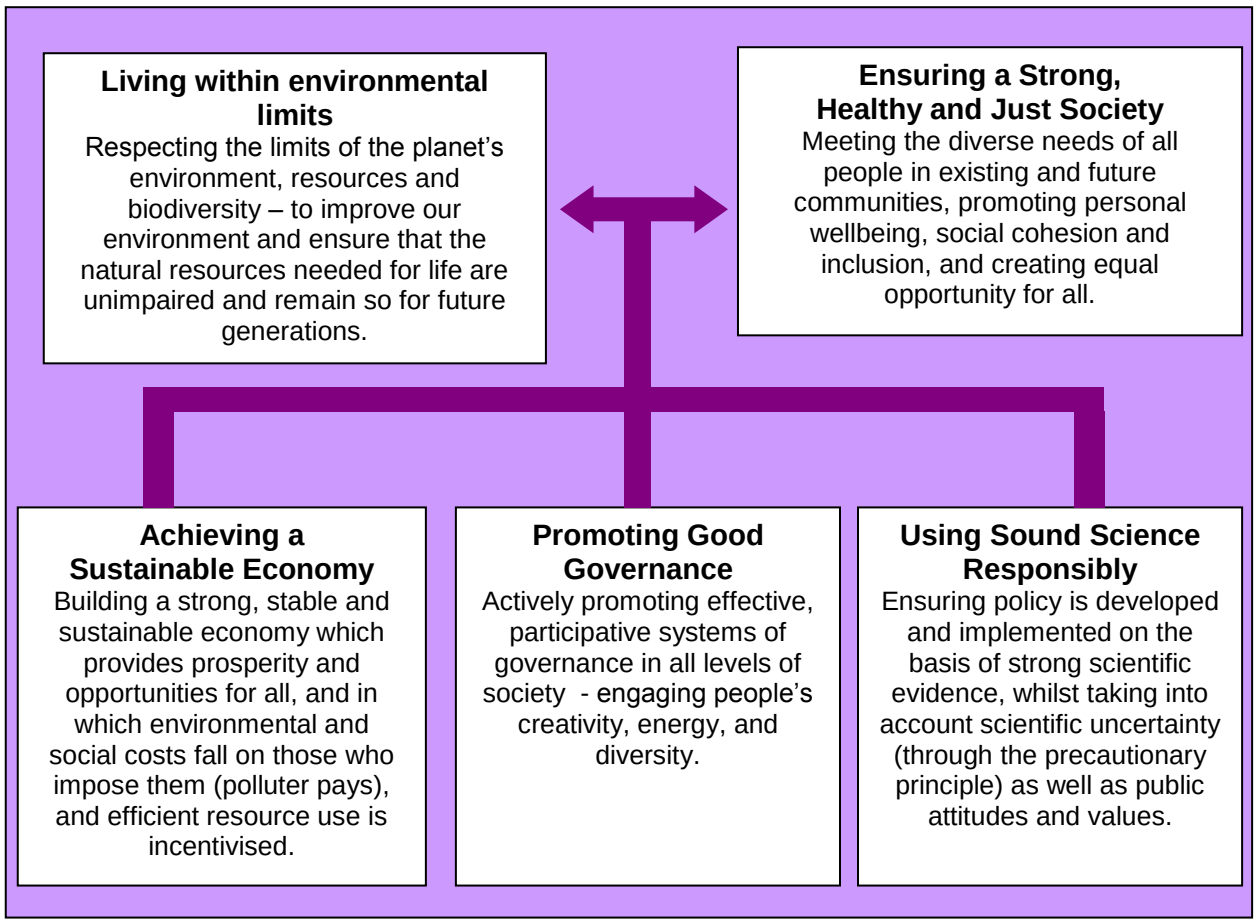


Figure 2.1: UK sustainable development principles (HM Government, 2005)

In order to review the progress of SD, the UK strategy for SD outlined 68 indicators including twenty key 'UK framework indicators' that are highly relevant and important to SD in the UK. Each year, the UK government measures the progress of these 68 indicators to identify whether there has been an improvement, deterioration or no change compared to previous years. These measures help to provide an overview of progress across the four priority areas: (i) sustainable consumption and production; (ii) climate change and energy; (iii) natural resource protection and enhancing the environment; and (iv) creating sustainable communities and a fairer world, stated in the UK strategy for SD (HM Government, 2005).

Table 2.1: Priority areas in the UK strategy for SD (Sources: HM Government, 2005; DEFRA, 2010)

Priority Areas	Purpose	Main indicators
Sustainable consumption and production (SCP)	Ensure maximum production with minimum usage of resources.	covers indicators relating to emission, resource use and waste
Climate change and energy (CCE)	Secure a profound change in the way of generating and using energy, and in other activities that release these gases.	covers indicators relating to greenhouse gas emissions, electricity generation and energy supply
Natural resource protection and enhancing the environment (NRP)	Understand environmental limits, environmental enhancements and recovery to ensure a decent environment for everyone.	covers indicators relating to wildlife and biodiversity, farming, land use, fish stocks, air pollution and rivers
Creating sustainable communities and a fairer world (CSC)	Embody SD at the local level by creating sustainable communities.	covers indicators relating to poverty, health, crime, access, mobility, and local and domestic environments

Since the construction industry contributes to the creation of physical assets, which are the bases of virtually every aspect of development creating much of the world's man-made capital (Spence and Mulligan, 1995), it is clear that the various activities of the construction sector have to be regarded and analysed when considering SD. According to Bourdeau (1999), one side of the built environment supports economic development by providing infrastructure and buildings, while the other side impacts on resources such as land, materials, energy, water, human/ social capital on the living and working environment. Hence, it can be argued that direct and indirect effects from the construction industry to SD are significant. The next section of this chapter discusses the concept ‘sustainable construction (SC)’ which is the application of SD to the construction industry.

2.3 Sustainable Construction

Several authors define sustainable construction (SC) as the construction process which incorporates the basic themes of SD (Sage, 1998; Chaharbaghi & Willis, 1999; Parkin, 2000; Shelbourn et al., 2006). Confirming the above, Raynsford (2000) defined SC as a “subset of SD which aims to deliver built assets that enhances quality of life and customer satisfaction”. Chen and Chambers (1999) defined SC as “creating a healthy built environment using resource-efficient, ecologically-based principles”. A similar definition to the above was mentioned by ISO (2005), stating that SC brings about the required performance in built facilities with the least unfavourable environmental impacts, while encouraging economic, social and cultural improvement. Looking into all

these definitions, SC can be defined as the process of delivering a healthy built environment ensuring economic, social and environmental advancements.

SC helps minimise the environmental impacts of construction while enhancing social benefits that can be achieved from construction projects. The key drivers for implementation of SC are: the physical impression that local people have about the facility; government scrutiny of the construction process as a result of being a prominent, huge consumer of energy and resources; huge construction costs; and increased quality requirements from the built facilities (Brayford, 2003). Moreover, SC makes projects more cost-effective and more environmental friendly, while promoting high standards of living for people due to better performance of built facilities over their full lifecycle (Sterner, 2002). Similarly, Shen et al. (2008) also listed the benefits that SC offers: increased quality of life and enhanced customer satisfaction; offering flexibility and the potential to cater for user changes in the future; provides and supports desirable natural and social environments; and maximises the efficient use of resources.

The UK government published a number of documents highlighting the importance of SC to enhance the productivity and the effectiveness of the construction industry. For instance, Building a Better Quality of Life: A Strategy for More Sustainable Construction (DETR, 2000) emphasised the need for achieving SC and introduced a framework to the industry to ensure a strong contribution to the better quality of life. Moreover, Building for the Future: Sustainable Construction and Refurbishment on the Government Estate (NAO, 2007) also emphasised the need for achieving SC stating the Treasury, DEFRA and the Office of Government Commerce (OGC) as the lead and support departments in adopting more sustainable approaches. Similarly, the UK Strategy for Sustainable Construction (HM Government, 2008) declared the importance of achieving SC by introducing a clear process to deliver SC through set of ‘ends’ and ‘means’.

2.3.1 Importance of Sustainable Construction to the UK Economy

The construction industry is responsible for assuring a better quality of life for all people both nationally and globally since it makes an important contribution to the countries’ economy, technology and environment (DETR, 2000; HM Government, 2008). In most of the developing and industrialised economies the construction industry constitutes approximately 8-12% of GDP (UNCHS, 1993). In the European Union (EU-27),there

are about 2.3 million construction companies, contributing 9.8% to the overall GDP and employing around 12million people, which accounts for 7.1% of the total European workforce (Banias et al., 2010). Egan (1998) stated that the construction industry in the UK is one of the pillars of the domestic economy. Indeed, Cabinet Office (2011) reported that the construction industry output, which consists of public buildings; commercial buildings; homes and infrastructure, is worth over £110bn a year, where some 40% of this is in the public sector. In addition, the statistics show that combined building materials and associated professional services account for some 7% of GDP (Cabinet Office (2011) and provide employment for around 3 million people (HM Government, 2008).

Moreover, construction is well known in the UK for creating significant environmental problems, which can be clearly evidenced from the following statistics published in the literature.

- Nearly a third of all industry related pollution incidents in the UK are from construction (HM Government, 2008).
- The energy used in constructing, occupying and operating buildings represents approximately 50% of greenhouse gas emissions in the UK (Environment Agency, 2003)
- The industry uses over 420 million tonnes of material resources (Environment Agency, 2003)
- The industry converts 6,500 hectares of land from rural to urban use each year (Environment Agency, 2003)
- Approximately 13 million tonnes of building materials delivered to sites becomes waste without being used (Environment Agency, 2003)
- Annually, 120 million tonnes of construction and demolition waste is generated which is three times the waste produced by all UK households combined (WRAP, 2007).
- Construction and demolition is responsible for creating 32% of the hazardous waste in the UK (DEFRA, 2007a).
- Accounts for almost 50% of the UK carbon emissions (HM Government, 2008).
- Responsible for almost 50% of the UK annual water use (HM Government, 2008).
- A major source of noise and nuisance and may destroy wildlife habitats and hence biodiversity (Addis and Talbot, 2001)

- Over 90% of non-energy minerals extracted are used to supply the construction industry with materials (DETR, 2000).
- The amount of construction materials used annually is equivalent to 6 tonnes per head of population in the UK (Shelbourn et al., 2006)

Thus, the construction industry has a major role to play to support the UK's Sustainable Development Strategy by adopting SC Practices. In order to facilitate the SC practice within the UK construction industry, the government in 2008 introduced the Strategy for Sustainable Construction (HM Government, 2008).

2.3.2 The UK Strategy for Sustainable Construction

The UK Strategy for Sustainable Construction, which was introduced by HM Government in 2008, aimed at minimising the environmental impact from construction activities while maintaining a sustainable economy (HM Government, 2008). This strategy explicitly emphasised the need for dramatically reducing the environmental impact of building and infrastructure construction in order to meet the environmental targets. This strategy put forward a set of overarching targets related to the 'ends' and 'means' of SC, where the 'ends' represent sustainability issues and 'means' shows the processes to help achieve the 'ends' (HM Government, 2008).

Table 2.2 shows that the main focus was to minimise environmental impacts from the construction industry through this strategy, as many studies (Addis and Talbot, 2001; Ofori et al., 2000; CIRIA, 2001) revealed the need for minimising environmental impacts such as climate change, resource depletion, pollution and waste generation due to construction.

Table 2.2: The UK sustainable Construction Strategy targets (HM Government, 2008)

The 'Means'	
Procurement	To encourage adoption of the construction commitments in both public and private sectors to improve whole life value through best practice procurement and supply chain integration.
Design	To make designs of buildings, infrastructure, public spaces and places fit for purpose, resource efficient, buildable, sustainable, resilient, adaptable and attractive through greater use of design quality assessment tools.
Innovation	To increase sustainability in the construction process and built assets through innovation.

Table 2.2 cont.: The UK sustainable Construction Strategy targets (HM Government, 2008)

People	An increase in organisations committing to a planned approach to training (e.g. Skills Pledges; training plans; Investors in People or other business support tools; Continuous Professional Development (CPD); lifelong learning) and to reduce fatal and major accident rate by 10% year on year from 2000 levels
Better Regulation	To reduce administrative burdens in private and third sectors and public sectors by 25% and 30% respectively.
The 'Ends'	
Climate change Mitigation	Reducing total UK carbon dioxide (CO2) emissions by at least 26% on 1990 levels by 2020 and by at least 60% by 2050.
Climate change Adaption	To develop a robust approach to adaptation to climate change, shared across Government.
Water	To reduce per capita consumption of water in the home through cost effective measures, to an average of 130 litres per person per day by 2030, or possibly even 120 litres per person per day depending on new technological developments and innovation.
Biodiversity	Conservation and enhancement of biodiversity within and around construction sites is considered throughout all stages of a development.
Waste	By 2012, a 50% reduction of construction, demolition and excavation waste to landfill compared to 2008.
Materials	Materials used in construction have the least environmental and social impact as is feasible both socially and economically.

2.3.3 Importance of Waste Minimisation to Sustainable Construction

There are a number of past studies (Bossink and Brouwers, 1996; McDonald and Smithers, 1998; Yahya and Boussabaine, 2006; Osmani et al., 2008) and UK government publications (DEFRA, 2007a; HM Government, 2008) which raised concerns over the generation of high volumes of construction waste. Resource consumption and waste production over a building's life cycle through planning and construction, building use and management, maintenance and renovation, and finally dismantling or demolition trigger a number of environmental problems (Prasad and Hall, 2004). The UK construction industry generates substantial quantities of waste, while consuming valuable natural resources. According to the 'Waste and Resources Action Programme' (WRAP, 2007), the UK construction industry is producing 120

million tonnes of waste per year. DEFRA (2007a) revealed that this amount is more than three times the total household waste in the UK. Furthermore, the UK construction industry consumes 400 million tonnes of solid materials each year, where only two-thirds is added to the building stock and the rest is sent directly to landfill (CIOB, 2007). Lingard et al. (2001) argued that there is a positive correlation between waste prevention and environmental sustainability. The UK Strategy for Sustainable Construction also identified construction waste as an issue in SC and categorised it under 'ends', emphasising the need for construction waste reduction to achieve SC. Moreover, Augenbroe and Pearce (1998) listed waste minimisation among the top priorities in SC. Most of the resources used in the construction industry are non-renewables and thus require optimum usage to ensure the fulfilment of future user satisfaction to attain a sustainable built environment. However, the available data on construction waste quantities in the UK show that levels are unacceptable and not sustainable. Since the aforesaid findings from the literature review clearly correlate the importance of construction waste minimisation in the SC context, an attempt to identify the waste minimisation approaches would be an important step along the road to achieve sustainability targets in the construction.

2.4 Construction waste

The growing body of literature in the field of construction and demolition waste has produced several definitions for construction waste. The European Council Directive 91/156/EEC defined waste as "any substance or object which the holder discards or intends or is required to discard" (Directive 91/156/EEC [2], Article1, Letter a). Serpell and Alarcon (1998) defined waste as "any material by-product of human and industrial activity that has no residual value". Similarly, Formoso et al. (1999) defined waste as "any losses produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the client". However, Osmani et al. (2006) argued that the above definitions apply to all waste irrespective of whether or not it is destined for disposal or recovery operations.

Moreover, different authors defined the term 'construction waste' in different ways limiting the application of previous findings directly when coming to conclusions. For instance, Koskela (1992), Alarcon (1993), Serpell et al. (1995) and Ishiwata (1997) defined construction waste in relation to time delays, quality costs, lack of safety, rework, unnecessary transportation trips, long distances, improper choice of management, methods or equipment and poor constructability, which Alwi et al. (2003)

simplified and divided into three main categories: labour; machinery and material waste, while many other authors (Skoyles and Skoyles, 1987; Kulathunga et al., 2006; Yahya and Boussabaine, 2006) refer only to material waste. However, it is noteworthy to state that this research focuses only on material waste (see section 8.4), not labour and machinery waste, because material wastage is a greater concern in the SC context since construction activities generate large volumes of material waste and most of the raw materials from which construction inputs are derived come from non-renewable resources (Ekanayake and Ofori, 2000). Therefore, the forthcoming debate focuses on defining the term 'construction waste' in relation to 'material' in construction projects.

Past researchers generally define the term construction waste as the mixture of inert and non-inert materials arising from CD & E workplaces or sites of building and civil engineering structure (Cheung, 1993; Poon, 2007). Consideration of C & D waste together increases the difficulties of comparing construction waste figures from different construction sites as the proportion of construction waste and demolition waste generation varies from site to site (Ekanayake and Ofori, 2000). For an example, Peng et al. (1997) reported that the demolition waste generation is more than double the content of construction waste generation in the US. Tchobanoglous et al. (1977) has given more general definitions to construction and demolition waste where demolition waste is "waste from raised buildings and other structures" and construction waste is "wastes from the construction, remodelling, and repairing of individual residences, commercial buildings, and other structures". Additionally, Skoyles (1978) defined wastages of building materials as the "remains of the materials delivered on site after being used in the construction work". Skoyles and Skoyles, (1987) explained construction waste in a more detailed manner as "material which needs to be transported elsewhere from purpose of project due to damage, excess, or non-use or which cannot be used specifically due to non-compliance with the specifications, or which is a by-product of the construction process". The latter definition gives a better view of construction waste as it explains the reasons for material waste generation on site. Ekanayake and Ofori (2000) went further to explain the actions to be taken when construction waste is generated on site (i.e. land filling, incineration, recycling, reusing or composting) while highlighting the reasons for waste generation (i.e. material damage, excess, non-use, or non-compliance with the specifications). Therefore, this research adopted the definition of Ekanayake and Ofori (2000) for 'construction waste' which is "any material, apart from earth materials, which needs to be transported elsewhere from the construction site or used within the construction site itself for the purpose of land filling, incineration, recycling, reusing or composting, other than the

intended specific purpose of the project due to material damage, excess, non-use, or non-compliance with the specifications or being a by-product of the construction process", since this definition provide clear indications about 'materials' refer in this research study and the reasons of materials waste generation during the construction process.

2.5 Construction Waste Quantification

Over the past few decades, several studies have been conducted in different parts of the world to quantify construction waste generation. However, it is difficult to give an exact figure for waste quantity or rate on a typical site between different countries as these studies have adopted different methods to quantify waste from construction sites. For instance, some studies calculated the percentages of waste volumes or weights while some studies compare waste generation with the cost of initial materials delivery to the site. As such, Bossink and Brouwers (1996) reported that in the Netherlands, construction waste has been measured in three ways: total amount of construction waste; purchased amount of material; and total waste costs. Additionally, Yahya and Boussabaine (2006) emphasised that waste rates may not be comparable between countries mainly due to differences used in construction techniques, work procedures, and common practices. However, the published waste figures in literature clearly indicated the severity of materials waste generation in construction sites in different countries. In the Netherlands it is reported that construction waste constitutes 26% of the total amount of waste produced while in the USA it contributes 29% of the total waste stream (Ekanayake and Ofori, 2000). According to Pinto and Agopyan (1994), the construction project-level waste rate in Brazil is 20–30% of the weight of total materials on site and in Australia construction activity approximately generates 20–30% of all wastes deposited in landfills (Craven et al., 1994). Similarly, Tam et al. (2007b) revealed that 38 % of the disposed solid waste in Hong Kong was generated by construction and demolition (C&D) activities and their landfill sites would be filled in 10-15 years.

Moreover, construction waste figures published in the UK confirm that the construction industry is the largest single source of rising waste quantities that accounts for more than three times of the amount of household waste (DEFRA, 2007a), representing more than 50% of all landfill waste (Ferguson et al., 1995). Additionally, figures show that construction waste is responsible for creating 32% of the hazardous waste in the

UK (DEFRA, 2007a). But, it is important to note that the UK construction waste figures include both C & D waste quantities.

Even though, C & D combined waste increases environmental and social issues due to the increasing volumes of waste, the growing body of literature has given higher consideration to investigating construction waste as many of the raw materials used in the construction industry are extracted from non-renewable resources (Ekanayake and Ofori, 2000). The next section illustrates the guidelines to be followed in determining the best option to reduce construction waste generation issues.

2.6 Waste Management Hierarchy

The waste management hierarchy is a guide to determine the most favourable practical preferences to address the waste issues in construction sites. It represents the best practicable environmental options within the chain of priorities for waste management starting from the ideal situation of waste prevention and extending up to waste disposal, which is the least favourable option (Figure 2.2) (DEFRA, 2007a).

This hierarchy gives clear indications that waste management must primarily aim to prevent waste generation from the start of the project since it helps to reduce the costs associated with handling, managing and eliminating many of the waste disposal problems (Peng et al., 1997). This was further confirmed by several authors stating that source reduction is the best way of minimising construction waste usually within a process (Cohen and Allen, 1992; Begum et al., 2007). However, when waste prevention is not possible the hierarchy suggests reusing either for the same purpose or for a different purpose since it needs the minimum of processing and energy. Failing the above, recycling/composting and energy recovery is the next option in the waste management hierarchy. However, this was given a considerably lower ranking because both these options require additional energy and resources to reduce waste levels. Waste disposal is the last option in the waste management hierarchy when all the other options are not possible to implement as it increases the number of environmental problems.

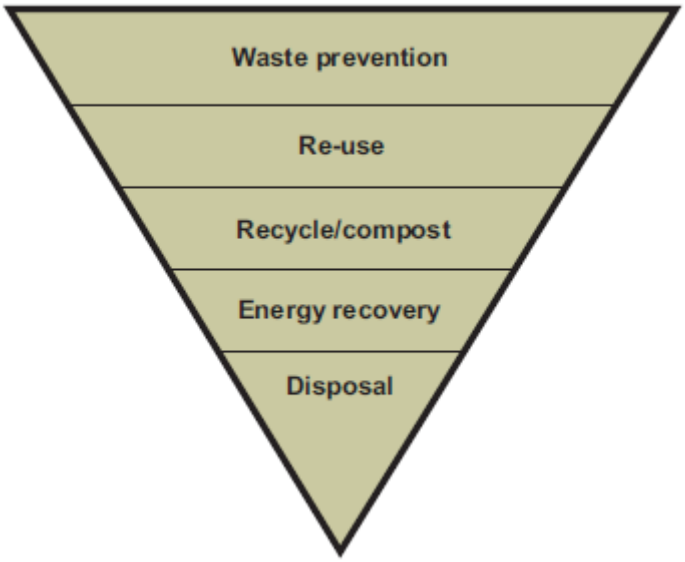


Figure 2.2: Waste Management Hierarchy (Source: DEFRA, 2007a)

Apart from the waste management hierarchy, there is a consensus in the literature that waste reduction is the most effective and efficient method to minimise construction waste providing solutions to a number of construction waste related problems (Peng et al., 1997; Baldwin et al., 1998; Formoso et al., 2002; Esin and Cosgun, 2007). Therefore, the next section of this chapter will further discuss the waste prevention/minimisation option in the waste management hierarchy.

2.7 Waste Minimisation

Waste minimisation is an in-plant process which reduces, eliminates or avoids the generation of waste (Cohen and Allan, 1992). Even though literature simply defined waste minimisation as the reduction of waste at source, different authors have given different definitions to waste minimisation. For instance, the Environment Agency (2001) defined waste minimisation as “the reduction of waste at source, by understanding and changing processes to reduce and prevent waste’’ indicating the ways in which waste can be minimised. A much different definition to the above was given by EPD (2003) stating waste minimisation as “a process or activity that either eliminates or reduces waste generation at the source or allows reuse or recycling of waste for benign purposes”. This definition incorporates ‘reuse and recycling’ also as part of waste minimisation where the former definition considers only ‘waste reduction at source’. However, the former definition is considered more appropriate for current

research since it focuses construction waste minimisation through the identification of waste sources and suggesting process changes to reduce and prevent waste.

Subsequent sections of this chapter will further discuss waste minimisation to recognise its importance as a solution for a number of construction waste related issues

2.7.1 Construction Waste Minimisation Drivers

A number of researchers have highlighted the importance of waste minimisation to reduce adverse effects (i.e. pollution, consumption of natural resources and land fill volumes) due to construction waste generation both nationally and globally (Graham and Smithers, 1996; Faniran and Caban, 1998; Thormark, 2000; Coventry et al., 2001). Apart from the above, Skoyles and Skoyles (1987) highlighted a number of project level problems related to construction waste generation such as poor performance, financial losses to contractors, additional costs to clients and less productivity. Moreover, recent researchers have shown that environmental, economical, industrial, and government policy and regulations significantly drive the construction industry towards waste minimisation (Osmani et al., 2006; Jaillon et al., 2009), which are discussed in the subsequent sections of this chapter.

2.7.1.1 Environmental Drivers

Construction waste creates a number of environment problems. In literature, several authors have specified that limited landfill sites to accommodate higher volumes of construction waste are becoming a serious problem as they are rapidly running out, especially in developing cities (Chan and Fong, 2002; Kartam et al., 2004 ;Esin and Cosgun, 2007; Wang et al., 2010). For example, in the USA construction and demolition waste represents about one third of the landfill volumes (Chun et al., 1994) while in Canada the waste volume is over 35% (Esin and Cosgun, 2007). In the UK, construction waste consumes more than 50% of landfill volumes and projected statistics reveal that landfills will reach their capacity by 2017 (Harman and Benjamin, 2003). Moreover, Wong and Tanner (1997) revealed that in Hong Kong landfill sites predicted to last for approximately 40-50 year would close in 2010. Even so, these figures show the significance of landfill volume consumption by construction waste in developing cities, it could be argued that the landfill consumption rates are not as high as previous predictions since Hong Kong landfill sites still exist.

Another major issue highlighted in the literature due to increased volumes of construction waste is pollution, which has an impact on air pollution, water pollution, and its associated energy usage (Yahya and Boussabaine, 2006). Esin and Cosgun (2007) stated that construction waste that is deposited in forests, streams, ravines and empty spaces causes erosion, contaminates wells, water tables and surface waters, attracts pests, creates fire hazards, and detracts from the beauty of natural areas. Additionally, the increasing volumes of waste create unnecessary demand for transportation trips to landfill sites increasing energy use and air pollution. Apart from the above, landfill sites may contain biodegradable organic matters which release harmful greenhouse gases such as methane and carbon dioxide, ground water pollution, transportation issues and pollution due to dust, noise and odour resulting in air and water pollution. For instance, in 2001, UK landfill sites released 25% of the UK's methane emissions (DEFRA, 2006a). Hence, construction waste minimisation is given high propriety in the UK with the aim of minimising pollution. However, some authors specified that construction waste minimisation through reuse and recycling of construction waste is very hard since construction site waste consist of materials that contain high levels of contaminations and a large degree of heterogeneity (Brooks et al., 1994; Bossink and Brouwers, 1996). Furthermore, construction waste is much more difficult to dispose off as it contains hazardous materials such as asbestos, heavy metals, persistent organic compounds and volatile organic compounds not found in household waste (Esin and Cosgun, 2007). Statistics show that construction and demolition waste is the largest component of hazardous waste in England and Wales, constituting nearly 1.7 million tonnes (DEFRA, 2007a). However, since 2005 the UK has introduced a new legal requirement for hazardous waste disposal restricting its disposal to landfill sites where certain amendments have been made in 2009 to increase potential environmental benefits.

Increasing volumes of construction waste is of more concern because the construction industry uses a large number of raw material resources such as timber, sand, gravel and marl, which are derived from non-renewable resources and in danger of depletion (Bossink and Brouwers, 1996; Ekanayake and Ofofri, 2000). Moreover, Holm (1998) pointed out that approximately 40 percent of the materials produced are utilized in building and construction work with 25 percent of virgin wood, and 40 percent of raw stone, gravel, and sand used globally each year. In the UK, the construction sector uses over 420 million tonnes of material resources of which approximately 13 million tonnes of materials delivered to sites will not be used (Environment Agency, 2003). Moreover, Guthrie et al. (1998) revealed that 10% of all materials delivered to

construction sites in the UK are wasted due to damage, loss and over-ordering. Consequently, the inefficient consumption of natural resources generating large quantities of construction waste increase concerns of the loss of natural resources required for future usage.

The above illustrated environmental problems relate to: reducing availability of landfill sites necessary to accommodate construction waste; depletion of non-renewable natural resources; and environmental pollution associated with the waste generation, thereby driving the construction industry towards waste minimisation.

2.7.1.2 Economic Drivers

Previous research findings have shown a positive correlation between waste prevention and economic benefits in construction projects. Bossink and Brouwers (1996) indicated that nine percent of the total materials purchased end up as waste (by weight) and one to ten per cent of every single material contributes to the solid waste stream of the site. The true cost of construction waste is not only materials purchasing costs; but the cost of storage; transport and disposal cost; the cost of the time spent managing and handling the waste; and the loss of income from not salvaging waste materials (Osmani et al., 2006; CIRIA, 2006).Therefore, the true cost of waste is estimated to be around 20 times the disposal of waste (Innes, 2004). Several researchers emphasised that cost reductions caused by preventing the generation of construction waste is of direct benefit to most of the project stakeholders (Bossink and Brouwers, 1996; Yahya and Boussabaine, 2006).

In literature, it is widely discussed that, contractors may often experience loss due to extra overhead costs, delays, extra work on cleaning, and lower productivity due to construction waste handling costs and extra materials requirements (Skoyles and Skoyles, 1987; Ekanayake and Ofori, 2000). However, Skoyles and Skoyles (1987) argued that construction waste is a burden to clients as they have to bear the costs of waste eventually. Moreover, Teo and Loosemore (2001) estimated that companies producing high levels of waste are at a ten percent disadvantage in the tendering process making their survival more difficult in a competitive environment.

Similarly, waste disposal costs such as: landfill tax; transportation; waste handling labour costs are also additional costs to the contractors. The construction industry in the UK spends over £200 million on landfill tax each year (Innes, 2004). The government is gradually increasing the landfill tax from £24 per tonne in 2007 to £72

per tonne in 2013 to act as an incentive to reducing waste at source (HM Treasury, 2007).

Baldwin et al. (1998) highlighted certain benefits in construction projects through construction waste minimisation such as: saving money; increasing project profits; and ease of obtaining permissions for projects. Moreover, WRAP (2009a) reported that an efficient and effective approach to waste minimisation can typically save up to £110,000 on projects with a floor area of 7000m^2. Similarly, Envirowise (1999) highlighted that a comprehensive waste management programme would provide potential savings of 1% from construction projects, whereas WRAP (2010b) reported the typical savings (net of costs) would be around 0.2% to 0.7% of construction value (varying by project type). Moreover, businesses have opportunities of attracting government funding to implement waste minimisation practices (Osmani et al., 2006). Therefore, economic benefits drive construction project partners towards waste minimisation (Johnston and Mincks, 1995; Graham and Smithers, 1996; Baldwin et al., 1998).

2.7.1.3 Legislative Drivers

Literature suggests that there is a growing interest among many governments (i.e. Hong Kong, Australia, China, EU countries, New Zealand) to introduce and implement waste minimisation policies and regulations to drive the construction industry towards waste minimisation (McGrath and Anderson, 2000; Teo and Loosemore, 2001). The UK government also introduced a number of policies and regulations to manage and minimise waste (Osmani et al., 2006). However, legislative measures have different levels of influence on waste minimisation where some have compulsory implementation and some are voluntary. The following section describes legislative drivers in the UK to minimise construction waste which are divided in to three categories: legislations; policies and good waste practices based on their level of importance.

Legislations: Waste minimisation legislations are playing a vital role in minimising construction waste. The UK government established a number of regulations regarding the construction industry waste minimisation and management such as ‘Environmental Protection Act 1990’ and ‘Waste Minimisation Act 1998’. Additionally, the ‘UK Waste Strategy 2000’ mainly focused on recycling or recovering waste rather than waste minimisation, whereas ‘Waste Strategy for England 2007’ aimed to reduce waste by “making products with fewer natural resources”. Moreover, legislations, such as Landfill

Tax, the Aggregates Levy and the Hazardous Waste Regulations 2005 (amended in 2009) forced construction companies to implement construction waste reduction techniques to reduce waste disposal costs (Osmani et al., 2006).

The Landfill Tax was introduced in 1996 with the aim of reducing construction waste sent to landfill sites by encouraging the waste recycling rate. The Tax acts as an incentive for construction companies to reduce waste sent to landfill sites by means of financial incentives. Waste Strategy 2007 indicates the Landfill Tax escalator, which is to increase the standard rate of non-inert material disposal from £8/tonne in 2008 to £56/tonne in 2011, so that it will give greater financial incentives to businesses to reduce, re-use and recycle waste (DEFRA, 2007a). In addition, the Aggregates Levy was introduced in 2002 with the aim of reducing the impacts of extraction of aggregates (DEFRA, 2006b). Moreover, it promotes the use of alternatives to virgin aggregate and funds projects to reduce the local environmental impact of aggregate extraction and transport (DEFRA, 2004).

Site Waste Management Plans (SWMPs) were initially published by the Department of Trade and Industry (DTI, 2004) as a voluntary code of practice to assist construction contractors to better manage on-site waste. However, it became legislation and came into force in England in April 2008 (WRAP, 2008). Implementing SWMPs has become a mandatory requirement for all aspects of construction work worth more than £300,000 including a forecast of wastage as well as a record of types of waste and their destinations (WRAP, 2009b). In addition, projects over £500,000 must estimate the cost savings from waste management (DEFRA, 2008). SWMPs target two key interventions: the level of resource efficiency within the construction industry and the responsible management of any waste that is produced (DEFRA, 2007b).

Policies: The UK government recently introduced a number of policies to guide the construction industry towards waste minimisation and management. For instance, the government introduced Waste Strategy 2007, which tries to decouple waste growth (in all sectors) from economic growth and put more emphasis on waste prevention and re-use with the aim of reducing waste (DEFRA, 2007a). Similarly, the Strategy for Sustainable Construction (2008) sets targets to reduce construction, demolition and excavation waste to landfill sites by 50% of the levels of 2008 by 2012, and to achieve zero net waste by 2015 at construction site level and zero waste to landfill by 2020. Recently, the UK Coalition Government published the review of government waste policies aiming to move the “current throwaway society to a zero waste economy

through material resources reused, recycled or recovered wherever possible and only disposed of as the option of very last resort" (DEFRA, 2011).

Waste minimisation good practices: Waste minimisation 'good practices' are voluntary activities which the construction team implement to obtain financial or environmental benefits from their projects. HM Government (2008) underlined the importance of implementing waste minimisation good practices at site level and throughout the supply chain to achieve the target of reducing reduce construction, demolition and excavation waste to landfill by 50% in 2012 compared to 2008 levels. In the UK a number of institutions (i.e. WRAP, CIRIA, Environment Agency, Constructing Excellence,) have been established to support construction industry for waste minimisation and management. These institutions guide the construction industry towards waste minimisation with the support of their publications, workshops; best practice examples and guidance.

2.7.1.4 Industry Drivers

With the growing concern in the construction industry towards waste minimisation due to increasing environmental issues, lacking of economic benefits and introduction of various government initiatives to reduce construction waste generation it is it important to identify the actual drivers inside the system to initiate construction waste minimisation practices.

With the increase in awareness of construction waste minimisation and its benefits there is a growing demand from clients to improve environmental performances in construction projects (Osmani et al., 2006). The National Health Service (NHS), which is one of the largest public clients in the UK government, has initiated a response to the government targets on construction waste minimisation by documenting guidelines to be followed by NHS Trusts during construction (WRAP, 2010b). According to these guidelines, NHS Trusts as clients should take actions in two ways: (1) set clear and actionable requirements for reducing, reusing and recovering CD & E waste in their policies, strategies and procurement documentation; and (2) ensure that contractors measure and report on performance (WRAP, 2010b).

Literature shows that most of the main construction companies are also now showing a growing interest in construction waste minimisation. For instance, Ball (2002) revealed that most of the construction companies in Japan, UK, Sweden, Spain, Australia and

the USA are now pursuing the ISO 14000 standard and thus committed to concern over environmental issues as this accreditation is given to companies for their environmental concern and assurance procedures. Moreover, in 2010, over 500 large construction companies have committed to endeavouring to halve the amount of construction, demolition and excavation waste going to landfill by 2012 by adopting and implementing standards for good practice in reducing waste, recycling more, and increasing the use of recycled and recovered materials (WRAP, 2010c). Additionally, the major contractors started to monitor their supply chain partners to ensure waste minimisation practices in their projects. Further, various initiatives, such as 'Constructing Excellence', the 'Waste Resources Action Programme' (WRAP) and the 'Construction Industry Research and Information Association' (CIRIA) has started influencing the construction industry to broaden their attitudes over value for money concept to consider corporate social responsibilities rather merely thinking of economic value (Osmani et al., 2006).

2.7.2 Causes and Origins of Construction Waste

Construction waste source reduction can be defined as "any activity that reduces or eliminates the generation of waste at the source, usually within a process" (Begum et al., 2007). This is known in literature as the best way of minimising construction waste since it use the minimum amount of resources than in other methods (Cohen and Allen 1992; Begum et al., 2007). It is notable that in literature the phrase 'sources of waste' is used concurrently with the phrase 'origins of waste'. Literature reveals a large number of past studies conducted to identify origins of waste. However, these studies used different approaches to classify waste origins from construction projects.

For instance, some authors (i.e. Gavilan and Bernold, 1994; Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000) classified waste origins based on project level activities. Gavilan and Bernold (1994) classified waste origins based on different project activities and organised the causes of construction waste under six categories: design; procurement; handling of materials; operation; residual related; and others. A similar approach has been adopted by Bossink and Brouwers (1996) and further extended the list of causes of waste related to aforesaid waste origins at site level. Ekanayake and Ofori (2000) also categorised waste origins into four clusters: design, operational, material handling and procurement.

Soibeiman et al. (1994) and Pinto and Agopayan (1994) used a different approach to the above and related construction waste to material types such as steel, cement, concrete, sand, mortar, ceramic block, brick, timber, hydrated lime, ceramic wall tiles and ceramic floor tiles. Moreover, Rounce (1998) pointed out that major construction waste origins are related to the design stage, such as design changes; the variability in the numbers of drawings and the variability in the level of design details, whilst Keys et al.(2000) classified the origins of design and construction waste under the headings of manufacture, supplier, procurement, designer, logistics, client, contractor and site management. The latter classification indicates that waste origins are associated not only with project activities but also with project stakeholders.

Apart from the above, some researchers linked causes and origins of waste to the project lifecycle stages. A study by Graham and Smithers (1996) found that factors causing construction waste span the project life cycle, including design, procurement, materials delivering/handling, construction/renovation, and demolition. This was further confirmed by Osmani et al. (2008) stating that construction waste is effectively generated throughout the project from inception to completion while categorising design related waste causes into project lifecycle stages.

Since lifecycle categorisation of construction waste causes covered most of the issues related to construction waste generation, a lifecycle approach was considered to be the best method for compiling construction related waste causes in this research. However, different studies used the term ‘construction project lifecycle’ to refer different lifecycle stages. For instance, a well-known classification by the Royal Institute of British Architects (2007) divided the whole construction project lifecycle into eleven stages from appraisal to completion. This was later followed by a number of other studies (Osmani et al., 2008; WRAP, 2009) as the project lifecycle stages in a construction project. But, there are some studies (Graham and Smithers, 1996; Lu and Yuan, 2011) where the term ‘project lifecycle’ adopts the concept of cradle to grave, referring to the whole model from concept to demolition of a construction project. Since this research only considers construction waste minimisation (not demolition waste as stated in section 2.4) it was considered appropriate to adopt the RIBA Plan of Work stages (from appraisal to completion) as the ‘project lifecycle’. Additionally, for the purpose of this research study, the RIBA Plan of Work stages were broadly divided in four stages: pre-design; design; tendering and contract agreement; and construction, and compiled causes of waste mentioned in the literature.

2.7.2.1 Pre-Design Phase

Even though previous research studies revealed that waste can arise at any stage of a construction process from inception, through the design, construction and operation of the built facility (Spivey, 1974; Gavilan and Bernold, 1994; Craven et al., 1994; Faniran and Caban, 1998), very few research studies attempted to identify causes of waste in the pre design phase of a project. Very little evidence can be traced in the literature on causes of waste in the pre-design phase such as: lack of planning of project requirements; lack of identification of client's needs; improper detailing of documents; and incomplete briefs (See Table 2.3).

Table 2.3: Causes of waste in Pre-design phase (Compiled from literature)

Causes of waste	Source of reference
Lack of planning of project requirements	Tam et al. (2007b)
Lack of identification of client's needs	Kulathunga et al. (2006)
Improper detailing of documents	Kulathunga et al. (2006)
Incomplete design briefs	Osmani et al. (2006)

2.7.2.2 Design Phase

The design phase is a major waste origin in construction projects (Osmani et al., 2006; Poon 2007; Osmani et al., 2008). As shown in the Table 2.4, most of causes of waste in the design phase specified in the literature are related to drawings and materials selections and specification.

Table 2.4: Causes of waste in design phase (compiled from literature)

Causes of waste	Sources of reference
Drawings related	
Last minute design changes due to client's requirements during construction period	Gavailan and Bernold (1994); Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Poon et al. (2004a); Kulathunga et al. (2006); Osmani et al. (2006; 2008); Tam et al. (2007b)
Errors in drawing details/ lack of information in the drawings/Design complexities	Gavailan and Bernold (1994); Ekanayake and Ofori (2000); Poon et al. (2004a); Kulathunga et al.(2006); Osmani et al. (2006; 2008); Tam et al. (2007a)
Delays in drawings /Slow drawing revision and distribution	Osmani et al. (2006; 2008)

Table 2.4 cont.: Causes of waste in design phase (compiled from literature)

Causes of waste	Sources of reference
Materials selection and specification related	
Selection of non-standardised materials into the design /Not working to standard dimensions	Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Keys et al. (2000); Kulathunga et al. (2006); Osmani et al. (2006)
Designers lack of knowledge on alternative products	Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Kulathunga et al. (2006); Osmani et al. (2006)
Selection of low quality materials and products/ Unclear/unsuitable specifications	Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Keys et al. (2000); Kulathunga et al. (2006); Osmani et al. (2006; 2008)
Other	
Lack of attention paid to dimensional coordination of products/ Lack of communication and coordination	Ekanayake and Ofori (2000); Keys et al. (2000); Chen and Wong. (2002); Poon et al. (2004a); Kulathunga et al. (2006); Osmani et al., (2008)
Inadequate experience of the designer with construction sequences	Bossink and Brouwers, (1996); Ekanayake and Ofori, (2000)
Long project duration	Poon et al. (2004a)

A study by Ekanayake and Ofori (2000) revealed that a substantial amount of building construction waste on-site is directly related to design errors or related problems on which the site personnel have very little or no influence. Moreover, it is important to note that about one-third of construction waste on site arises due to design decisions (Innes 2004). A large number of authors revealed design changes during the construction, due to inadequate briefing at initial stage, as a major cause of waste in construction (Gavailan and Bernold, 1994; Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000; Poon et al., 2004a; Kulathunga et al., 2006; Tam et al., 2007b; Osmani et al., 2008). Moreover, errors in drawings, complex/lack of design information, and drawing delays were highlighted in the literature as other design related causes of waste (Gavailan and Bernold, 1994; Ekanayake and Ofori, 2000; Poon et al., 2004a; Kulathunga et al., 2006; Osmani et al., 2006; Tam et al., 2007; Osmani et al., 2008).

The design of a building embodies a diverse range of materials and products (Keys et al., 2000), which increase the complexity of waste reduction due to the generation of various waste types. The selection of non-standardised materials, low quality/

unsuitable materials, and the inadequate knowledge on alternative materials specified in the literature as causes of waste in construction during materials selection and specification (Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000; Keys et al., 2000; Kulathunga et al., 2006; Osmani et al., 2006).

Additionally, some authors specified that inefficiencies in communication and coordination (Ekanayake and Ofori, 2000; Keys et al., 2000; Chen and Wong, 2002; Poon et al., 2004a; Kulathunga et al., 2006; Osmani et al., 2008), lack of experience of the designer with construction sequences (Ekanayake and Ofori, 2000; Osmani et al., 2006) and long project durations (Poon et al., 2004a) as other design related causes of waste.

2.7.2.3 Contract Agreement/ Procurement Phase

Construction uses different procurement systems with different organisational structures and arrangements that can affect not only the design and construction stages of a project, but also cultural, managerial, environmental and political issues (Masterman, 2002). Ekanayake and Ofori (2000) stated that proper selection of a procurement system helps to ensure superior decision-making during the design and construction stages avoiding unnecessary extra work and reduction in materials wastage. Additionally, Baldwin et al. (1998) highlighted the issue that contracts could produce waste due to their contractual set-up, where waste is accepted as loss of profit. Several authors identified causes of waste connected with the project procurement system such as: incomplete/ inaccurate contract documents, method of tendering varying the percentage allowance of waste, and the type of contract varying the responsibility towards waste minimisation (Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000; Osmani et al., 2006; 2008).

Table 2.5: Causes of waste in contract agreement phase (Compiled from literature)

Causes of waste	Sources of reference
Errors in contract /tender documents	Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Osmani et al. (2008)
Incomplete contract documents at the commencement of construction	Ekanayake and Ofori (2000); Kulathunga et al.(2006); Osmani et al. (2008)
Type of contract varying responsibility towards waste minimisation	Skoyles and Skoyles (1987)
Method of tendering (allocation of waste allowance during tendering)	Skoyles and Skoyles (1987)

2.7.2.4 Construction Phase

Existing literature outlines a number of causes of waste related to the construction phase. Causes of waste specified in the literature are further classified into categories of: on site waste planning and management; material procurement; materials handling and storage; transportation; site operations; and residual as shown in the Table 2.6. According to the above categorisations, it is clear that most of the causes of waste in the construction phase occur due to human errors such as negligence, poor workmanship and inefficient communication which are in line with the findings of Kulathunga et al. (2006), which further highlights the significance of the human factor in construction projects, since the construction industry is highly labour intensive. According to the literature review findings, past researchers revealed that lack of planning and organisation of site activities also leads to increased waste generation in construction sites (Gavailan and Bernold, 1994; Bossink and Brouwers, 1996; Enshassi, 1996; Ekanayake and Ofori, 2000; Kulathunga et al., 2006; Osmani et al., 2006; Osmani et al., 2008). Moreover, literature emphasised a significant number of causes of waste in the construction stage related to materials procurement, handling, storage, and transport (Gavailan and Bernold,1994; Bossink and Brouwers,1996; Ekanayake and Ofori,2000; Kulathunga et al.,2006; Osmani et al.,2008).

Table 2.6: Causes of waste in construction phase (Compiled from literature)

Causes of waste	Source of reference
Material procurement	
Materials ordering errors (over/wrong ordering of materials)	Gavailan and Bernold (1994); Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Kulathunga et al. (2006); Osmani et al. (2008)
Supplier errors	Gavailan and Bernold (1994); Osmani et al. (2008)
Shipping errors	Gavailan and Bernold (1994)
Material storage	
Inappropriate material storage facilities onsite leading to damage or deterioration	Gavailan and Bernold (1994); Enshassi (1996); Ekanayake and Ofori (2000); Kulathunga et al.(2006); Osmani et al. (2006;2008)
Improper storing methods	Osmani et al. (2008)
Materials stored far away from point of application	Bossink and Brouwers (1996); Osmani et al. (2008)

Table 2.6 cont.: Causes of waste in construction phase (Compiled from literature)

Causes of waste	Source of reference
Material handling	
Material supplied in loose form	Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Kulathunga et al. (2006); Osmani et al. (2008)
Onsite transportation methods from storage to the point of application	Ekanayake and Ofori (2000): Osmani et al. (2008)
Inadequate material handling	Gavailan and Bernold (1994); Osmani et al. (2008)
On site management and planning	
Lack of onsite management plans	Bossink and Brouwers (1996); Osmani et al. (2008)
Improper planning for required quantities	Bossink and Brouwers (1996); Ekanayake and Ofori (2000);Kulathunga et al. (2006); Osmani et al. (2008)
Delays in passing information on types and sizes of materials and components to be used	Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Osmani et al. (2006; 2008)
Lack of on-site material control	Kulathunga et al. (2006); Osmani et al. (2008)
Lack of supervision	Osmani et al. (2008)
Site operation	
Accidents due to negligence	Gavailan and Bernold (1994); Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Kulathunga et al. (2006); Osmani et al. (2008)
Unused materials and products	Osmani et al. (2006; 2008)
Equipment malfunction	Gavailan and Bernold (1994); Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Kulathunga et al. (2006); Osmani et al. (2008)
Poor workmanship causing rework	Gavailan and Bernold (1994); Bossink and Brouwers (1996); Kulathunga et al. (2006); Osmani et al. (2008)
Use of wrong materials resulting in their disposal	Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Kulathunga et al.(2006); Osmani et al. (2008)
Time pressure	Osmani et al. (2008)
Poor work ethics between project team and labourers	Ekanayake and Ofori (2000); Kulathunga et al.(2006); Osmani et al. (2008)
Poor communication between project partners	Ekanayake and Ofori (2000); Kulathunga et al. (2006)
Damage caused by subsequent trades	Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Kulathunga et al. (2006)

Table 2.6 cont.: Causes of waste in construction phase (Compiled from literature)

Transportation	
Damage during transportation	Bossink and Brouwers (1996); Ekanayake and Ofori (2000); Kulathunga et al. (2006); Osmani et al. (2008)
Difficulties for delivery vehicles accessing construction sites	Osmani et al. (2008)
Insufficient protection during unloading	Bossink and Brouwers (1996); Osmani et al. (2008)
Inefficient methods of unloading	Bossink and Brouwers (1996); Osmani et al. (2008)
Residual	
Waste from application process (i.e. over preparation of mortar)	Gavailan and Bernold (1994); Bossink and Brouwers (1996); Kulathunga et al. (2006); Osmani et al. (2006; 2008)
Off -cuts from cutting materials to length	Gavailan and Bernold (1994); Bossink and Brouwers (1996); Osmani et al. (2008)
Waste from cutting uneconomical shapes	Bossink and Brouwers (1996); Osmani et al. (2006; 2008)
Packaging	Bossink and Brouwers (1996); Osmani et al. (2008)

The above discussion clearly indicates that causes of waste could arise at any stage of a construction process from inception to completion. However, the existing research findings are not enough to determine the impact of each waste cause on generating construction waste. Moreover, it can be argued that the impact of each waste cause in terms of generating waste could differ from project to project depending on the nature of project, size of project and stakeholder relationships. Therefore, it is important to identify the particular causes of waste applicable for each project and their impacts on waste generation to identify the most appropriate waste minimisation approach.

2.7.3 Waste Minimisation Approaches

The current and on-going research studies on construction waste minimisation and management are diversified into different areas. A recent research conducted by Osmani et al. (2008) broadly categorised the waste minimisation approaches proposed in the previous research findings in to eleven clusters (see Table 2.7).

Table 2.7 Waste minimisation and management approaches (Source: Osmani et al., 2008)

Waste minimisation approaches	Sources of reference
Construction waste quantification and source evaluation	Gavailan and Bernold (1994); Bossink and Brouwers (1996); Faniran and Caban (1998); Ekanayake and Ofori, (2000); Poon et al. (2004a); Kulatunga et al. (2006); Guzman et al. (2009)
On-site construction waste sorting methods and techniques	Poon et al. (2001); Wang et al. (2010)
Development of waste data collection models, including flows of wastes, waste management mapping, to help the handling of on-site waste and eco-costing of construction waste	Treloar et al. (2003); Shen et al. (2004); Yahya and Boussabaine (2006); Hao et al. (2010)
Development of on-site waste auditing and assessment tools	McGrath (2001); Chen and Wong (2002)
Impact of legislation on waste management practices	Eikelboom et al. (2001); Tam et al. (2007b); Hao et al. (2008a)
Improvements of on-site waste management practices	McDonald and Smithers (1998); Hao et al. (2008a); Tam (2008)
Reuse and recycling in construction	Lawson et al. (2001) ; Emmanuel (2004)
Benefits and factors of waste minimisation	Rounce (1998); Coventry et al. (2001); Begum et al. (2007)
Waste minimisation manuals, including guides for designers	Coventry and Guthrie (1998); Greenwood (2003)
Attitudes towards waste	Lingard et al. (2000); Teo and Loosemore, (2001); Sander and Wynn (2004); Kulatunga et al. (2006); Begum et al. (2009)
Comparative waste management studies	Conventry and Guthrie (1998); Chen and Wong (2002)

According to the waste minimisation and management clusters shown in the Table 2.7, it can be noticed that most of the waste minimisation approaches identified by the past and on-going research findings mainly focused on on-site waste management. Even so, previous research findings identified large numbers of waste causes and origins in the pre design phase, design phase and contract agreement phase only very little research focused on these stages when proposing waste minimisation approaches.

Even so, no clear approach has been specified by past researches to address causes of waste during the pre-design phase, little evidence can be noticed in existing literature that emphasises the requirement of client commitment towards waste minimisation. For example, Dainty and Brooke (2004) revealed that the clients must

demand better waste performance from principal contractors, whereas Poon et al. (2004b) highlighted that clients are responsible for planning at pre-tender and pre-contract stages to limit post-contract variations. Similar views to the above have been stated by Ekanayake and Ofori (2000; 2004) and Tam et al. (2007a) revealing the importance of cultivating waste minimisation culture among clients to demand waste minimisation requirements from other stakeholders.

Recent literature has increased interest in identifying waste minimisation opportunities in the design phase. For instance, some researchers recommended waste minimisation manuals and guidance documents for designers (Coventry and Guthrie, 1998; Greenwood, 2003); importance of materials appropriate to the specification to suit the building expected lifetime (McDonald and Smithers, 1996; Coventry et al., 2001); and increase in the use of pre-fabricated elements in designs (McDonald and Smithers, 1996; Dainty and Brooke, 2004; Tam et al., 2007a; Baldwin et al., 2009; Jaillon et al., 2009). Moreover, a study done by Keys et al. (2000) provided a list of short and long term methods for designing out problems of waste including: use of prefabrication and off-site products; standard components; realistic component sizes, capacity and specification; minimising temporary works; optimising design lives; allowing specification of recycled materials in design; designing for recycling and ease of disassembly; identification of building products that create waste; and efficient communication. In addition to these researchers, in the UK, certain bodies (i.e. WRAP, OGC) have introduced design waste minimisation guidance and checklists. For instance, WRAP (2010d) recently introduced a detailed guide for design teams to design out waste from building projects. This guide consists of five key principles: design for reuse and recovery, design for offsite construction, design for material optimisation, design for waste efficient procurement, and design for deconstruction and flexibility. Moreover, OGC (2007) introduced a sustainable design checklist to reduce waste from construction projects.

In addition to the design waste minimisation approaches, very few approaches are evidently related to the contract agreement phase. A study by Greenwood (2003) suggested clients consider contractor's waste minimisation experience in the tender invitation documents and to give priority in the process of awarding the contract. Moreover, Greenwood (2003) pointed out that the need to customise standard tendering conditions and contracts to suit a particular project to avoid conflicts and ambiguities with project stakeholders during the construction process. Furthermore, Dainty and Brooke (2004) suggested inserting contractual clauses specifying waste

minimisation incentives/penalties for poor waste performances in the contract documents. The findings of a study conducted by Tam et al. (2007a) also suggested the importance of having prior contractual agreements with the main contractor in terms of waste minimisation. Moreover, McDonald and Smithers (1996) highlighted the need for a clear mechanism to identify designers' waste minimisation efforts to be reflected in the final tender price in traditional tendering process.

Waste minimisation approaches suggested by past and on-going researchers focuses only on a single stage in a construction project. However, past research indicates that waste can arise at any stage of the construction process from start to completion (Spivey, 1974; Gavilan and Bernold, 1994; Craven et al., 1994; Faniran and Caban, 1998; Ekanayake and Ofori, 2000). Moreover, Poon (2007) emphasised that construction waste reduction should be considered at an early stage and by all parties involved in the building process. Similarly, Dainty and Brooke, (2004) highlighted the need for establishing an integrated waste minimisation strategy by clearly allocating waste minimisation responsibilities to project stakeholders. Additionally, the same study emphasised the importance of transferring waste minimisation responsibility from the client to the principle contractor(s) and thereafter to the subcontractors and suppliers who are responsible for different trades in a project to effectively reduce waste generation from construction. A similar view to the above was declared by Shen et al. (2004) stating that the clients should motivate other stakeholders to reduce construction waste generation. In addition to the perspective of project stakeholders involved from the beginning of the project until completion in reducing construction waste generation, some research studies recognised the need for planning and implementing waste minimisation practices throughout the project lifecycle stages. For instance, Begum et al. (2007) specified the need for planning and organising waste minimisation practices during the design and tender stages even though they are actually going to be implemented during the construction stage. Moreover, a recent publication by WRAP (2010g) shows the activities to be undertaken by the project team from the start of the project until completion to obtain waste minimisation benefits from construction projects. The above discussion clearly indicates the emerging need in the construction industry to consider a more integrated lifecycle approach to effectively minimise construction waste generation.

Since every construction project has unique characteristics there could be certain limitations in applying any waste minimisation approach directly from one project to another. For example, design standardisation would not be possible for projects that

have to follow a strict set of building regulations (i.e. HBNs and HTMs in healthcare projects). Therefore, to effectively implement the aforesaid waste minimisation practices, it is worth investigating specific waste generation issues and waste minimisation best practices to address waste issues in particular projects.

The subsequent sections in this chapter attempt to identify: current and future trends in healthcare construction projects; sustainable healthcare construction; healthcare construction and waste origins in the process; and waste minimisation best practices.

2.8 Healthcare Construction and Waste Generation

2.8.1 Current and Future Trends in Healthcare Construction in the UK

Healthcare is one of the most significant sectors in many of the countries in the world representing a significant proportion in those countries' economies. Each year, across Europe billions of Euros are invested in new and refurbished healthcare buildings. According to statistics, capital investment on healthcare buildings accounts for 2-6% of total health care expenditure in the countries of the World Health Organisation (WHO) in the European region (WHO, 2007). The scale of the healthcare industry varies from large hospitals down to individual GP surgeries and is one of the largest and most complex property portfolios in Europe (Hudson et al., 2003). In the UK, the Department of Health (DH) is responsible for the delivery of healthcare services in England (NHS Estate, 2005) and it is the overall policymaking body for healthcare (Tudor, 2007).

The National Health Service (NHS) in the UK is the worlds largest publicly funded health service (Tudor et al., 2005; Bunt and Haris, 2009) with one of the largest property portfolios comprising hospitals, clinics, dental surgeries, out-patient surgery centres, birth centres and nursing homes (Holmes et al., 2006). The NHS in England alone employs more than 1.3 million people and currently operates with a budget of over £100 billion which is ten times its original budget (Bunt and Haris, 2009). Fulfilling the need of a free healthcare service that exist over decades, the NHS was set up in 1948 by the post-war labour government effectively "nationalising" municipal and charitable hospitals to provide a free at point of need health service (Holmes et al., 2006). NHS services can be broadly divided into two main divisions: (1) primary care and (2) acute care. Primary care is a term used to describe community-based health services that are usually the first and often the only point of contact that patients have with the health service (Holmes et al., 2006). It covers services provided by GP

practices, dental practices, community pharmacies and high street optometrists (DH, 2011). Acute or secondary care normally takes place in a hospital (Holmes et al., 2006).

In 1997, the Strategic Plan for the Modernisation of the NHS was outlined with an indication of the way in which the government expects the NHS to change and to modernise services over the next ten years. A key theme of the plan was to offer a fast, convenient and high standard service delivered to people when required (DH, 2000). The plan has a strong emphasis on locality-focused services such as primary care and community health practitioners (Holmes et al., 2006). About ninety per cent of patients' contact with the NHS is for primary care services (NAO, 2005) with around 314 million consultations per year (DH, 2007a). However, based on the findings of the Department of Health/Partnerships UK, Homes et al. (2006) revealed that only 40 per cent of primary care premises are purpose built; almost half are either adapted residential buildings or converted shops; less than 5 per cent of GP's premises are co-located with a pharmacy; and around 80 per cent are below the recommended size. Additionally, it was revealed that the benefits of single bed spaces in hospitals rather than shared ward space provides privacy and dignity for patients, reduces noise levels, increased control over comfort and reduced risk of hospital acquired infections (Lawson, 2005). But statistics show that more than 50% of NHS buildings dated from before 1948 (DH, 2007a) and thus require modifications to facilitate current and future healthcare requirements. Hence, the UK government launched a healthcare modernisation programme to upgrade the existing buildings and to construct new buildings to meet current and future healthcare needs. The strategic plan for the modernisation of healthcare buildings was outlined in 1997 and the NHS Plan 2000 provided a detailed ten year plan with the aim of providing a better health service designed around the patients to suit to their needs in the 21st century (NHS, 2000). Building futures (2002) highlighted the use of: new forms of procurement based on partnering and long-term relationships; greater integration of design and construction; increased levels of performance measurement and monitoring and the development of strategic planning and design information to support the planning, design and building programme for healthcare environments as distinctive features in this healthcare modernisation programme.

The healthcare modernisation programme includes new construction and renovations to both acute care and primary care facilities. With this building programme the healthcare industry is currently experiencing historic levels of growth with the largest

programme of investment the country has ever seen. In the UK, capital expenditure on healthcare has increased from around £1.1 billion in 1997/98 to around £5.5 billion in 2007/08, that is almost four times what it was in 1997 in real terms; an average annual increase in real terms of over 10%; an average annual increase of over 15% since 1999/00; and a spent total of £29 billion (DH, 2007a). Figure 2.3 shows the total capital expenditure on healthcare by the NHS during the past few years and it is important to note the rapid growth in capital investment from 2000 due to the healthcare modernisation programme. Even so, DH declared a small decline on capital expenditure from 2010/11 to 2014/15 (£5.1 billion to £4.4 billion) (DH, 2010), the total capital expenditure is still significant in terms of country's economy.

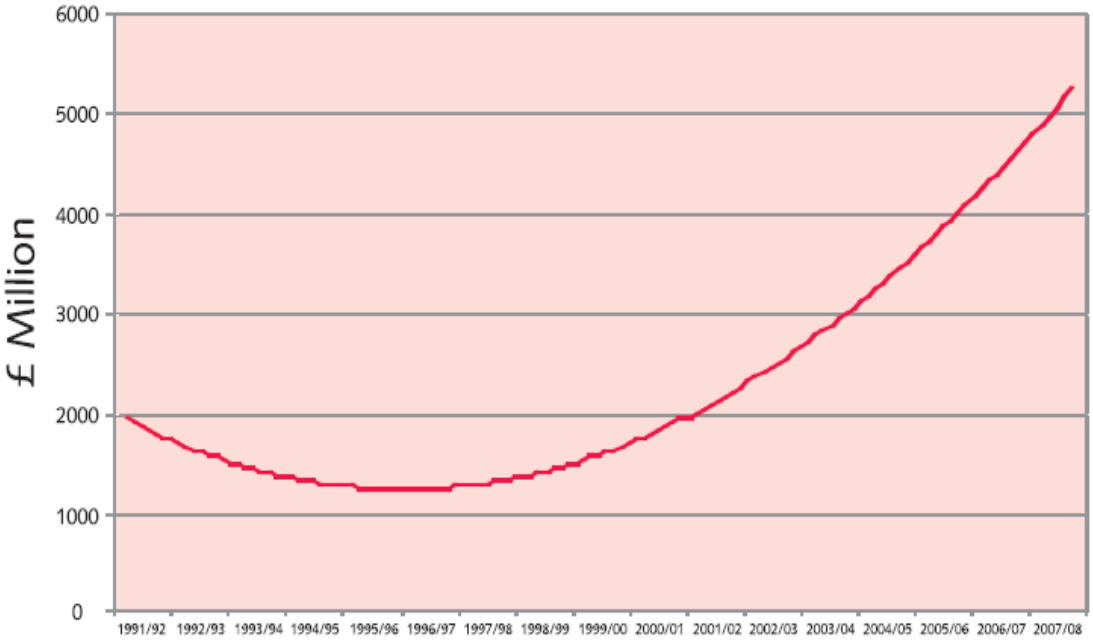


Figure 2.3: Capital expenditure on healthcare in the UK (Source: DH, 2007a)

As a result of NHS modernisation programme, almost a third of the acute and general NHS estates (i.e. excluding PCTs) were replaced and therefore, the figure of 50% out-dated hospitals had been reduced to 20% by 2007 (DH, 2007a). The NHS planned to complete 100 major hospitals by 2010 (88 buildings (67 PFI and 21 public capitals worth over £4.9 billion) and have 24 (19 PFI and 5 public capital worth £4.6 billion) were under construction including several large hospital schemes (i.e. Barts and London NHS Trust (£ 1billion); St Helens and Knowsley (£338 million); and women's and children's and specialist eye hospital in Manchester (£512 million)) (DH, 2007a).

Other than the above, a national programme for public capital building and refurbishment schemes (ProCure 21) was rolled out in September 2003. Under this programme, over 165 projects amounting to £717 million had been completed by 2007

and in total around 283 schemes have been registered through the programme at a value of approximately £2 billion (DH, 2007a).

In parallel to the major (acute) hospital construction and refurbishment programmes discussed above, there is a remarkable trend in building/refurbishment/replacement of primary/GP premises in the country. Meeting the NHS 2000 plan targets, 2,848 GP Premises had been refurbished/replaced by end of 2004 and 674 One-Stop Primary Care Centres had opened by end of 2006 (DH, 2007a).

The next section of this chapter highlights sustainability provisions and issues in the UK healthcare construction programme.

2.8.2 Sustainable Healthcare Construction

SC aims to maximise the benefits that built assets can bring to the local community and economy whilst minimising the impact of the construction and operation phases on the environment (SHINE, 2006). It brings about the required performance with the least unfavourable environmental impact, while encouraging economic, social and cultural improvement (ISO, 2005). More than an optimisation of any single component, sustainable design and construction represents the integration of materials and methods that, together, create the physical manifestation of a building (Vittori, 2002). SC should enhance the long-term usability and value of the building, increase the productivity of healthcare staff, improve patient recovery and user satisfaction, be adaptable to change, use resources such as energy and water efficiently in its construction and throughout its lifetime and minimise waste by reusing and recycling building and other materials (DH, 2005; SHINE, 2006).

The Learning Network for Sustainable Healthcare Buildings (SHINE, 2006) has identified the following key environmental impacts associated with the healthcare facilities in the UK:

- 45 million Giga Joules of energy consumed per year;
- 40 billion litres of water consumption per year;
- 3.4 million tonnes of CO_2 emitted per year;
- 0.9 million tonnes of Carbon emissions per year;
- Air pollution costs the NHS between £17-60 million a year;
- 350,000 tonnes of healthcare-related waste generated per year (NHS only)

Specific targets were set out and implemented by the NHS to achieve cost savings and reduce the impacts on the environment associated with the operation of its existing assets and the construction of new buildings. Delivering Sustainable Development DH Action Plan 2007/08 (DH, 2007b) reported that: the NHS Purchasing and Supplying Agency (PASA) purchases 100% of the energy for all DH sites from renewable sources at no extra cost; carbon emissions have come down 15% since 1999/2000; water use is 5.3m^3 per person per year against a government target of 7.7 m^3; and DH recycles more than 80% of office waste (against a target of 40%). Additionally, DH's action plan sets targets to address the Sustainable Operations for the Government Estate (SOGE) targets for year 2020. These measures mainly cover the areas of: energy efficiency (reduction in primary energy consumption by 15% by 2010 and 30% by 2020 based on 2000 levels, and the use of 10 per cent of electricity from renewable sources by 2010); carbon emission (reduce 12.5% by 2010 and by 30% by 2020, compared with 1999/2000 levels); deliver a carbon neutral department by 2012; reduct rising waste levels and increase recycling; water (management of consumption); green transport; and sustainable procurement (DH, 2007b). However, these DH sustainability target set clear benchmarks for only energy consumption and carbon emissions. Thus, DH needs to set more specific targets on the areas of water management, CO_2 emissions, and waste minimisation and recycling to experience the real benefits of SC.

As listed in the Delivering Sustainable Development DH Action Plan 2007/08 (DH, 2007b), waste minimisation and recycling is an important target in achieving sustainable healthcare buildings. There are a number of benefits the healthcare industry can achieve through waste minimisation such as: reducing environmental impacts from disposing of waste; complying with HNS policy of greening the environment and statutory obligations; and reducing current and future costs for waste management. Healthcare waste refers to any waste produced by, and as a consequence of, healthcare activities (DH, 2006). The NHS in England and Wales produces approximately 384,698 tonnes of combined waste per year (Material Health, 2004). In healthcare construction projects, waste disposal is a complicated process, since they generate large varieties of waste. For instance, the Department of Health (2006) broadly categorised waste into two major categories: hazardous and non-hazardous, where, hazardous waste categories include: infectious waste; laboratory chemicals; fluorescent tubes; cleaning chemicals; photo chemicals; oils; batteries; waste electronics; asbestos; paints; solvents and contaminated land. And non-hazardous waste categories include: domestic waste; food waste; offensive/hygiene waste; packaging waste; recyclates; ground waste; and construction and demolition

waste. With the growth in the construction and refurbishment of healthcare projects, reduction of the quantities of construction and demolition waste can be considered significant in achieving the UK Sustainable Construction Strategy targets.

2.8.3 Healthcare Construction Waste Minimisation

Healthcare construction waste is defined as any waste that is generated as a result of some form of construction, demolition or renovation that is taking place in a healthcare setting (HWS, 2008). The increasing number of building projects in the healthcare sector contributes significantly to the total quantity of construction waste generation in the UK, some of which is hazardous and has the potential to pollute the environment unless properly managed (Townend and Cheesman, 2005) However, NHS sustainability targets still does not establish a specific benchmark to minimise and recycle construction waste from healthcare projects and following the UK Sustainable Construction Strategy targets which is to reduce construction, demolition and excavation waste to landfill by 50% in 2012 compared to 2008 levels, to achieve zero net waste by 2015 at construction site level and zero waste to landfill by 2020.

Several case studies undertaken by the Waste and Resources Action Programme (WRAP) identified common construction waste material generated in healthcare-related construction projects such as: plasterboard, metal, timber, plastic, concrete, packaging, ceramics, soil, bricks and blocks; by monitoring waste arising during the final stages of the structural phase, the internal phase and the fit-out phase (WRAP, 2006a; WRAP, 2006b). Moreover, WRAP (2010b) illustrates that a significant cost saving can be achieved from waste minimisation in healthcare projects. Therefore, construction waste reduction from healthcare projects is important to reduce adverse effects on environment and society while achieving financial benefits.

In order to set up a systematic construction waste minimisation mechanism, it is necessary to obtain comprehensive knowledge about the healthcare project lifecycle to effectively discover waste generating issues in the construction process. The subsequent section explores characteristics and complexities in healthcare project lifecycle stages and causes of waste associated with each project lifecycle stage.

2.8.4 Healthcare Construction and Waste Origins in the Construction Process

In order to provide a quality healthcare service, healthcare buildings should be safe, effective, patient-centred, timely, efficient, and equitable (Taner et al., 2007). Moreover, there is a general consensus in the literature that healthcare buildings are different and more complex than other buildings (Akintoye and Chinyio, 2005). For instance, Dainty and Brooke (2004) selected a healthcare project as a case study to identify the effective waste minimisation strategies for complex and large projects, while Chan (2000) selected a healthcare project as a case study to assess the suitability of enhanced design and build procurement system for complex projects. Even though these studies claimed healthcare buildings as 'complex', none of the above studies stated a clear definition for 'complex buildings' or any basis for categorising healthcare buildings as 'complex'.

The dictionary definition to the term 'complexity' is "the state of being formed of many varied interrelated parts" (Oxford Dictionary, Online). On that basis, a complex building can be simply defined as "a structure (as a building) made up of interconnected or related structures" (The Free Dictionary, 2011). Baccarini (1996) defined a complex project as "consisting of many varied interrelated parts and can be operationalised in terms of differentiation and interdependency". Moreover, the latter study identified organisational and technological complexities as the most commonly observable complexities in construction projects. While introducing a more comprehensive definition to 'complex buildings', New Zealand Registered Architects Board (online) highlighted the characteristics that could be seen in complex buildings such as:

- complicated structural requirements;
- multiple occupancy or special purpose user requirements;
- complicated spatial articulation;
- complex planning and coordination of complex construction systems, materials, building services, and fittings; and
- challenging site configuration and existing features.

However, it is important to note that these characteristics are common for any complex building and to-date no significant study had been conducted to identify complex

features which are particular to healthcare buildings. Therefore, the subsequent sections attempt to identify the complex and different features in healthcare buildings and their impact on causes and origins of construction waste in project lifecycle phases highlighting the existing knowledge gaps in the literature.

2.8.4.1 Pre Design and Contract Agreement

The pre-design phase is the process of gathering, organising, and interpreting information that defines the project's scope and foundation to start off detailed design (Lima and Augenbroe, 2007). In any construction project, the main objective of the pre-design phase is to produce a project brief which defines the project requirements to assist the facility design, construction, and maintenance processes throughout the building lifecycle. A precise definition for the scope of the project maximises the project outcomes throughout the lifecycle of the facility while enhancing the satisfaction of the project stakeholders.

The project scope definition process and the involvement of stakeholders in the process greatly vary with the procurement system used in the project. For instance, within traditional procurement systems, clients appoint consultants to whom they describe the project scope whereas in integrated procurement systems it is mostly the contractor (Masterman, 2002). Lam (2000) states that the traditional approach has been found to be failing to satisfy client's needs in healthcare projects that are becoming larger and more sophisticated and create greater difficulty in the management of complex design and construction. Moreover, data published by the UK government and the NHS (see section 2.8.1) clearly indicates that the current and future healthcare construction projects use non-traditional procurement systems such as: Private Finance Initiative (PFI), Procure 21(P21), and Local Improvement Finance Trust (LIFT) where the latter two were especially introduced by the NHS for healthcare projects. These procurement systems are comprised of multi-disciplinary teams working from the start of the project to its completion.

Private Finance Initiative: PFI projects are long term relationships between the public and private sectors. This is a system whereby the private sector undertakes to finance the total procurement process on behalf of the public sector with payment being delayed until the project is completed and ready for occupation at handover (Bagnal, 1999). In addition, PFI projects transfer most of the risks from the public to the private sector, with public sector clients retaining only those few risks for which they are well equipped to handle (Akintoye and Chinyio, 2005). Thus, PFI enables the private

partner to build a facility to the output specifications agreed with the public agency, operate the facility for a specified time period under a contract or franchise with the public sector client and then transfer the facility to the latter party when the contract expires (Akintoye and Chinyio, 2005). The fundamental advantage over this method is that the client is able to take over an operational facility while reducing the public sector's capital expenditure in the short term.

ProCure 21: Sir John Egan's review of the state of the construction industry led to the launch of partnering framework by the government and the introduction of P21 by the Department of Health. The aim of P21 is to introduce long-term relationships between the NHS and the construction industry to establish partnering arrangements and effective supply chain management (NHS, 2004) to obtain high quality design through continuous improvement (NHS, 2007). The P21 lifecycle consists of six phases: definition; team selection; scheme launch; scheme development; delivery; and evaluation, where the major advantage is the inherent flexibility within the process (NHS, 2007). It encompasses examples of innovation and best practice throughout the process such as the use made by the supply chains of standardisation and off-site construction and modularisation. Benefiting from multi-disciplinary expertise across the supply-chain at an early stage vastly improves the business case process, makes savings onsite, reduces risk and ensures a better product (NHS, 2007). This collaborative team approach reduces the number of advisors needed by the clients and the contractor and it ensures the guaranteed maximum price as the final cost. Any cost overrun within the process or cost saving will be borne by the principal supply chain partners (PSCP) according to the agreement (NHS, 2007). The NHS recently introduced a successor to P 21 that is Procure 21^+ ($P21^+$) to reflect the changing policy landscape, NHS structure, economic environment, client demands and changes in procurement practice (NHS, 2011). It is important to note that the underlying principles have not fundamentally changed, even though some changes have been done to the contract provisions, guidance and processes (NHS, 2011).

Local Investment Finance Trust (LIFT): NHS LIFT was announced in the NHS Plan 2000 as a new investment mechanism for the redevelopment of the primary and social care estate (DH, 2007a). LIFTs are a variation on the PFI theme; which apply PFI principles but, unlike conventional partnering arrangements between client and contractor, the LIFT scheme is a joint venture whereby the construction and management is 40 per cent owned by the local Primary Care Trust (PCT) (Holmes et al., 2006). LIFT establishes public-private partnership companies (LIFTCo) comprising

of: local public sector healthcare organisations; selected private sector organisations and community health partnerships, which work with local organisations to deliver tailor-made facilities for primary and social care (Community health partnerships, 2011) (Figure 2.4)

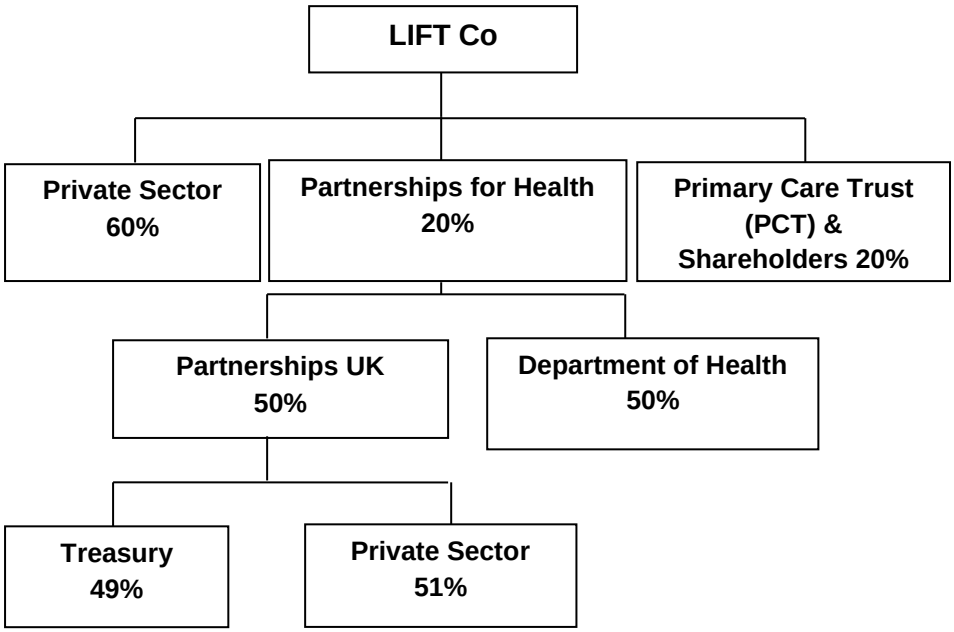


Figure 2.4: Structure of LIFTCo (Holmes et al., 2006)

Holmes et al. (2006) argues that the LIFT system is flexible and thus allows provision of a range of buildings including GP premises, one-stop primary care centres, integrated health and local authority service centres, and community hospitals. Moreover, the same study highlighted some advantages in LIFT schemes such as: reduction of whole-life costs and emphasises of value for money over the lifespan of a project; encouraging energy efficiency; and waste minimisation. Thus, it can be argued that the LIFT schemes provide increasing impetus towards achieving sustainability than other traditional procurement schemes.

The current partnering procurement systems used in healthcare construction in the UK clearly indicates that contract agreement between the client team and the construction team takes place before starting the detail design and allows a multi-disciplinary approach from the start of the project unlike traditional procurement systems (Chan and Chan, 2004). Also, it is important to note that the characteristics in both P21 and LIFT schemes do not vary significantly compared to other partnering agreements. For instance, P21 and LIFT schemes work as a team to achieve mutual objectives while

searching for continuous measureable improvements similar to other partnering procurement systems. However, these two procurement systems were customised by the NHS to suit healthcare construction project environments (i.e. introducing new funding mechanisms, long terms partnering agreements, and multiple projects) to obtain further benefits of adopting partnering procurement systems.

In literature, several authors (McDonald and Smithers, 1996; Greenwood, 2003, Tam et al., 2007a) highlighted that construction waste causes could be influenced by the selected procurement system. For instance, the effect of some causes of waste (i.e. type of contract varying the responsibility towards waste minimisation, method of tendering) could greatly vary with the relationship and understanding among project team members. Moreover, McDonald and Smithers (1998) emphasised the need for a future study to identify the ways in which differing construction procurement systems affect the generation of on-site waste as a result of the different interrelationships involved in alternative procurement processes. This was further confirmed by a recent research study by Gamage et al. (2009), which particularly focused on enhanced design and build projects and customised causes of waste particular to enhanced design and build projects. Since no clear evidence can be found in the literature relating to construction waste causes particular to partnering procurement systems, it is worth exploring the causes of waste particular for healthcare projects since healthcare projects use specific partnering procurement systems such as P21, P21^{+} and LIFT.

Other than causes of waste linked to the procurement system, issues related to project planning and project scope definition are the other significant causes of waste in the pre-design phase of a project. A study by Lima and Augenbroe (2007) mentioned that ineffective communication, poor scope definition, unique technical background of stakeholders and complex decision environments are the major problems in the pre design phase of a healthcare project. However, this study does not extend its findings to identify the relationship with the healthcare pre-design phase problems with construction waste generation.

In healthcare projects, the number of project stakeholders involved in the project requirements identification phase is considerably large. This was further confirmed by a recent study conducted by Sengonzi et al. (2009) specifying that end users (i.e. patients, staff), boards (i.e.NHS, Trust, PCT), construction providers, funders, community and pressure groups, government and regulatory authorities participate in the project requirements identification phase representing the client organisation.

Therefore, it can be argued that, in the first instance, the large number of users involved during the project requirements identification phase increases the complexity of identifying all the project requirements which could lead to poor scope definition. Moreover, Gibson et al. (2006) stated that inadequate or poor scope definition in a construction project tends to increase the final project cost due to rework and interruption to project activities. Also, rework is commonly known in literature as a major cause of waste in the construction projects (see Table 2.6). Hence, there are clear grounds in the literature to assume that the involvement of a large number of project stakeholders in the pre-design phase of a project could increase construction waste generation due to lack of understanding of client requirements at the start.

Moreover, Lima and Augenbroe (2007) reported inherent complexities within the decision environments in healthcare projects as the result of: the diverse and unique technical background of stakeholders with different priorities and expectations of the final facility; the desire to achieve multiple objectives at once; the management of multiple criteria and alternatives; the need to justify decisions; and difficulties in understanding the problems. Thus, efficient communication among project stakeholders during the pre-design phase in a healthcare project is arguable.

While referring to the above arguments on healthcare pre-design phase complexities and their ability to impact adversely on construction waste generation, the requirement of a further study was recognised. Thus, preliminary data collection was conducted to identify the exact causes of waste related to the pre-design and contract agreement phase in healthcare construction projects (see chapter 4).

2.8.4.2 Design Phase

The development of the concept design agreed between the client team and construction team during the pre-design and contract agreement phase is the main task performed by the project partners during the design phase. Healthcare designs are considered complex and unique, since they comprises of functionally and operationally-interconnected, built and technical elements that interact with several management systems. Therefore, unlike other buildings, where a poorly designed environment may cause dissatisfaction and annoyance, inhibit effective communication, or contribute to relatively minor health problems; in a healthcare environment the consequences of getting the design wrong can be far more serious, including death (Becker and Parson, 2007). Furthermore, patient satisfaction is an important parameter in the process because it has been associated with commitment

to return to and recommend the hospital to others (Clark and Malone, 2006). Therefore, the design of healthcare buildings needs to increase the likelihood of a facility that functions well for patients, staff, hospital administrators and facility planners. Well-designed buildings with features such as natural light, good ventilation and access to green spaces can result in quicker patient recovery. However, Lawson (2005) mentioned that maintaining the balance between quicker patient recovery features and critical adjacencies within the departments in a healthcare facility is a very stressful process to the designers indicating the level of complexity in a healthcare design. The requirement to follow Healthcare Technical Memoranda (HTMs) and Healthcare Building Notes (HBNs) introduced by the NHS further increase complexities in healthcare designs.

Moreover, healthcare designs require integration of a large number of mechanical and electrical (M & E) services, which accounts for nearly 50% of the total project cost (Lam, 2000), increasing design associated complexities. In terms of functional considerations, Thomson et al. (1998) suggested that the healthcare building designs need to be flexible to facilitate future changes (i.e. climate, new ways of working, new technology, changing healthcare demands, advances in science and medicine and changing patterns of disease) without significant structural or fabric alteration. However, some authors (FHN, 2004; Dowdeswell and Heasman, 2004; Gaiser and Barlow, 2007) have pointed out that the contractual complexities in healthcare specific procurement systems act as barriers to change if flexibility and adaptability have not been embedded into both the design philosophy and the partnering arrangements.

Therefore, complexities in healthcare building designs increase difficulties in measuring, evaluating and selecting the best design manually (DH Estates & Facilities, 2008). To address such complexities, a number of design evaluation tools have been introduced by the NHS such as: NEAT (NHS Environment Assessment Tool), BREEAM Healthcare (Building Research Establishment's Environmental Assessment Method); AEDET (Achieving Excellence Design Evaluation Toolkit); and DRP (Design Review panel) (see Table 2.8).

Table 2.8: Healthcare design evaluation tools

Tools	Description
NEAT (NHS Environmental Assessment Tool)	**Purpose:** To improve resource and cost efficiency in NHS building stock ensuring a pleasant environment. **Types of buildings assess:** • New build; • Refurbishment; and • Existing Estate ***This tool was replaced in July 2008 with BREEAM Healthcare due to:** • Changes in building regulations • Improving standards in both DH and industry • No longer best practice • No third party verification • Lack of guidance for users and specifiers
BREEAM healthcare (Building Research Establishment's Environmental Assessment Method)	**Purpose:** To help mitigate the environmental impact of buildings through appropriate design, refurbishment and management. **Types of buildings assess:** • All healthcare buildings containing medical facilities **Assessment criteria:** • In existing buildings credits will be given to following areas: Management; Health & wellbeing; Energy; Transport; Water; Materials; Waste; Land use & Ecology; Pollution • All new builds require achievement of an "Excellent" rating and all refurbishments require achievement of a "Very Good" rating under BREEAM Healthcare.
AEDET (Excellence Design Evaluation Toolkit)	**Purpose:** To evaluate the quality of design in healthcare buildings. **Types of buildings assess:** • existing buildings, plans for new buildings, imaginary buildings, and various stages during the design of healthcare facilities. **Assessment criteria:** evaluation has 3 major sections: • Impact: performance, engineering, construction • Build quality: character & innovation; form and materials; staff and patient environment; urban & social integration • Functionality: use, access, space
NHS Design Review Panel (DRP)	**Purpose:** To provide advice, guidance and support to ensure good design **Types of buildings assess**: • Reviews a range of schemes across community and acute health sectors procured by PFI, LIFT or public capital **Assessment criteria:** evaluation has 3 major sections: • **Master planning:** design response to the local context in terms of access, transport and siting • **Quality of place:** design support to the high quality care and environment for patients, visitors and staff • **Sustainability:** design anticipations for future service developments and responds to requirements posed by climate change

Most of the design phase causes of waste are due to design changes, design complexities, delays in designs, materials selection and specification, inefficiencies in communication and coordination and inadequate experience of designers (See Table 2.4). Vittoti (2002) revealed that the complexities of human health implications, increases the difficulty in making design decisions. Material selection and product and equipment specifications are more important for healthcare buildings than other types of construction. However, it could be argued that there could be more chances for the design team to make incorrect decisions due to the complex nature of the environment in which the decisions are made due to human health implications. Additionally, incorrect drawing details and flawed selection of materials were explicitly stated in the literature as causes of construction waste (see Table 2.4). Hence, it can be assumed that these complexities could lead to increases in construction waste generation from healthcare projects. However, no clear evidence has been published in literature to establish a clear link between complexities in healthcare design decision environments with construction waste generation and thus this area requires further study.

Additionally, published literature demonstrates design stage complexities in healthcare buildings due to healthcare building regulations, adaptability and flexibility needs, and M & E services requirements (Lam, 2000, FHN, 2004; Dowdeswell and Heasman, 2004; Gaiser and Barlow, 2007). However, no clear evidence can be found in literature to recognise the effect of these complexities on causes and origins of waste.

Furthermore, Akintoye and Chinyio (2005) mentioned that the use of healthcare specific procurement systems, such as LIFT and P21, enables project participants to work collaboratively in speeding-up and finalising the design. In terms of waste generation, the use of highly integrated procurement systems could be advantageous. For instance, collaboration between project partners during the early design phase could lessen the impacts on waste generation due to inappropriate materials selections and specifications, delays in drawings, incorrect drawing details, and inefficiencies in communication and coordination. However, literature findings fail to identify the exact outcomes due to the application of non-traditional procurement systems on design waste origins in healthcare projects.

Consequently, a preliminary data collection study was conducted to identify exact causes of waste related to the design phase in a healthcare construction project (see chapter 4).

2.8.4.3 Construction Phase

With the use of non-traditional procurement systems in healthcare project delivery, a clear cut difference between the design phase and construction phase cannot be perceived due to the early designer-contractor collaboration (Chan and Chan, 2004). Construction practices directly impact on long term health and sustainability goals and therefore the whole construction team, including the project manager, main contractor, and subcontractors are all committed to achieving sustainability goals in healthcare construction. Additionally, healthcare buildings are subject to many changes during the operation phase as interior spaces are reconfigured, remodelled and outfitted with new furnishings and equipment, reflecting changes in management and delivery systems (Vittori, 2002). But there is a common view in literature that hospitals are often remarkably resistant to change, both structurally and culturally (McKee and Healy, 2002). However, hospital refurbishment presents a number of unique challenges because in most of the healthcare refurbishment projects the facility needs to stay fully operational throughout the lifetime of the project and thus, noise, dust and vibration must be kept to an absolute minimum due to potential adverse effects on patient recovery time (OGC, 2006). Based on the above discussion on literature review findings, emphasis has arisen to identify particular causes of construction waste in healthcare projects.

A large number of past studies identified causes of waste during the construction/renovation stage such as: materials procurement errors; inappropriate materials storage; improper materials handling; lack of site management and planning; errors in site operations; inappropriate transportation; and residual waste (see Table 2.6). By and large these are causes of construction waste on all construction sites irrespective of the size or the type of construction/renovation project.

Healthcare facilities need to operate continuously throughout the facility lifecycle and therefore construction and renovation activities often take place on live hospital sites increasing complexities in site operations, materials handling and storage facilities, transportation inside the site, and site waste management activities. A study conducted by WRAP (2006b) revealed that in large and congested healthcare sites segregation of different waste streams is challenging especially when sub-contractors are not allocated waste minimisation responsibilities. As discussed in section 2.8.3.2 healthcare buildings require a large number of M & E services. By their very nature, building services cannot be designed and installed independently as these vital

elements have to be fully integrated with other building components and require a high level of coordination. Lam (2000) revealed that the lack of integration and coordination of building services into the main construction work are detrimental to the success of a project, as they could delay other construction activities, create major monetary claims, unsightly services, and potentially difficult maintenance.

As discussed above, healthcare construction and renovation complexities due to continuous operation of other healthcare facilities on site, large and congested sites, and the large number of trades involved in the process, increasing communication and coordination issues, it can be argued that the waste generation from healthcare projects is significant. On the other hand, the use of non-traditional procurement methods for healthcare construction might reduce construction waste generation as a result of early project team formation that allows communication and coordination enhancements from the start of the project. However, literature findings are not enough to clearly identify the effects on waste generation due to embedded complexities in the healthcare construction process. Therefore, a preliminary data collection study was conducted to identify exact causes of waste related to the construction/renovation phase in a healthcare construction project (see chapter 4).

2.8.5 Healthcare Construction Waste Minimisation Practices

2.8.5.1 Pre Design and Contract Agreement Phase

In the pre-design phase most of the causes of waste are associated with the definition of the scope of the project (see Section 2.7.2.1). Past researchers revealed that process of scope definition is relatively complex in healthcare projects due to complex decision environments and involvement of large numbers of stakeholders (Lima and Augenbroe, 2007; Sengonzi et al., 2009). In order to increase efficiency in the project scope definition process, Lima and Augenbroe (2007) suggested involving all the necessary project stakeholders and conducting a formal decision making process which offers a structured way for solving problems and verifying factors to maximise the chances for a successful healthcare project by increasing efficiency, precision and satisfaction of the parties involved. Although, the above study did not refer to the importance of early project stakeholder involvement and implementation of formal decision making process in terms of waste minimisation, it could be argued that the clear set up of project scope could avoid waste generation by avoiding incomplete briefing, inefficient communication and coordination, lack of planning and identification of client’s needs. However, roles and relationships established within project

stakeholders, project management approaches, patterns of communication and information systems, the forms of contracts, and the overall management of the project organisation are all consistent with the selected procurement route (Lam, 2000). Therefore, these findings revealed the need for a preliminary data collection study to identify the impacts of early, project stakeholder involvement and formal decision making processes on construction waste minimisation in healthcare projects with the use of specific procurement systems like P21 and LIFT (see chapter 4).

A recent publication of WRAP (2010b) encouraged NHS Trusts to set: key performance indicators through Site Waste Management Plans; sustainable procurement and supply chain engagement; continue to embed good practice within guidance for capital programmes; and local reporting in accordance with corporate social responsibility and public accountability requirements to reduce waste sent to landfill sites during healthcare construction projects. Moreover, it was suggested that construction waste reduction targets should be incorporated into the NHS Trust Sustainable Development Management Plan, NHS Trust Estate Management Plan and Project Brief to assess the performance on waste minimisation from healthcare projects while embedding targets for continuous improvement.

2.8.5.2 Design Phase

As discussed in the Section 2.7.3, very little research has been conducted to examine design-related waste minimisation practices and most of these are related to waste minimisation guides and manuals; selection of materials; design standardisation; use of offsite products; and design out waste methodologies. Due to complexities in healthcare designs, the direct applicability of design waste minimisation practices to healthcare projects is arguable. It is, therefore, important to examine the suitability and applicability of the design related waste minimisation practices, discussed in section 2.7.3, to healthcare projects. On the other hand, several major healthcare contractors in the UK such as Yorkon, Skanska and Laing O'Rourke reported that they have achieved significant reductions in construction waste by adopting off site construction techniques (i.e. pre cast units, modular construction etc.) in their healthcare projects.

A report produced by Healthcare Without Harm (2005) recommended adopting an upfront, integrated, holistic design process to include all the institutional stakeholders (i.e. architects, engineers, users, etc.) on the healthcare design process for proper programming and opportunity identification during conceptual design. In order to facilitate rapid changes in treatment, information technology, expansion or renovation,

the above report further suggested designing flexible healthcare spaces. Literature widely discusses the effective use of information modelling systems for buildings with complex designs to make in-depth comparisons of more alternatives in a shorter time period in the process of selecting the best design (Suermann and Issa, 2007; Eastman et al., 2011). For instance, a study conducted by Abdou et al. (2003) proposed an internet based decision support system for healthcare projects to support architects in determining the internal sizes and layouts of the building. Similarly, Manning and Messner (2008) highlighted the importance of using Building Information Modelling (BIM) for healthcare projects to obtain benefits of: rapid visualisation; better decision support upstream in the project development process, rapid and accurate update of changes, reduction of man-hours required to establish reliable space programmes; increased communication across the whole project development team (users, designers, capital allocation decision makers, contracting entities, and contractors); and increased confidence in completeness of scope by identifying defects during the early stages. Apart from the above, the NHS has developed several design evaluation tools (see Table 2.8) to facilitate comparisons between alternative designs to select the best design for the project. Even so, construction waste minimisation is considered as one parameter in comparing alternative designs in some tools introduced by the NHS (i.e. BREEAM Healthcare), to date, no specific tool has been published by the NHS focusing on construction waste minimisation.

Therefore, based on the above arguments it can be assumed that the complexities in healthcare designs could be reduced with the use of integrated design approaches, information modelling systems, decision support systems; design evaluation tools; and flexible designs. However, literature fails to establish a clear link with the use of aforesaid techniques in healthcare projects to reduce construction waste generation, and thus, a further study is required to assess the appropriateness of above techniques in terms of construction waste minimisation (see chapter 4 and 5).

2.8.5.3 Construction Phase

A large number of researchers have recommended a variety of onsite construction waste minimisation approaches (see section 2.7.3). However, it can be argued that the effectiveness in implementing these waste minimisation approaches could vary with the site conditions, stakeholders' relationships, and project waste reduction targets. Recently conducted case studies by WRAP, on healthcare construction projects, lists and summarises the key waste minimisation and management practices required to achieve expected project waste targets in healthcare projects. Most of these studies

focused on the implementation of site waste management plans in compliance with legislation (WRAP, 2010c, WRAP, 2010e) and revealed the importance of forecasting waste quantities, setting waste targets, investigating waste reuse and recycling options, and monitoring and updating SWMP targets accordingly to manage construction waste from healthcare projects. Furthermore, WRAP (2010f) highlighted the importance of developing a proper site logistics strategy to plan materials ordering, delivering, storing and handling in a healthcare project to minimise construction waste generation.

Additionally, several studies included the importance of planning and management of site activities, conducting training programmes for site operatives, implementing a taking back policy for packaging, effective communication, good team building and allocation of waste minimisation and management responsibilities to project stakeholders as good practices to implement into healthcare projects to reduce construction waste generation (Lam, 2000; WRAP, 2010e; WRAP, 2010f).

2.9 Summary

The aim of this chapter was to examine the construction waste generation issues with specific reference to healthcare projects and to identify the existing knowledge gaps in the literature. The review showed that the construction industry plays a vital role in the UK economy and the construction waste reduction is important to achieve SC. The four main construction waste minimisation drivers in the UK are: environmental drivers, economic drivers, legislative drivers and industry drivers. The literature review findings showed that the causes of construction waste span across the whole project lifecycle starting from the pre-design phase through to project completion. However, most of the waste minimisation approaches specified by previous researchers focused only on site waste minimisation and management albeit, few recent research studies place increasing emphasis on the design phase and contract agreement phase.

With the significant increase in healthcare capital investment in the UK, a number of SC issues emerged in healthcare construction projects including construction waste generation. Moreover, the review identified that healthcare construction projects are complex and different compared to other building projects due to a number of inherent complexities in the healthcare project lifecycle such as: complex decision environments; the large number of project stakeholder involvement in the project; complex M & E services; and complex site conditions due to the constant on-site operation of the existing facilities. Even though these characteristics inevitably help to

identify the complex nature of healthcare construction projects, no clear evidence exists in literature to establish a link between complexities in healthcare projects and construction waste generation. Therefore, the review indicated a need for further study to investigate the particular causes of construction waste related to healthcare projects; the effect of complex features in construction waste generation; and best waste minimisation practices to be implemented throughout healthcare construction projects. The next chapter presents the research methodology followed in this research study.

3

RESEARCH METHODOLOGY

3.1 Introduction

The aim of this chapter is to outline the research methodology used to achieve the research's aim and objectives. The chapter begins with an introduction to the philosophical perspectives of research, specifically discussing the underlying philosophical assumptions and their stances. The next section describes the widely used research approaches and discusses the approach adopted for this research study. The chapter then examines and explains the selected research design for the study and highlights the grounds for the selection.

Subsequently, the chapter discusses the actual research process that covers the initial impetus; the literature review, preliminary data collection and analysis; case study data collection and analysis; HC-WMF development and validation. Each of the above sections describes how the research process was undertaken to collect the required data: the instrument design and testing, the strategy for selecting respondents and the process adopted for data analysis.

3.2 Philosophical Stance (Theoretical Perspective)

Research aims to investigate a problem systematically and thoroughly aiming to interpret, describe, predict or explain a phenomenon. Tan (2002) defined the term 'research' as a careful and systematic process of inquiry to find answers to problems of interest. In order to qualify as 'research', the process must be, as far as possible, controlled, rigorous, systematic, valid and verifiable, empirical and critical (Kumar, 1999). Hence, every research project must carefully select the most suitable procedural framework to interpret, describe, predict or explain a phenomenon, which is normally termed the 'research methodology'. Although, the terms 'research method' and 'research methodology' could be seen as related concepts, their meanings are different. The term 'research method' refers to the techniques or procedures used to

gather and analyse data related to some research question or hypothesis (Blaikie, 1993); whereas, 'research methodology' refers to the principles and procedures of the logical thought processes that can be applied to a scientific investigation (Fellows and Liu, 2008).

Creswell (2003) stated that three questions needed to be addressed when selecting the research methodology:

- What knowledge claims are being made by the researcher?
- What strategies of inquiry will inform the procedures?
- What methods of data collection and analysis will be used?

Therefore, methodology does not simply refer to a set of methods; rather it refers to general philosophies of science and detailed research methods (Saunders et al., 2007), such as surveys and statistical analyses, that are used to analyse data to test hypotheses (Tan, 2002). According to the 'research onion' concept introduced by Saunders et al. (2007), methodology includes philosophy, approaches, strategies, methods, choices, time horizons, data collection and analysis techniques and procedures.

Understanding the philosophical stances of the research is the first step in designing a research methodology. The term 'research philosophy' relates to the development of the knowledge and the nature of that knowledge (Saunders et al., 2007). According to Easterby-Smith et al. (1991), understanding the philosophical positions in the research is essential as it could help researchers to clarify research designs; recognise the most suitable among them and identify and create those that are most appropriate. In addition, research philosophies guide the researcher to consider the research constraints of different subjects or knowledge structures (Easterby-Smith et al., 2002).

There are three widely discussed philosophical branches in research: Ontology, Epistemology and Axiology (Saunders et al., 2007). According to Fellows and Liu (2008), Epistemology is the branch of philosophy that concerns the origins, nature, methods and limits of human knowledge. It describes how the researcher knows the reality (Tan, 2002; Creswell, 2007) and the grounds for that knowledge (Remenyi et al., 1998).

Ontology refers to the nature of reality or the nature of knowledge and describes what knowledge is. It is concerned more with assumptions in conceptual reality than epistemological considerations (Guba, 1990; Tan, 2002; Saunders et al., 2007; Fellows and Liu, 2008). It questions the existence of reality apart from specific objects and events (Saunders et al., 2007; Fellows and Liu, 2008).

Saunders et al. (2007) mentioned that axiology is a branch of philosophy that studies a researcher's value judgement. It explains which of the researcher's values, ethics and beliefs go into the research and any assumptions about value systems.

Even though some authors view epistemology, ontology and axiology as three dimensions of a research philosophy, they can be better presented as three different characteristics within one dimension (see Figure 3.1). As shown in Figure 3.1, key research philosophies can be placed in a continuum of which the two extreme ends are the positivist paradigm and the interpretive paradigm.

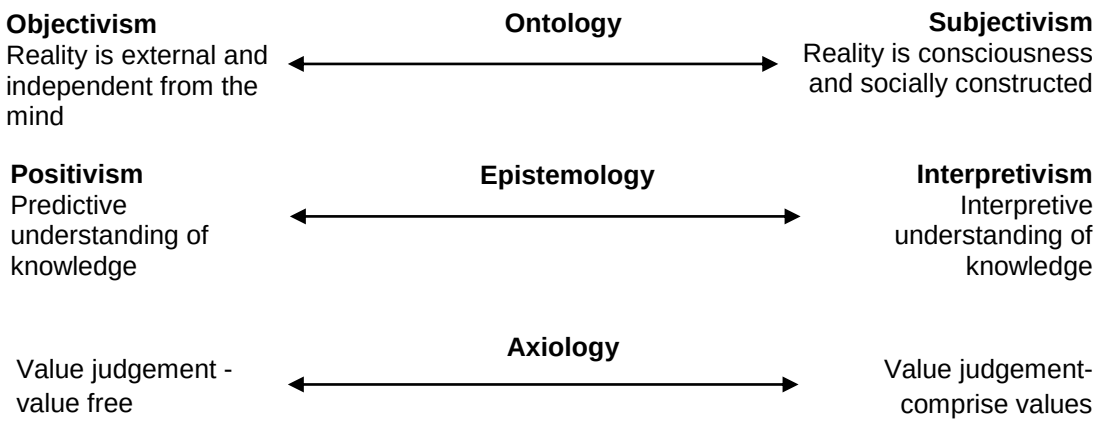


Figure 3.1: The research philosophy continuum (compiled from the literature)

The positivist paradigm is based on, firstly, the ontological assumption that the reality is external and independent from the mind (it has one single truth); secondly, the epistemological assumption that the knowledge grounds on predictive understanding; and thirdly, on axiological assumption that the value judgement in the research is free from values and thus unbiased. Conversely, the interpretive paradigm, which is known as phenomenological or social constructivism is based on, firstly, ontological assumption that reality is consciousness and socially constructed (has multiple truths); secondly, on the epistemological assumption that knowledge grounds on interpretive understanding; and thirdly, based on axiological assumption that the value judgement of the research comprises of values and is thus biased. Easterby-Smith et al. (1991)

compared the characteristics of two extreme paradigms: positivism and interpretivism (social constructivism), these are shown in the Table 3.1.

Table 3.1: Comparison between positivism and social constructivism (interpretivism) (Easterby-Smith et al., 1991)

Characteristics		Positivism	Interpretivism (Social constructivism)
Basic beliefs:	The world	External and objective.	Socially constructed and subjective.
	The observer	Independent.	Part of what is being observed.
	Human interest	Not relevant.	Value-laden and driven by human interest.
Researchers should:	Focus on	Facts.	Meanings.
	Explanations	Look for causality and fundamental laws.	Understand what is happening in a situation.
	Unit of analysis	Reduced to simplest elements.	Look at the complexity of the total situation.
	Research progress through	Hypothesis and deductions.	Develop ideas through induction.
Preferred methods	Concepts	Operationalising concepts so that they can be measured.	Use multiple methods to establish different views of phenomena.
	Sampling	Use large samples.	Small samples but investigated in depth or over time.

Table 3.1 shows that the positivist and interpretivist paradigms are divergent and in two extreme positions. With the comprehensiveness of real world situations, concerns are raised among researchers about obtaining complete views on issues using either of these paradigms alone (Mingers, 1997). Therefore, supporting the suggestions of Lee (1991) about the possibilities of combining both the positivist and interpretivist approaches to provide different views of the same phenomena, Mingers (1997) emphasised the requirement of multiple views of reality in research (multi-paradigm research). Literature identifies the philosophical stance of ‘pragmatism’ in line with the above (Murphy, 1990; Creswell, 2007; Saunders et al., 2007; Tashakkori and Teddlie, 2009) where the most important determinant of the research philosophy adopted is the research problem that is going to be studied and the questions being asked about a particular problem rather than merely focusing on the methods (Saunders et al., 2007; Creswell, 2009). According to Cherryholmes (1992), Morgan (2007) and Creswell (2009) the basic features of pragmatism are as follows:

- Pragmatism is not committed to any one system of philosophy and reality;
- Individual researchers have a freedom to choose the methods, techniques and procedures of research that best meet their needs and purposes;

- Pragmatists do not see the world as an absolute unity;
- Truth is what works at the time; it is not based in a dualism between reality independent of the mind or within the mind;
- Pragmatist research examines the questions 'what' and 'how' to research, based on the intended consequences i.e. where the researcher wants to go with it;
- Pragmatists agree that research always occurs in social, historical, political and other contexts;
- Pragmatists believe in an external world independent of mind as well as those logged in the mind and the need to stop asking questions about the reality and laws of nature; and
- Pragmatism opens the door to multiple methods, different world-views and different assumptions, as well as different forms of data collection and analysis.

Pragmatism allows the researcher to use multiple methods of data collection and analysis techniques where inquiring can be liberally drawn from both quantitative and qualitative assumptions (Creswell, 2007; Saunders et al., 2007; Tashakkori and Teddlie, 2009). Therefore, the researcher using a pragmatic world-view has opportunities to use multiple/mixed data collection methods to best answer the research question, using both quantitative and qualitative sources of data collection, focusing on the practical implications of the research and emphasising the importance of conducting research that best addresses the research problem (Creswell, 2007).

As far as this research study is concerned, the researcher is not influenced by a pre-determined view on what is acceptable knowledge and therefore it was not initiated particularly with either a positivist view or an interpretivist view. Moreover, it could be said that this research was not directed by any theories, but rather directed towards the research questions that emerge out of the literature. Therefore, rather than considering the most suitable methods, this research study gave priority to understanding the research problems and the most suitable approaches and methods to investigate knowledge about these problems. Thus, the philosophical position of this research is more towards the pragmatic knowledge claim position as the research was expected to choose the methods and procedures that best met the research problem and objectives.

3.3 Research Approach

Once the research philosophy was identified, the next stage was to select an appropriate research design. The selection of the research design depends on the extent to which the researcher clarifies the theory at the beginning of the project (Saunders et al., 2007). The term 'theory' can be explained as "an explanation of observed regularities" (Bryman, 2004). Blaikie (2000) defined the term 'theory' from different perspectives: firstly, theories are "the current state of knowledge about why something happens"; secondly, theories "provide explanations by establishing connections between the subject of interest and other phenomena" and thirdly, theories are "a set of propositions that state a relationship between concepts". These dictate many characteristics of a theory such as: cause and effect relationships, links between concepts/variables and the requirement for testing.

In the literature, there are two broad approaches to research design based on the understanding of theory at the start of the research study, namely: the deductive approach and the inductive approach. In the deductive approach, the researcher develops a theory and hypothesis (or hypotheses) and designs a research strategy to test the hypothesis, whereas in the inductive approach, the researcher collects data and develops a theory as a result of that data (Saunders et al., 2007). Similarly, Tan (2002) stated that induction is the movement or generalisation from the data/facts (observations, empirical world or reality) to theory; while deduction is the opposite, with the data/facts testing the theories. Table 3.2 summarises the differences between the deductive and inductive research approaches.

Even though a rigid difference can be noted between deduction and induction, as shown in Table 3.2, Saunders et al. (2007) argued that it is perfectly possible to combine deduction and induction within the same piece of research. Moreover, several authors emphasised that this combination is often advantageous as it enables the researcher to gather benefits from both approaches (Yin, 2003; Gill and Johnson, 2002; Saunders et al., 2007).

As discussed in Section 2.8, very little research has been done in the current research area. Thus, very little background information pertaining to this research study was found within the existing literature. Hence, a need to conduct a further study to firmly establish contextual settings related to this research study was recognised. Therefore,

this research study started with the deductive reasoning approach with a problem definition and lead to an inductive reasoning approach of theory building.

Table 3.2: Comparison between the deductive and inductive approaches (Saunders et al., 2007).

Induction	Deduction
• Move from data to theory. • A more flexible structure to permit changes as the research progresses. • Less concern with generalisation. • Collection of qualitative data. • Researcher is part of the research process. • Gathering an understanding of the meaning humans attach to events. • Close understanding of the research context.	• Move from theory to data. • Search to explain causal relationships between variables. • Collection of quantitative data. • Scientific principles. • A highly structured approach. • Researcher independent of what is being observed. • Operationalised concepts to ensure clarity of definition. • Select large samples to generalise findings. • Application of controls to ensure validity of data.

Since there is no clear-cut path in selecting an appropriate research design once the philosophical positions and theory testing and theory building requirements were identified; the next step was to take up the challenging task of selecting an appropriate research design to carry out the process of data collection and analysis.

3.4 Research Design

Research design can be thought of as the means of arriving at conclusions to a particular research question (Tan, 2002). It provides a framework for the collection of data and its analysis (Bryman, 2004). When selecting a research design, Yin (2003) suggested three factors to consider: the type of research question; the extent of control an investigator has over actual behavioural events, and the degree of focus on contemporary, as opposed to historical, events. A number of authors introduced several research designs and associated terminologies. For instance, Yin (2003) mentioned five research design types: experiment, survey, archival analysis, history and case study. The same author noted that each of the research designs can be used for exploratory, descriptive and explanatory research. Similarly, Saunders et al. (2007)

named ‘research design’ as ‘research strategies’ in the ‘research onion’ and identified seven strategies: experiment, survey, case study, action research, grounded theory, ethnography and archival analysis. Furthermore, Bryman (2004) stated five research design types: experimental, cross sectional, longitudinal, case study and comparative study. Equally, Tan (2002) noted six common types of research design: case studies, surveys, experiments, co-relational research, causal-comparative research and historical research. Although there are several classifications to the research designs, Saunders et al. (2007) noted that no research design is inherently superior or inferior to any other and the selection will be guided by research question(s), objectives, the extent of existing knowledge, the amount of time and other resources available and the philosophical underpinnings. However, each research design has its own strengths and weaknesses and, therefore, requires an inclusive and pluralistic analysis of each research design to identify the one most suitable to address the research problem(s) in a given situation.

Creswell (2009) went further and divided the above-mentioned research designs/strategies into two categories, namely quantitative and qualitative. Qualitative research strategies explore the meaning that individuals or groups ascribe to a social or human problem through inductive reasoning, while quantitative research designs examine relationships among variables through a deductive reasoning approach (Creswell, 2009). Since this research study more appropriately fits into the inductive reasoning approach, after the problem formulation, as discussed in Section 3.3, qualitative research strategies such as ethnography, grounded theory, case studies, phenomenological research and narrative research seem more applicable. In ethnography, the researcher observes and studies the behaviour of the subject over a long period of time through participant observation (Saunders et al., 2007; Creswell, 2009). The researcher also actively engages in the social world being researched and the research process is flexible (Saunders et al., 2007). Grounded theory research discovers theory grounded in the participant views where the ‘research problem’ emerges from the first level of preliminary data collection (Saunders et al., 2007; Creswell, 2009). Phenomenological research inquires into the essence of human experiences about a phenomenon as described by participants (Creswell, 2009). Narrative research is a strategy of inquiry in which the researcher studies the lives of individuals and asks one or more individuals to provide stories of their lives (Creswell, 2009). However, case study research can be differentiated from the above four research strategies (ethnography, grounded theory, narrative research and phenomenological research) as it provides an in-depth investigation by studying ‘cases’

in an uncontrollable environment. Case study research investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 2003). This method uses multiple data collection techniques and allows a combination of both qualitative and quantitative data collection techniques (Yin, 2003; Saunders et al., 2007).

A case-study-based research design was selected for theory-testing and theory-building in this research study for several reasons. Firstly, ethnographic research design which requires the researcher to actively participate in the problem environment was considered unsuitable as the 'level of analysis' in this research focused more on organisational level and project level rather than the deeper individual or psychological level to explore the phenomenon of waste generation in healthcare projects across the whole building lifecycle. Secondly, grounded theory research design, which searches for research questions through a field study was disregarded, as grounds for this research study had emerged from the literature review findings rather than from the views of respondents. Thirdly, a phenomenological research design was ruled out as this research did not focus on developing patterns and relationships of meanings based on participants' experiences about a phenomenon. Finally, a narrative research design was considered inappropriate, as participants' stories about their lives were not necessary for context-setting in this research study.

According to the theoretical definition of Yin (2003), the case study method is "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". Also, case study research allows the use of multiple sources of evidence (data triangulation) when developing theoretical grounds and it is a preferred strategy when 'how', 'what' and 'why' questions are being posed (Yin, 2003; Saunders et al., 2007). It is an accepted research design when a holistic and in-depth investigation is needed. Moreover, Yin (2003) stated that a case-study design can be differentiated from other qualitative research designs as they allow theories to be developed prior to preliminary data collection. Considering all the above facts, case study research design was selected as the most appropriate qualitative research strategy for theory-testing and theory-building in this study. However, theories that are developed through case study research designs have certain limitations, one of which is a lack of generalisability. Hence, selection of study samples should be done carefully to minimise effects due to the above weaknesses.

As shown in Figure 3.2, Yin (2003) distinguishes case study strategies based upon two discrete dimensions: single case vs. multiple case and holistic case vs. embedded case. A single case is often used when it represents a critical or extreme or a unique case to observe and analyse a phenomenon. Conversely, multiple case studies can be used to observe patterns among similar cases and to generalise findings (Yin, 2003; Saunders et al., 2007). Yin's (2003) second dimension refers to the 'unit of analysis'. For example, if a whole organisation has been selected as the source of data on a certain phenomenon, it is called a holistic case. Conversely, if different departments/sub-units/work-groups in a single organisation are selected as different units, it is called an embedded case study (Yin, 2003; Saunders et al., 2007).

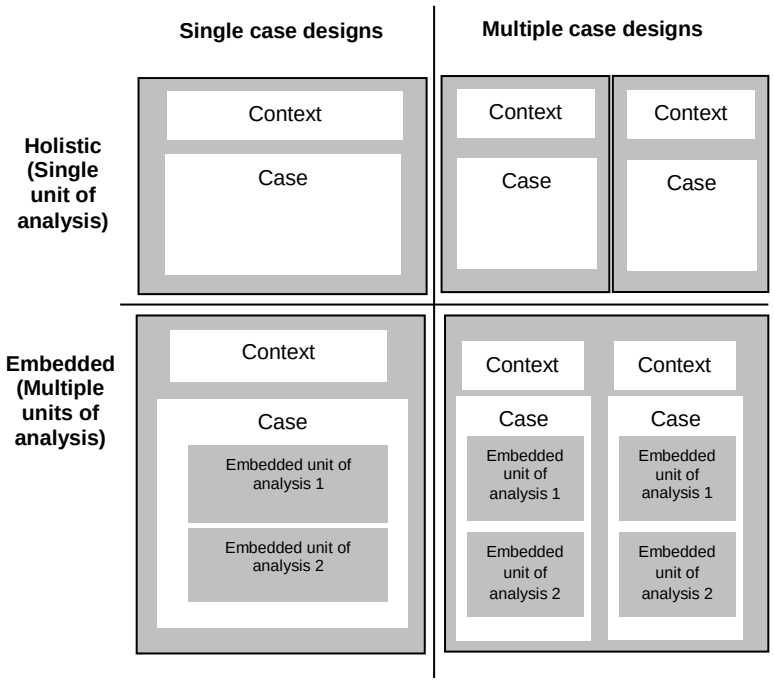


Figure: 3.2 Case study designs (Source: Yin, 2003)

In this research study, one healthcare project was considered as a single unit and thus a holistic case study design was used to investigate the phenomenon. In order to avoid limitations in case studies due to lack of generalisability, as discussed above, a multiple case study design was adopted. Hence, the case study design used in this research can be termed as a 'holistic, multiple case study'.

Once the research design was identified, the next step was to select the appropriate techniques for data collection and analysis. The next section in this chapter explains the total research process followed in this study based on the selected case study research design.

3.5 Research Process

Different authors specified different stages in the research process. According to Kumar (1999), a research process has eight steps: formulating a research problem; conceptualising a research design; constructing an instrument for data collection; selecting a sample; writing a research proposal; collecting data and writing a research report. A similar process to the above was specified by Sekaran (2003) as including six steps: broad problem identification; preliminary data gathering; problem definition; theoretical framework; hypothesis development and research design. Saunders et al. (2007) argued that even if the number of stages in a research process varies, it usually includes formulating and clarifying a topic, reviewing the literature, designing the research, collecting the data, analysing the data and writing up. Thus, the following sections describe the research process of the current study in line with the basic six-step process specified by Saunders et al. (2007).

3.5.1 Initial Impetus

The initial impetus to conduct a research study generally emerges through the interaction between the researcher's previous experience, the desire to learn and an available opportunity (Remenyi et al., 1998). This research study is part of Engineering and Physical Sciences Research Council (EPSRC) funded project entitled Health and Care Infrastructure Research and Innovation Centre (HaCIRIC). The HaCIRIC project has four collaborative research centres: Loughborough University; Salford University; Reading University and Imperial College. The whole project has seven themes and the Loughborough University theme was 'innovation in facility design and construction processes'. Six research projects were formulated under the remit of Loughborough University, and the broader area stimulated through this PhD study was creating a sustainable built environment: a new approach for healthcare resilience, energy and waste management'. However, the objectives of the PhD research significantly differed from the research project objectives and thus, it was conducted individually by the PhD researcher.

Having identified a broader research area with a contemporary issue in the construction industry, the research study moved to a comprehensive literature review to identify a specific knowledge gap and a researchable problem for this doctoral study (see Chapter 2).

3.5.2 Literature Review

A literature review is the "documentation of a comprehensive review of the published and unpublished work from the secondary sources of data in the areas of specific interest to the researcher" (Sekaran, 2003). A comprehensive literature review enables the researcher to identify the current state of knowledge particular to a topic to ensure that the previous findings have not been found repeatedly. Hence, an extensive literature review was carried out in the process of understanding lifecycle construction waste generation in healthcare projects. The literature review started with a background study, which was further expanded to identify the knowledge gaps after defining the research problem. The findings of the extended literature review are presented in Chapter 2 of this thesis.

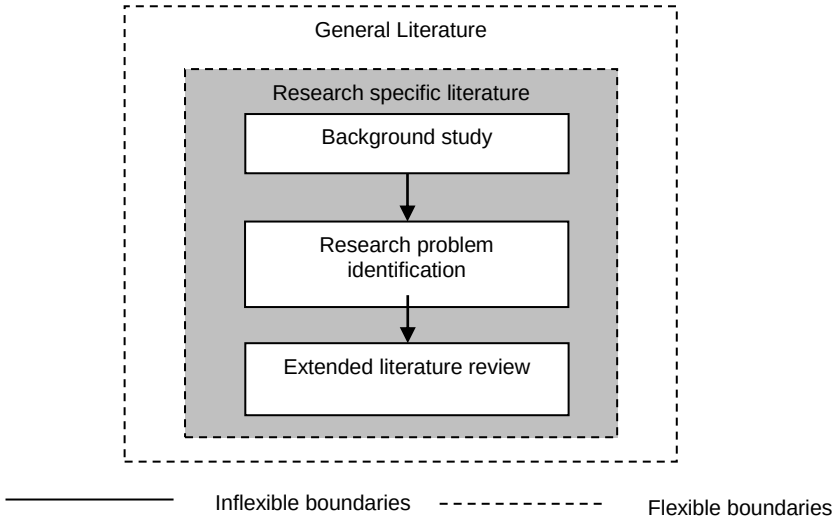


Figure 3.3: Literature review process

Hart (1998) emphasised that a literature review should possess several qualities such as: appropriate breadth and depth; rigour and consistency; clarity and brevity and effective analysis and synthesis. With the aim of maintaining these qualities in this literature review, firstly, a careful literature search was carried out using journal articles, conference papers, web publications (i.e. BRE, CIRIA), government reports (i.e. NHS, DH) books and theses that were available in the online databases (i.e. Emerald full text search, Science Direct, Zetoc search, ArticleFirst) and in the University library. The search was carried out using a 'snowball' technique in which the search was gradually extended through the references and key authors within the already found literature. The keywords used in searching the literature were 'sustainable construction', 'construction waste' 'healthcare construction' and 'construction waste minimisation'. Even though the search mainly included publications related to construction, the search was carried out in general fields to triangulate the theories. In addition to the above

keywords, the literature search was carried out on ‘research methodologies’ to identify philosophical positions, research approaches, research designs, data collection and data analysis techniques, giving particular attention to identifying the most appropriate research design to adopt in this research study.

Secondly, the searched literature was grouped into three categories (sustainable construction, construction waste and healthcare construction) and saved into three different folders, including several sub-folders within each folder for easy future reference. These references were then read and relevant publications were summarised for future consideration. Moreover, references were recorded in the Endnote software under the categories of ‘sustainable construction’, ‘construction waste’ and ‘healthcare construction’.

Thirdly, the selected and clarified literature was analysed and interpreted around the key themes (i.e. importance of waste minimisation to sustainable construction, causes and origins of waste, complexities in healthcare projects, best approaches and strategies for construction waste minimisation etc.) in this research. Once the data was organised around these key themes, summaries and gaps were identified and updated. This process initially analysed a broad area of literature related to this study, and progressively narrowed it down, while exploring and identifying existing knowledge gaps. Hence, this process adopted the funnel concept, specified by Remenyi et al. (1998) to narrow down the literature synthesis, where the wide end represents the general field of study and research problem identification denotes the narrow end of the funnel (See Figure 3.4).

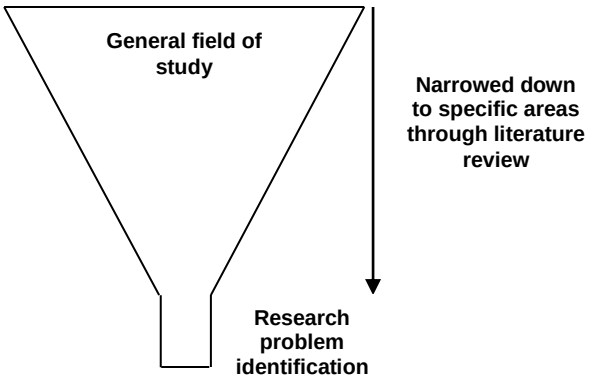


Figure 3.4: Funnel approach to literature synthesis

However, this literature review process did not follow a very smooth path. Instead, literature searching, evaluation and analysis encountered problems such as dead ends.

For example, literature provides no clear evidence about the effect of complexities in healthcare buildings for construction waste generation even though the literature more commonly referred to healthcare buildings as “complex” and “different” (see Section 2.8). Hence, this literature review failed to fully articulate the research problem and thus, a preliminary data collection study was recommended.

3.5.3 Preliminary Data Collection

As discussed in Section 3.5.2, a preliminary data collection study was undertaken to obtain a clear view on the construction waste generation issue in healthcare projects to clearly identify the research problem while providing firm grounds for the main data collection study.

Preliminary studies were useful when exploring or searching through a problem or situation to provide insights and ideas as it was particularly helpful in breaking broad, vague problem statements into smaller, more precise, sub-problem statements (Zikmund, 2000; Naoum, 2001). The available literature did not clearly indicate the most suitable approach to minimise construction waste from healthcare projects, the particular causes and origins of waste in healthcare projects and the ways in which the complexities in healthcare projects affect construction waste generation (see Section 2.8). Consequently, a preliminary data collection study was conducted to address the literature limitations regarding healthcare-construction-waste-related data, and therefore establish a firm base for the research.

When the researcher has a limited amount of data or experience or knowledge about a research issue, an exploratory study is needed as the initial step to examine the feasibility of further study by indicating what might be relevant to study in more depth (Hart, 1998; Malhotra & Birks, 2000). Additionally, explanatory studies allow the researcher to define the problem more precisely, identify relevant courses of action, or gain additional insights before going on to confirm further findings. The exploratory study can be based on a single investigation or a series of informal studies to provide the background information needed to form the foundation of a good research study through triangulation (Zikmund, 2000; Malhotra & Birks, 2000; Hart, 1998). Thus, an exploratory study was designed in this research to:

- Formulate research problems more precisely and establish a clear focus for main data collection;
- Build theories for the study;

- Clarify findings from the literature;
- Establish priority areas for the main data collection and to
- Increase the researcher's familiarity with the research problems and the practical difficulties of carrying out the research.

Selection of Interviewees

Interviews were selected as the most suitable method of collecting the required information, as the preliminary data collection study focused on a more generalised but in-depth investigation into the waste generation issues particular to healthcare construction. This study aimed to propose a lifecycle approach to reduce construction waste from healthcare projects since a growing body of literature clearly established the need for a further study to investigate a lifecycle approach to the minimisation of construction waste. Therefore, it was decided to conduct interviews with key stakeholders in the main lifecycle phases in a healthcare project, namely: client representatives (Estate Managers, General Managers), architects and contractor representatives (Project/Site Managers, Project Directors) with previous experience in healthcare projects with the aim of identifying construction waste generation issues across all healthcare project lifecycle stages. In addition to healthcare construction experience, interviewees' experience on other building projects was also considered as an important factor in the selection process, because the preliminary data collection study aimed to compare waste generation severity in healthcare buildings with other building projects.

This preliminary study consisted of nine interviews including: three interviews with client representatives, three interviews with architects and three interviews with contractor representatives. The interviews were conducted from December 2008 to March 2009. The architects and contractors for the preliminary data collection study were selected from the UK top 100 consultancy and contracting organisations having a good profile in healthcare construction. Additionally, to select suitable client representatives, Estates/Facilities departments in NHS trusts and Primary Care Trusts were contacted by telephone. Moreover, as per Yin (2003), geographical accessibility was given high priority when selecting the interviewees to increase convenient access. Thus, priority was given to the UK Midland regions. As a result, six NHS trusts, three Primary Care Trusts, eleven architectural companies and seven contracting organisations were contacted by phone to arrange the nine interviews.

Pre-interview Questionnaire Template and the Process

Before conducting the interview, a pre-interview questionnaire was sent to all the interviewees with two intentions in mind. Firstly, to save time during the interview to discuss 'why' 'what' and 'how' questions in detail (i.e. how healthcare complexities relate to construction waste generation; what are the best methods to reduce construction waste generation in healthcare projects and why?). Secondly, to minimise bias when interpreting and answering questions, this was highlighted by Yin (2003) as a major weakness in interviews.

The pre-interview questionnaire consisted of three sections: background information, causes of waste in construction in the healthcare lifecycle and waste minimisation practices in the healthcare construction (see Appendix 3.1). The questionnaire was tested using a pilot study before being sent to the interviewees. The pilot test helped to improve the quality of the questionnaire template by enhancing poorly worded questions and the questionnaire format (i.e. lack of spaces to record answers) (Fellows and Liu, 2008). Moreover, pilot testing helped to refine the questionnaire and eliminated problems in understanding and answering questions and improved the validity of the contents of the questionnaire and so improved the reliability of the data. This pilot study was carried out with four construction management researchers in the Civil and Building Engineering Department at Loughborough University who have worked in the construction industry as architects and project managers. As a result, two questions were re-worded to improve the clarity of the questions. Moreover, most of the respondents stated that they had to spend 20–30 minutes completing the questionnaire. This helped to determine the appropriate time required for a particular respondent to complete the questionnaire. The final version of the pre-interview questionnaire template (Appendix 3.1) was based on three revisions and a pilot study.

Interview Template and the Process

The aim of the interviews was to obtain further clarifications of the answers given in the questionnaire. Similar to the pre-interview questionnaire, the interview template also consisted of three sections: background information, causes of construction waste in the healthcare lifecycle and waste minimisation practices in the healthcare industry. A pilot interview was conducted with the two construction management researchers in the Department of Civil and Building Engineering at Loughborough University in order to enhance the clarity of the questions, assess the time required for each section, test the voice recording devices and act as a practice session prior to the actual interview

series. The final version of the interview template (Appendix 3.2) was based on three revisions. The first two revisions helped to improve the contents of the interview template to ensure that the questions covered all the issues to be discussed during the interview; whereas the final revision improved the clarity of the questions and the language. During the actual interviews, the time taken for each interview ranged from 45 minutes to one hour, with an average time of 50 minutes. Furthermore, the questions were mainly focused on obtaining in-depth answers. Thus, probing questions were asked as appropriate, based on the literature review findings and interviewees' responses, to obtain comprehensive answers.

All the interviews were recorded after obtaining prior approval from the interviewees. This helped to eradicate weaknesses while taking notes during the interviews such as data losses. The next section describes the main data collection process in this research study, which is the case-study-based interviews.

3.5.4 Case Studies

The findings of the preliminary data collection study revealed the importance of a further study to explore construction waste generation issues in-depth to: identify causes of waste that impact significantly on construction waste generation in healthcare projects; identify the relationship between healthcare complexities and causes of waste and identify the best waste minimisation practices to address causes of waste. Therefore, exploratory case studies have been selected as the most suitable method to collect data since case studies allow in-depth investigations of issues in real-life situations. The unit of analysis of the study was the case study. Considering the following factors, four case studies were selected for this research study.

Relevance to the context and generalisability: From the findings of the literature review and preliminary data collection, the two major healthcare building types in the UK were identified as being for primary care and acute care. Two case studies from each of the above types were selected to get a holistic view on waste generation from healthcare projects and to compare the similarities and dissimilarities within these two healthcare categories. In order to reduce lack of generalisability in case study designs, careful consideration was given to selecting healthcare projects with different characteristics (i.e. procurement methods, type of construction, site conditions) to enhance the ability of generalising findings to a wider population (see Table 5.1).

Access to data: Careful consideration was also given to the accessibility of data in all the project lifecycle phases when selecting case studies, since this study focused on a lifecycle approach to the minimisation of construction waste. For example, during the case study selection stage special attention was given to ensure that the three stakeholder groups: clients, architects and contractors, were willing to provide waste-related details in the selected case study.

Geographical accessibility: The geographical accessibility was also considered, as discussed in Section 3.5.4, when selecting case studies to increase convenient access during the data collection phase. Therefore, the first priority was given to the UK Midlands and followed by London.

In an exploratory case study design, Yin (2003) specified six methods of collecting data: document analysis; archival records, interviews, direct observations, participant information and physical artefacts. Table 3.3 illustrates the strengths and weaknesses for each data collection method.

Table 3.3: Strengths and weaknesses of data collection techniques within case studies (Source: Yin, 2003)

Data collection techniques	Strengths	Weaknesses
Documentation	• Can be reviewed repeatedly • Not created as a result of the case study • Contains exact names and details of events • Broad coverage of incidents over long duration and many events	• Retrievability can be low • Selection can be biased • Reporting can be biased • Limited access to documents
Archival records	• Same as above for documentation • Precise and quantitative	• Same as above for documentation • Accessibility due to privacy reasons
Interviews	• Can directly focus on the case study topic • Provide perceived casual inferences	• Can be biased due to poorly-structured questions • Response bias • Inaccuracies due to poor recall Reflexivity
Direct observations	• Covers events in real-time • Covers context of knowledge	• Time-consuming • Selectivity • Reflexivity • High cost

Table 3.3 cont.: Strengths and weaknesses of data collection techniques within case studies (Source: Yin, 2003)

Data collection techniques	Strengths	Weaknesses
Participant observation	• Same as above for direct observation • Insightful for interpersonal behaviour and motives	• Same as above for direct observation • Bias due to investigator's manipulation of events
Physical Artefacts	• Insightful for cultural features • Insightful for interpersonal behaviour and motives	• Selectivity • Availability

In case studies, initially, the use of 'documentation' and 'archival records' are disregarded when selecting the most appropriate data collection technique, due to the limited accessibility to all the necessary documents in the project lifecycle stages and limited opportunities to obtain in-depth answers on construction waste generation issues in healthcare projects through 'how' and 'why' questions. Also, there were limitations get all Secondly, 'direct observations' and 'participant observations' were considered inappropriate for this study due to the limited time period and the need to avoid bias in the data, as observations were reported by several authors to be highly vulnerable to researcher and participant bias (Easterby-Smith et al., 1991; Yin, 2003). Thirdly, the use of 'physical artefacts' as a source of data was overlooked since this study was felt to need a much deeper approach. Albeit the use of multiple sources of evidence enhances the richness of data due to the data triangulation opportunities in case study designs, this study collected data only through interviews due to the availability of information and the limited time available.

Interviews are appropriate when answers to questions require further clarification and illustration. Therefore, in case studies, interviews were adopted to collect data since it enables the researcher to obtain a high response rate and useful gathering of in-depth and supplementary information particular to the research study while providing opportunities to explain questions and provide any further clarifications (Kumar, 1999). Moreover, semi-structured interviews have been selected over the other two interview categories: unstructured interviews and structured interviews, because semi-structured interviews provide more flexibility to put questions to the interviewee to obtain in-depth answers than would be possible in structured interviews, and the questions were developed based on the findings of the preliminary data collection study results and thus were not unstructured. Moreover, semi-structured interviews are appropriate for understanding the relationships between variables (Saunders et al., 2007). Case studies also aim to identify relationships with healthcare complexities and causes of

waste and the best waste minimisation practices to address the causes of waste. Therefore, semi-structured interviews were considered as the appropriate data collection technique.

Selection of Interviewees

In order to represent the main lifecycle phases: the pre-design and contract agreement phase, the design phase and the construction/renovation phase; client representatives, architects and contractor representatives respectively were selected from these case studies to take part in interviews. The 'snowball' sampling technique was followed when contacting interviewees for the study to select the most appropriate interviewees form each phase in the project lifecycle to obtain reliable and essential information. Face-to-face, in person, semi-structured interviews were conducted to collect data in this study. However, for some interviews, several project partners attended for the interview representing one lifecycle stage. On those occasions, the interviews were conducted as group discussions where questions were put to all the participants and they collectively discussed their opinions and experiences. This has happened in four interviews (client representatives (1) and contractor representatives (3)) where the group of respondents attending varied from two to four people.

Interview Template

The interview template used in these case studies contained four sections: background information; causes of construction waste and their relationship to functional/operational features in the healthcare project; construction waste minimisation strategies and further thoughts. In this interview template, some questions were open-ended while in others findings from the preliminary data collection study were listed as options to be selected by the interviewee. However, these questions were not completely closed-ended questions since detailed explanations were obtained during the interviews by using probing questions. Pilot interviews were conducted with two construction management researchers working for the HaCIRIC project in the Department of Civil and Building Engineering at Loughborough University in order to enhance the clarity of questions, assess the time required for each section and to test the voice recording devices prior to the actual interviews. The final version of the interview template (Appendix 3.3) was based on five revisions.

Interview Process

After obtaining interviewees' consent for their participation in the interviews, a follow-up dissemination of the interview template was carried out (Appendix 3.3). This was sent to all selected interviewees at least one week prior to the scheduled interview date with

the intention of allowing interviewees to prepare for the interview questions and, importantly, aiming to gather a wealth of information relevant to the questions to be raised in the interview (Fowler, 2002). The interview schedule comprised: the aim of the research; the aim of this study; the interview agenda, clearly showing the time allocation for each section and the contact details of the researcher.

A conversational style was adopted to facilitate the discussion of topics during the interviews. To obtain clarifications and interviewee's opinions, further probing questions were posed to each interviewee. These probing questions explored issues emerging from the literature, the results of the preliminary data collection study, interviewees' answers during the discussion and the views of other respondents in the same case study. Each interview was audio recorded with the permission of the respondent, as the recorded interviews were very helpful at the analysis stage, through subsequent scrutiny and helped to ensure accuracy and objectivity in recording responses (Fellows and Liu, 2008). Additionally, an attempt was made to strictly follow the time allocation for each section when conducting the interviews and the duration of interviews varied from 50 minutes to 80 minutes. Approximately three months (from November 2009 to February 2010) were spent in conducting these twelve interviews (three from each of the four case studies). Figure 3.5 illustrates the interview process followed within each case study.

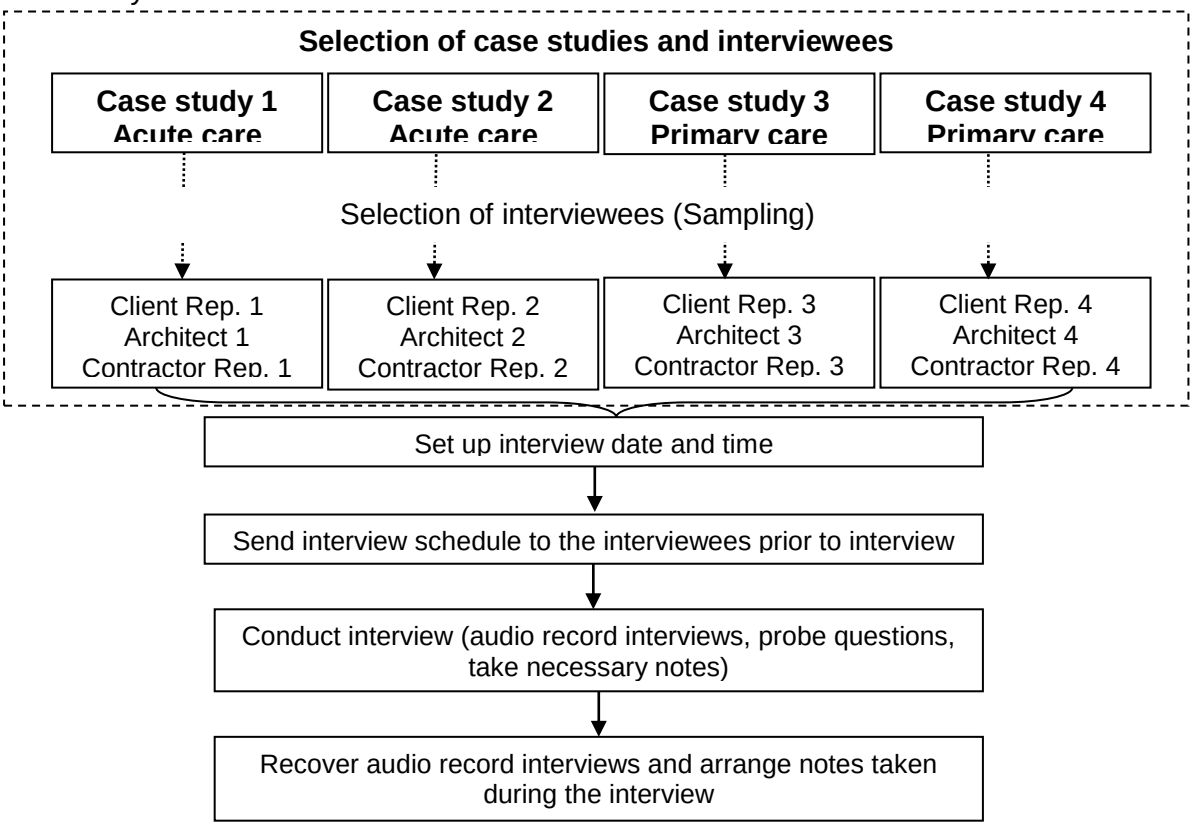


Figure 3.5: Interview process

3.5.5 Design and Development of HC-WMF

Once the data collection and analysis had been completed, the research focused on the design and development of the HC-WMF. The key findings from the preliminary interviews and case-study-based interviews clearly suggested that there is a need for a lifecycle construction waste minimisation method for healthcare projects. This was supported by the literature which provided no clear evidence of a process to follow when designing and developing lifecycle waste minimisation models or frameworks. A study conducted by Serpell and Alarcon (1998) used the construction process improvement (CPIM) method adapted from traditional problem-solving methodology to construction performance improvement through the reduction of waste and the elimination of non-value-adding activities. They also mentioned that the general problem-solving addresses a situation where what is happening is less than desirable, with the aim of rectifying the problem. Therefore, the basic concept for the HC-WMF design was also established based on the principles of general problem-solving methodology and followed the six-step process mentioned in the CPIM during the development of HC-WMF (see Section 6.2). The SAT was developed to monitor and evaluate the implementation of the HC-WMF to obtain feedback and learning outcomes from healthcare projects to ensure continuous future improvements. Figure 3.6 illustrates the methodological approach followed during the development of HC-WMF and SAT.

As shown in Figure 3.6, the HC-WMF development process consists of four main stages: stage one focused on the identification of the need for lifecycle waste minimisation for healthcare projects; stage two diagnosed the causes of waste in healthcare projects and the best waste minimisation strategies to implement in a healthcare project lifecycle; stage three focused on the design and development of HC-WMF, which was validated in stage four. Further explanations about HC-WMF design and development, their formats and contents are presented in Chapter 6.

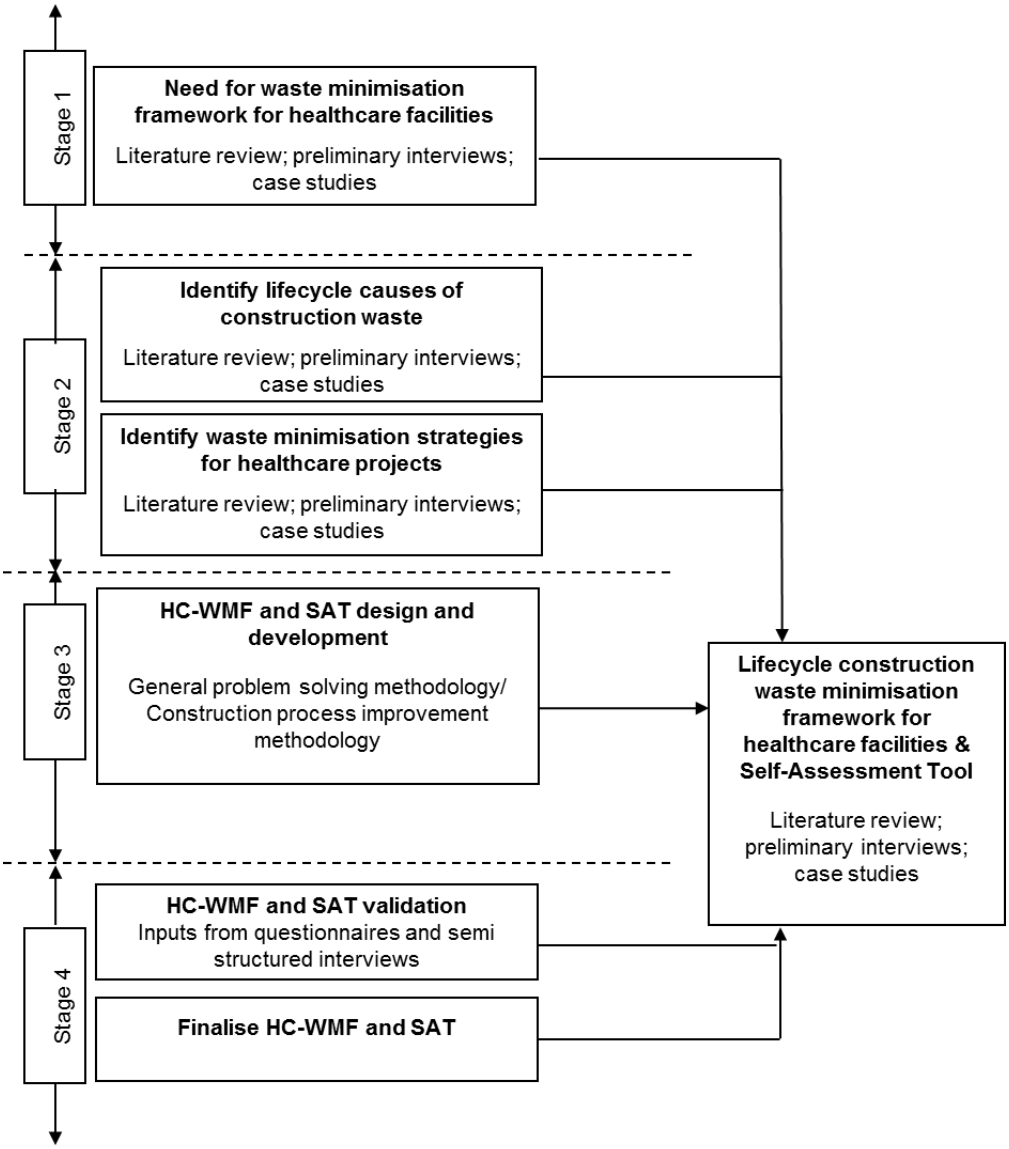


Figure 3.6: HC-WMF development methodology

HC-WMF Validation Method

The aim of the HC-WMF validation is to examine the appropriateness of the HC-WMF to reduce construction waste from healthcare projects and discuss its implementation process. The validation process focused on the clarity of the proposed HC-WMF, the importance of waste reduction strategies and activities that are embedded in the HC-WMF, the appropriateness of self-assessment procedures and a potential implementation strategy for the proposed HC-WMF. The HC-WMF validation process consisted of three stages, which are discussed in the subsequent sections.

Pre-Validation Process

The HC-WMF was discussed with four construction management researchers at Loughborough University working with the HaCIRIC project with the aim of refining the HC-WMF structure, language, clarity of contents and clarity of information flow. Additionally, these discussions focused on gathering further improvement suggestions from researchers based on their previous experience of developing frameworks and conducting validation studies.

HC-WMF Validation Questionnaire

The aim of the validation questionnaire was to improve the HC-WMF in terms of clarity, information flow and contents with regard to waste minimisation activities in each lifecycle phase (see Appendix 3.4). The questionnaire survey was conducted with 26 respondents who had participated in the data collection process in this research during preliminary data collection and case-study-based interviews. The composition of the respondents who have participated in this validation questionnaire is shown in Table 3. 4.

Table 3.4: Composition of HC-WMF validation questionnaire participants

Data collection study	Client representatives	Architects	Contractor representatives
Preliminary data collection	3	3	3
Case-study-based interviews	5	5	7
Total	**8**	**8**	**10**
Total respondents			**26**

The validation questionnaire was developed using Survey Monkey software and was conducted online as it is an economical method and facilitated the collection of data from a number of respondents scattered over a large geographical area in the UK during a certain period of time (Sekaran, 2002; Flower, 2002). This questionnaire consisted of three main sections: section one focused on HC-WMF validation; section two focused on SAT validation and section three focused on HC-WMF implementation strategy. The aim of first section was to determine the clarity of the framework in terms of structure, contents and waste minimisation process and information flow; the relevance of the suggested lifecycle phases to the implementation of waste minimisation activities; the relevance of the suggested waste minimisation strategies and waste minimisation activities to reduce construction waste generation from healthcare projects and to provide further improvement suggestions. The aim of section

two was to determine the clarity of the instructions and assessment method proposed in the SAT, the relevance of the scale and assessment procedure suggested and to elicit suggestions for further improvement to the SAT. The aim of section three was to identify potential implementation strategies for the HC-WMF and obtain further improvement suggestions. Other than open-ended questions, a five-point Likert scale was used to obtain the respondents' views on the HC-WMF.

Since this questionnaire was launched online, the link to access the online questionnaire was sent to participants through an email along with softcopies of HC-WMF and SAT. Additionally, the hardcopies of HC-WMF and SAT were sent to all the participants to make it easier for them when completing the questionnaire. This questionnaire survey was conducted over three weeks from October 2010 to November 2010. In order to increase the response rate of participants, two follow-up rounds were conducted during the questionnaire survey administration process (telephone calls and emails).

The data collected from the HC-WMF validation questionnaire survey was analysed using descriptive statistics as discussed in Section 3.6.1. Based on the questionnaire results, some improvements were made to the HC-WMF as discussed in Section 6.2.4.5.

HC-WMF Validation Interviews

Following the HC-WMF validation questionnaire, four semi-structured, face-to-face interviews were conducted with the contractor's Project Managers who have experience in working in healthcare projects. Moreover, all these four interviewees were new to this research study. During the selection of interviewees, project managers who were external to the previous studies were selected for two main reasons:

1. To obtain views about the HC-WMF from the stakeholders who are responsible for implementing HC-WMF and to carry out a self-assessment according to the validation questionnaire results, and

2. To establish the external validity by selecting interviewees who had not participated in the research study during the data collection stages (preliminary study and case studies).

The HC-WMF validation interview template consist of two sections. The first section aimed to examine the appropriateness of the proposed HC-WMF and identify a suitable

implementation strategy for the HC-WMF. The second section aimed to examine the appropriateness of the proposed SAT and identify an appropriate method to perform the self-assessment (Appendix 3.5). The time allocation for the interview was 60 minutes and the proceedings consisted of: introduction to the HC-WMF and SAT (5 minutes); HC-WMF implementation (25 minutes); SAT implementation (25 minutes) and further thoughts (5 minutes). Four interviews were conducted over approximately three weeks from December 2010 to January 2011. The qualitative data gathered through semi-structured interviews were analysed using the constant comparative method as discussed in Section 3.6.2. The data generated through semi-structured interviews was used to improve the HC-WM and SAT by amalgamating corrective actions and the changes proposed during the semi-structured interviews.

3.6 Data ordering and Analysis

3.6.1 Quantitative Data Analysis

Even though this study mainly collects qualitative data through semi-structured interviews, there were a few questions in the pre-interview questionnaire and HC-WMF validation questionnaire that generated quantitative data. The quantitative data generated from these two questionnaires had different scales of measurement including: interval/ratios, ordinal, nominal and dichotomous. However, the main objective of the pre-interview questionnaire was to capture the broad views associated with construction waste generation in healthcare projects. Meanwhile, the HC-WMF validation questionnaire aimed to obtain views on the appropriateness of the HC-WMF to reduce construction waste generation from healthcare projects. Therefore, a simple and meaningful data representation approach was given priority. Mostly, descriptive statistics were used in this research to analyse data related to different questions. Descriptive statistics describe or summarise data that include counts (numbers or frequency); proportions (percentages); measures of central tendency (the mean, mode and median) and measures of variation (range and standard deviation) (Fink, 2006). However, while analysing data from the pre-interview questionnaire and HC-WMF validation questionnaire, computing counts (numbers or frequency) and proportions (percentages) were used as the appropriate method of reporting data. Therefore, the statistical analysis techniques considered in this study were non-parametric procedures. Moreover, all the quantitative data obtained in this research study was manually arranged with the support of Microsoft Excel 2007, without using any quantitative data analysis software like SPSS.

3.6.2 Qualitative Data Analysis

Most of the data collected in this research study through preliminary interviews, case-study-based interviews and HC-WMF validation interviews were qualitative data. Bogdan and Biklen (1982) defined qualitative data analysis as "working with data, organising it, breaking it into manageable units, synthesising it, searching for patterns, discovering what is important and what is to be learned and deciding what you will tell others". In the data-ordering and analysis stage of this research, the audio-recorded interviews were transcribed. This was done manually while listening to the audio-recorded interviews. Due to the open-ended nature of the interview questions, the data transcribed was of an unstructured nature consisting of data unrelated to the study, long paragraphs and similar concepts in different locations of the text. With the aim of arranging data in a manner that would give a general sense of the information while reflecting the overall meaning of an answer, each transcript was read several times, cleaned-up and the contents of the transcription organised into a proper order.

Then, the constant comparative method introduced by Glaser and Strauss (1967) was followed to analyse the qualitative data. The constant comparative method allows one to compare different pieces of data, refine or tighten up categories and move on to higher conceptual levels (Bryman, 2008, Tashakkori and Teddlie, 2009). During data analysis, data was treated as potential indicators of concepts and the indicators were constantly compared to identify the concepts with which they fitted best (Bryman, 2008). Glaser and Strauss (cited in Lincoln and Guba, (1985), p. 339) described the four distinct stages of the constant comparison method as follows:

1. Comparing incidents applicable to each category,
2. Integrating categories and their properties,
3. Delimiting the theory, and
4. Writing the theory.

However, the data analysis phase in this research study followed only the first two steps named by Lincoln and Guba (1985) as ‘unitising’ and ‘categorising’ the data. During the ‘unitising’ process, narratives given by the interviewees were divided into the smallest pieces of meaningful information under each interview question. For example, the underlying reasons for the origination of waste due to healthcare construction drawings were identified during the data collection studies in this research. These were referred to as ‘units of information’ and were initially given tentative names

for easy reference. However, during the process, these names were more appropriately modified/replaced to increase clarity and to avoid repetition. Subsequently, during the 'categorisation' process those units of information that related to the same content were brought together. During the categorisation process, careful consideration was given to maintaining the internal consistency while creating entirely mutually-exclusive groups. Figure 3.7 shows the qualitative data analysis process.

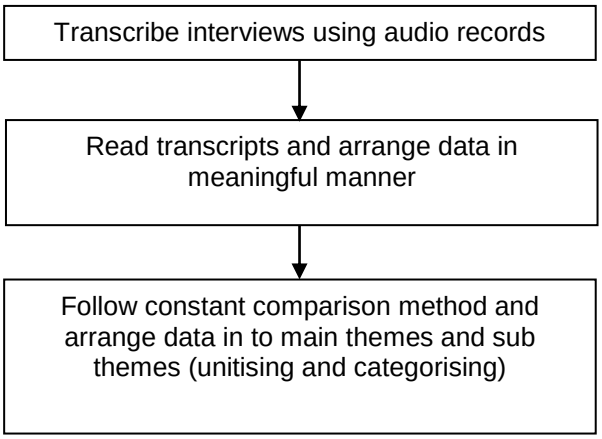


Figure 3.7: Process of qualitative data analysis

Since most of the interview questions were prepared either based on the findings of the literature review and the preliminary data collection, the investigated issues were mostly distinct to others. This simplified the data 'unitising' and 'categorising' process and therefore, the entire data analysis process was carried out manually without using qualitative data-analysis software. Microsoft Excel 2007 was used for data storage and manipulation purposes.

3.7 Data Validity and Reliability

Research 'bias' is a key concern in both quantitative and qualitative research studies since it affects the validity and reliability of research findings, and consequently deviates from true findings. Most of the possible causes of research bias might arise due to inaccuracies in the research design, administration and reporting processes. Thus, substantial attention should be given by the researchers to cope with effects of bias on research outcomes to ensure validity and reliability of research outcomes. In this research several measures were adopted to enhance the validity and reliability of the research outcomes. This section examines the validity and reliability measures in this research.

3.7.1 Reliability

Reliability is concerned with whether alternative research would reveal similar information (Easterby-Smith et al., 2002; Bryman, 2003). The goal in establishing reliability is to minimise errors and biases in a research study (Yin, 2003). In qualitative research, reliability may lead to concerns due to lack of standardisation in the data collection process (Saunders et al., 2007). A number of authors highlighted that the interviewer's bias due to his/her comments, tone and verbal behaviour adversely affect the reliability of the data findings (Yin, 2003; Saunders et al., 2007). Hence, Yin (2003) suggested following a properly documented procedure to establish the reliability of the findings. With the aim of establishing the reliability of the findings in this research study, the documentation procedure followed during the preliminary data collection stage, the case study stage, the HC-WMF validation stage and the data ordering and analysis stage has been described throughout this chapter (See Sections 3.5.3, 3.5.4 and 3.5.5). Moreover, during the preliminary data collection study, a pre-interview questionnaire was sent to the interviewees prior to conducting the interviews, to eliminate data bias due to interviewer influence as described in Section 3.5.3.

3.7.2 Validity

Validity is the degree to which the researcher has measured what he/she has set out to measure and its strength in qualitative research (Creswell, 2009). Unlike in quantitative research, where the researcher has statistical methods to check the validity of the research findings, in qualitative research studies ensuring data validity is challenging. However, the extent to which the data is valid in a qualitative research determines the accuracy of research outcomes (Creswell, 2009). Hence, qualitative researchers employ certain procedures to establish the accuracy of the research findings. Table 3.5 shows the measures that were taken in this research to ensure the validity of the data.

Even though this research had taken a number of initiatives throughout the research study to establish reliability and validity of the research out comes, the nature of qualitative studies limits the ability of the researchers to comment on the degree to which the research outcomes are accurate. Therefore, it is worthwhile in qualitative studies to identify and acknowledge the limitations relating to the validity and reliability measures of the research outcomes (See Section 8.4).

Table 3.5: Data validity improvement measures

Validity Improvement Techniques (Sources: Patton, 2003; Yin, 2003; Creswell, 2009)	**Actions taken in this research**
Comprehensive documentation of data collection and analysis procedure	• Used well-structured questionnaires and interview templates for data collection to make sure that all the important areas discussed during the interviews. • Audio recorded and transcribed all the interviews conducted to collect data during preliminary study, case study and HC-WMF validation study to make sure that all the important information provided by the participants is captured correctly. • Checked transcriptions several times to make sure that they do not contain mistakes made during transcription.
Triangulation	**Methods triangulation:** Check out the consistency of findings using different data collection methods. • Adapted different research methods including interviews, case studies, questionnaires and literature review **Triangulation of sources**: Check out the consistency of findings using different data sources. • Checked and compared findings of preliminary interviews, case studies, HC-WMF validation study and literature review findings. **Analyst triangulation:** Use multiple analysts to review findings • Not applied directly in this research since the PhD researcher mainly involved in the data analysis. • However, during the HC-WMF validation study, participants from the preliminary study and case studies were given opportunity to verify the findings. • External views were obtained from healthcare contractors during the HC-WMF validation interviews apart from the participants who involved to the study during the preliminary data collection and case studies. • Reviews from PhD supervisors, progress assessments from internal examiners at the end of first year and second year, and comments on refereed conference papers were considered as external expert views. **Theory/Perspective triangulation:** Use multiple perspectives/theories to interpret data. • Used perspectives of healthcare clients, architects and contractors throughout the study to compare perspectives of key stakeholders in healthcare construction projects throughout the project lifecycle.

3.8 Summary

This chapter examined the research methodology adopted in this research study to achieve its aim and objectives. It has given an overview of the literature on research

philosophy, research approaches and research designs while explicitly mentioning the adopted research methodology including its philosophical stance, research approach, research design, data collection methods, data analysis process and techniques, validation process and validity and reliability measures.

The research has been founded on a pragmatic philosophical stance and adopted a combination of both the deductive and inductive approaches. A preliminary data collection study has been carried out using a pre-interview questionnaire followed by semi-structured interviews to fill the knowledge gaps in the literature to establish a firm base for the research. Face-to-face, semi-structured interviews based on case studies were conducted for the main data collection in the study. Basic concepts of the problem-solving methodology were considered for the development of the HC-WMF. A questionnaire and semi-structured interviews were conducted to validate the developed HC-WMF. The chapter also explained the data collection processes including the selection of interviewees, preparation and contents of interview templates and questionnaires and pilot studies. In order to analyse the quantitative and qualitative data, this research study used descriptive statistics and the constant comparative method respectively. Finally, the chapter discussed the use of multiple data collection methods and multiple sources of evidence in this research study to establish the validity and reliability of the findings. The data analysis is presented in the subsequent chapters.

4

PRELIMINARY STUDY

4.1 Introduction

In the previous chapters, the literature review highlighted the fact that healthcare facilities are very complex buildings and suggested that further study is needed to identify the main issues related to waste generation and minimisation. A preliminary study was conducted by interviewing healthcare clients, architects and contractors with the aim of identifying particular causes of waste and best practice waste minimisation strategies for healthcare projects.

The aim of this chapter is to discuss the findings of the preliminary data collection study. It begins with the background information to the preliminary data collection study including methodology, study objectives and interviewees' background information. The chapter then proceeds to the results obtained from the study including: a comparison of healthcare buildings with other buildings in terms of waste generation; the special functional and operational features in healthcare buildings which affect waste generation; and causes of waste perticular to healthcare projects. The interviewees' views regarding the best waste minimisation practices for healthcare projects throughout the building lifecycle have been presented in the subsequent sections of this chapter. The results obtained from the preliminary data collection become the basis for case-study-based interviews which form the main source of data in this study as discussed in Chapter 5.

4.2 Study Background

The literature review discussed the importance of further research to fill the gaps in the literature and to establish a firm base for the research. A preliminary data collection study was conducted with nine interviewees: three healthcare clients (C1, C2, C3); three healthcare architects (A1, A2, A3); and three healthcare contractors (B1, B2, B3). This study had two data-collection stages. For the first step, a pre-interview

questionnaire was sent to all the nine interviewees to obtain a better understanding of their background information and the issues of waste generation peculiar to healthcare projects. Secondly, interviews were conducted with the same respondent group to discuss the answers given to the pre-interview questionnaire in more detail. Figure 4.1 illustrates the process of preliminary data collection with a clear indication of the objectives in each step.

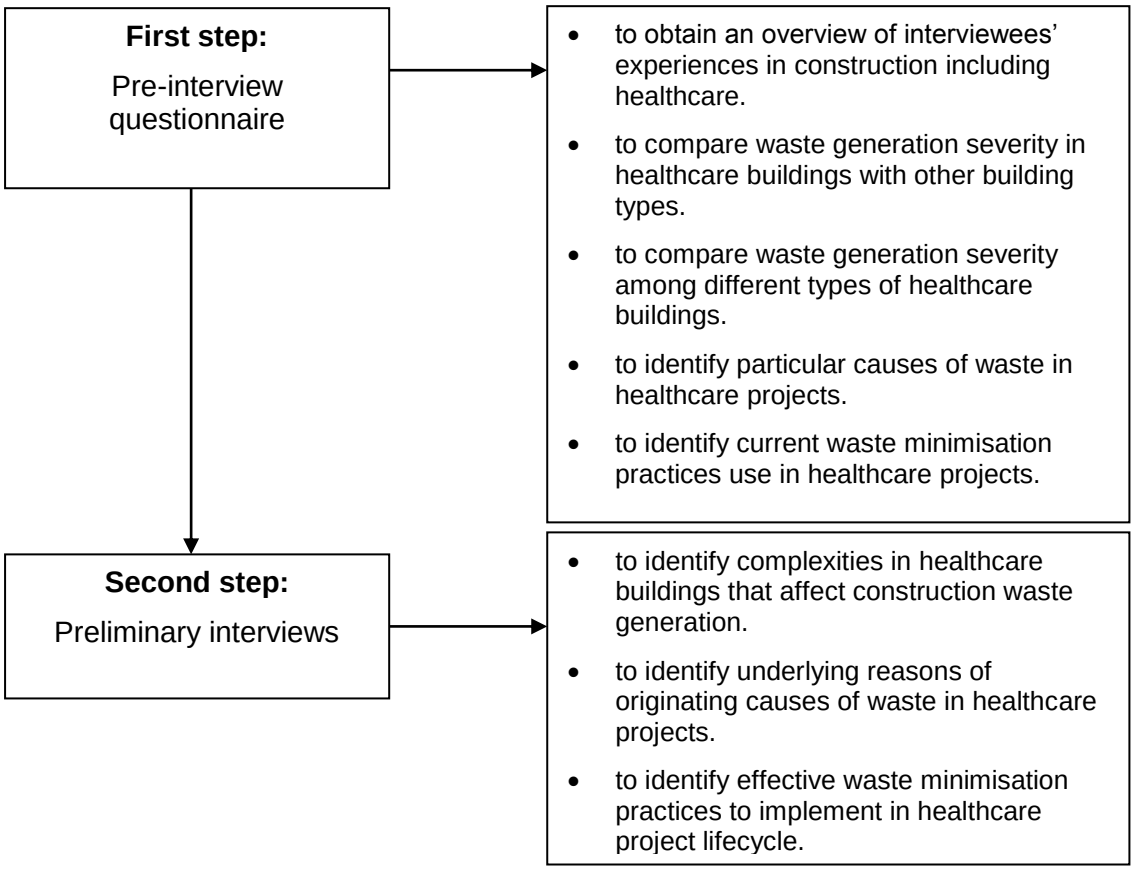


Figure 4.1: Process of preliminary data collection

4.3 Background of the Interviewees

The pre-interview questionnaire was sent to all nine interviewees as the first step of this preliminary study, as shown in Figure 4.1. In the questionnaire, respondents were asked to state their total work experience, experience in the construction industry and experience in the healthcare industry in order to obtain an idea about each respondent's healthcare experience and experience in other sectors. According to the results shown in Figure 4.2, all the respondents had worked in the construction industry from the beginning of their career with most of them (7 of 9) having more than 20 years work experience. It is also important to note that they all worked on healthcare projects for not less than half of their total career.

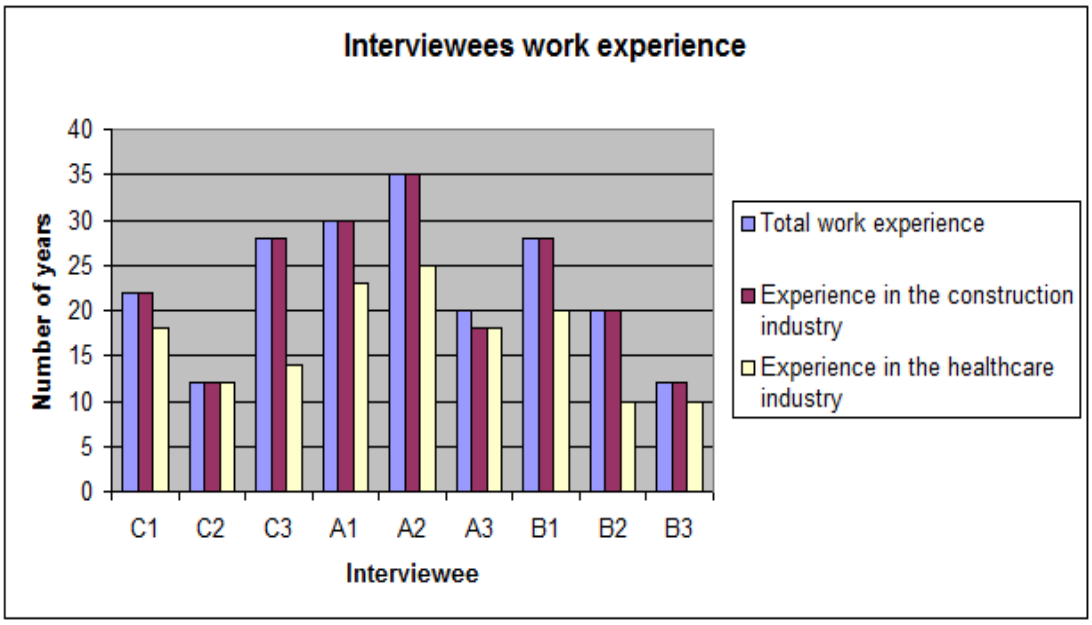


Figure 4.2: Interviewees' work experience

To avoid bias when comparing healthcare buildings with other building types, the interviewees were selected with experience in various building projects. Thus, in the pre-interview questionnaire, respondents were asked to tick all the types of building projects that they have worked on during their career and the results obtained are shown in Table 4.1. According to the results, more than two thirds of interviewees had experience in commercial, healthcare, hotel, industrial, office, residential and educational buildings.

Table 4.1: Preliminary interviewees industry experience

Type of building	Number of interviewees			Total Number
	Clients	Architects	Contractors	
Commercial	1	3	2	6
Healthcare	3	3	3	9
Hotel	1	3	2	6
Industrial	1	3	3	7
Office	2	3	2	7
Residential	1	3	2	6
Educational	1	3	3	7

4.4 Waste Generation in Healthcare

The interviewees were asked to rate waste generation according to their experience in commercial, healthcare, hotel, industrial, office, residential and educational buildings using a five-point Likert scale (1= No waste generation, 5= Very high waste generation) to recognise the types of buildings with high waste generation rates. According to the results, most of the respondents rated waste generation in healthcare buildings as either 'high' or 'very high; while allocating considerably lower rankings for other building projects (refer Table 4.2).

Table 4.2: Waste generation severity in different building types

Type of Building	No waste 1	Very low waste 2	Low waste 3	High waste 4	Very high waste 5	Total number of respondents
Commercial		2	3		1	6
Healthcare		1	1	5	2	9
Hotel		2	2	1	1	6
Industrial		3	3	1		7
Office			4	2	1	7
Residential			2	2	2	6
Educational		2	1	4		7

In addition, during the interviews, nearly all the respondents (8 of 9) highlighted "complexities in healthcare buildings compared to other buildings" as the main reason for generating high quantities of construction waste from healthcare projects, further confirming the findings of the literature review. The results also indicate that residential buildings and educational buildings also contribute significantly in generating construction waste, however, almost all (8 of 9) the respondents agreed that "healthcare buildings are more vulnerable in terms of waste generation than residential or educational buildings due to inherent complexities in healthcare projects".

According to the findings of the literature review, healthcare buildings can be broadly categorised according to two functions: acute care projects; and primary care projects. Since the healthcare sector in the UK has been investing in a large building programme including new constructions and refurbishments to both acute care and primary care facilities, this study further attempted to recognise the most vulnerable type/s of

healthcare projects in terms of construction waste generation. Hence, in the pre-interview questionnaire, the respondents were asked to rate waste generation in different types of healthcare projects according to their experience of past projects.

Table 4.3: Waste generation rate in healthcare projects

Type of Hospital Building	High				Medium				Low			
	C	A	B	To	C	A	B	To	C	A	B	To
New acute hospitals	2	1	1	4	0	2	1	3	0	0	0	0
Acute hospital refurbishments	1	1	2	4	0	2	0	2	0	0	0	0
New primary care buildings	0	0	1	1	0	3	1	4	0	0	0	0
Primary care refurbishments	0	1	2	3	0	2	0	2	0	0	0	0

(C= Client; A= Architect; B= Contractor)

The pre-interview questionnaire results revealed (see Table 4.3) that all types of healthcare projects, whether new constructions or refurbishments, generate medium to high levels of waste in both acute care and primary care projects. These results imply construction waste generation as a decisive factor for all healthcare projects irrespective of size or type. In the interviews the reason given by most of the respondents (8 of 9) for the high waste rates for all types of healthcare projects was the complexities in healthcare buildings. Explaining the above, during the interview, one architect reported:

> *"…. the more complicated the building is and the more complicated the building services are, there is more risk that there would be waste. I don't think you can make a great distinction between smaller and larger projects in waste quantities, all healthcare projects are complicated and service heavy…." (A1).*

4.5 Healthcare Complexities and Waste Generation

In-depth discussions were held during the interviews to reveal the complex features which lead to high waste generation from healthcare projects. These features were broadly categorised into two: functional features; and operational features. The following sections illustrate the ways in which these features increase construction waste generation from healthcare projects with the support of some examples taken from the interview transcripts.

4.5.1 Functional Features

In most healthcare buildings, each room has to perform a different function. Unlike other buildings, to perform these functions each room is required to maintain certain standards specified in healthcare building notes (HBNs) and healthcare technical memorandums (HTMs). Hence, most of the interviewees (6 of 9) argued that the complex nature of functions in adjacent rooms requiring different shapes, different sizes, different materials, different medical equipment and stringent environmental controls increases the quantities of waste during the facility construction. Explaining the above, one respondent reported:

> *"Complexity in a healthcare building is compounded by the variety of functions which can be undertaken in a healthcare facility and the fact that many of these functions are adjacent to each other and require different needs in adjacent rooms. One building may have different room types where each room requires complex equipment specification and co-ordination, strict environmental controls, different shapes and sizes. These could result in generating more waste compared to other buildings …." (C1).*

Moreover, some interviewees (5 of 9) stated that the identification of all the complex functions in a healthcare project is very difficult at the start of the project as multiple users with different priorities are engaged in the process, therefore, they have revealed the above as a reason for increased waste generation due to late changes in the client's requirements as requirement-identification is challenging issue at the very beginning of the project. Confirming the above, one contractor mentioned that:

> *"…. one building has to satisfy a lot of functional needs. Various users have various requirements. This makes it very difficult to capture all the user requirements at the very beginning of the project and, sometimes, users change their requirements very late in the project. These later changes in the client's mind ended up with huge waste arising...." (B3).*

Another most important feature highlighted by the interviewees related to waste generation in healthcare projects was the complexities in mechanical and electrical services. Almost all the respondents (8 of 9) confirmed this, declaring that waste generation was a result of the high density of materials use, rework, off-cuts etc. due to extensive services use. During the interview, one architect stated that:

> *"…. the amount of services required for healthcare buildings is greater than a normal building. Additional legislation/regulations etc. apply in healthcare*

and are required above the normal building regulations/H&S 1974 etc. etc. These can be stated as the most complex building forms I have been involved with due to the high building services installations, usually 60% M&E services, which in the main are 'life critical' and central to the efficiency of the building. This increases the density of materials going into the building, clashes between building elements, off-cuts etc. etc. which increase waste in other words.…" (A3).

Some interviewees (4 of 9) mentioned that healthcare buildings need specific materials for specific places to satisfy healthcare building regulations. Hence, respondents argued that it increases the density and the number of materials per m^2 of the building, leading to high waste compositions compared to other buildings of similar size. A contractor reported:

"…. healthcare has a high density of fit-out in relation to services, equipment and fixtures and fittings. Also, the use of special materials and a large number of materials to satisfy Healthcare Building Notes and Healthcare Technical Memoranda. When the density of materials in the building is high, density of work done in that area is also high. So there could be a high rate than in other type of a building due to high chances for damages…." (B2).

Other than the above-specified functional features, two interviewees specified the changing nature of the functional requirements from project to project limiting the use of past healthcare experience for future projects as another reason for high waste generation from healthcare projects due to the lack of opportunities for continuous improvements through past experiences.

4.5.2 Operational Features

As well as functional features, the interviewees revealed some operational features which lead to high rates of waste in healthcare projects. Almost all the respondents (8 of 9) confirmed that constructing/renovating a healthcare building in a live hospital site creates enormous complexities in site activities. They highlighted the requirements of emergency access roads, temporary accommodation for patients and staff, high-quality partitioning to avoid disturbances due to noise and dust etc., as grounds for generating waste in live healthcare sites due to inadequate storage facilities, temporary partitions and temporary accommodation for patients and staff. Highlighting the above, they

established the view that construction activities in a live hospital site produce more waste. One contractor reported:

> *"…. In healthcare, the construction process is often phased on live sites. Healthcare buildings with live wards need emergency access roads for emergency vehicles, a lot of temporary accommodation with all the service needs for patients and staff, quality finishes etc .etc…. Emergency access roads in most of the healthcare sites limit on-site storage facilities for materials….. Materials used for partitions and temporary materials often ended up as waste unless properly managed...." (B1).*

Since most of the healthcare buildings have to operate continuously throughout their lifetime and are subjected to high wear and tear all the time, most of the interviewees (6 of 9) stated that healthcare buildings generate a lot of waste throughout the lifetime of the facility due to unexpected maintenance and replacements unless good quality materials have been used initially and maintained appropriately throughout the building lifetime. In reporting the above, one client stated:

> *"…. the facility operates 24x7 and wear and tear is very high in the buildings. Systems are more complex. The level of finish required is high for infection control purposes. All surfaces should be cleaned far more than in any other type of building. They have to be more resilient. Lighting, heating and everything should be of high quality. Therefore, materials selection should be done suitably to avoid unnecessary replacements when the facility started its operation …." (C3).*

Also, a few interviewees (3 of 9) declared that healthcare buildings have to be adaptable and flexible for future changes to fulfil future management and user requirements. Since healthcare requirements change rapidly with improvements in medical technology, interviewees stated that healthcare projects generate high quantities of waste throughout the building lifecycle due to frequent modifications. In reporting this, one contractor said:

> *"…. healthcare has many different users and has 30-40 directors for a hospital with their own 'most important' lists. So we found it very difficult to identify and meet all the requirements. Also, medical treatment methods vary very quickly and the government issues new standards, new documents and new ward refurbishments where buildings have to upgrade to facilitate these. Because of these reasons, I believe there are high possibilities for changes throughout the lifetime of the building which generate waste throughout …." (B2).*

Referring to all the above statements, it can be said that complexities in functional and operational features in healthcare projects increase construction waste generation throughout the healthcare building lifecycle. Furthermore, it can be argued that causes of waste and their impacts on generating waste in healthcare buildings could vary from the generic causes of waste specified in the literature because of these special features. The next section of this preliminary study aimed to map the causes of waste particular to healthcare projects to distinguish them from the generic causes of waste specified in the literature.

4.6 Causes of Construction Waste in Healthcare Projects

In the pre-interview questionnaire, respondents were asked to tick the causes of waste particular to healthcare projects and the waste production rate of each waste cause based on their previous experiences in healthcare projects (see Table 4.4). In addition, detailed discussions of the respondents' views took place during the interview with the aim of obtaining explanations, reasons and examples for the answers given in the pre-interview questionnaire. However, the majority of the respondents (8 of 9) said that rating causes of waste according to their waste production rate cannot be done generally as could vary with factors such as site constraints, persons involved, time-scale etc. The following shows some comments made by clients, architects and contractors during the interviews to illustrate the above ideas.

> *"…. It's very hard to rate waste generation in a general sense, because these all could vary with site spaces, contractor waste attitudes etc.…" (C3).*

> *"…. rating could be different from project to project…." (A1).*

> *"…. I have no idea about the rate of waste production in general as this could slightly varies with the site constraints, project targets, complexities and sometimes with the available time as well.…" (B1).*

A further study was arranged to identify the most likely causes of waste in healthcare projects through real case studies. These are discussed in Chapter 5. Table 4.3 shows the number of respondents who have specified relevance to healthcare projects of causes of waste identified in the literature.

Table 4.4: Causes of waste in healthcare projects

Causes of waste	Relevant				Not Relevant			
	C	A	B	To	C	A	B	To
Pre-Design and contract agreement								
Inefficiencies in communication and coordination	3	3	3	9	0	0	0	0
Incomplete briefing	1	3	3	7	2	0	0	2
Lack of client's awareness of the construction process	1	3	3	7	2	0	0	2
Waste minimisation issues not embedded in the brief	2	2	3	7	1	1	0	2
Inconsistencies in the contract documents	1	3	3	7	2	0	0	2
Type of contract	1	3	3	7	2	0	0	2
Type of tendering	1	0	0	1	2	3	3	8
Design								
Lack of knowledge of alternative materials	3	3	3	9	0	0	0	0
Incorrect drawing details	3	3	3	9	0	0	0	0
Complex designs generating a lot of off-cuts	2	3	3	8	1	0	0	1
Over-/under-specification	2	3	3	8	1	0	0	1
Inefficiencies in the communication and coordination	2	3	3	8	1	0	0	1
Design changes	1	3	3	7	2	0	0	2
Delays in drawings	1	3	3	7	2	0	0	2
Lack of awareness about the waste generation in construction	2	2	3	7	1	1	0	2
Construction/Renovation								
Poor workmanship causing rework	2	3	3	8	1	0	0	1
Inefficiencies in the communication and coordination	2	3	3	8	0	0	0	0
Lack of a site waste management plans for every project	2	3	3	8	0	0	0	0
Material handling and storage facilities on site	2	3	3	8	0	0	0	0
Damages to materials during transportation	2	2	3	7	0	0	0	0
Ordering the wrong materials	2	2	3	7	0	1	0	1
Equipment malfunctioning causing rework	1	2	3	6	1	1	0	2

(C= client; A= architect; B= contractor; To= total)

4.6.1 Pre-design and Contract Agreement Phase

According to the study results, all the respondents (9 of 9) agreed that 'inefficiencies in communication and coordination' are a major cause of waste in the pre-design and contract agreement phase of a healthcare project. Since a large number of partners with highly varying requirements are involved in the process, interviewees said that they have experienced some misunderstandings among project stakeholders in their past projects, which later lead to the generation of considerably high quantities of waste.

> *"…. it is very hard to communicate with all the clients and end-users in healthcare projects. Healthcare projects are public projects. Even the general public can also influence the project requirements. In many cases we found it really difficult to identify all their requirements at the start of the project. This has resulted in some later changes to the drawings. With all these experiences, I believe communication is one of the major issues in generating waste in healthcare…." (A2).*

Additionally, seven (of 9) respondents acknowledged causes of waste such as: 'incomplete briefing'; 'client's lack of awareness of construction process'; 'waste minimisation issues not embedded in contractual clauses'; 'inconsistencies in the contract documents'; and 'type of contract varying the responsibility towards waste' could occur in the pre-design and contract agreement phase in any healthcare project.

As healthcare project requirements are large and very complex, the interviewees declared that the tendency to obtain an 'incomplete brief' from the clients is higher in healthcare projects compared to other buildings. In reporting the above, one architect stated that:

> *"…. healthcare project requirements are vast and complex. Different end-users have different requirements. They are not sure about what they want at the start of the project. According to my experience, incomplete briefing is a common issue in all healthcare projects.…" (A3).*

However, two clients (out of 3) held a totally different view to the above and argued that they always try to give as complete a brief as possible to the design team but designers' expectations are high and unrealistic.

Additionally, architects and contractors believed that 'clients' lack of awareness in construction' significantly affects the generation of waste in healthcare as they do not have knowledge about site activities and do not give priority to waste minimisation initially. The following comment by a contractor during the interview clearly explains the above.

> *"…. clients don't have knowledge about site activities. Most of them are doing it for the first time. Also, they don't think that they are responsible for minimising waste. So they don't care about these things at the start of the project where I think more opportunities are available…." (B2).*

Furthermore, most of the architects and contractors stated that clients do not usually attach sufficient importance to waste minimisation, assuming it to be a responsibility of the contractor; therefore, they agreed by 'not including waste minimisation clauses into

the brief' as a cause of waste in healthcare projects. During the interview, an architect explained:

> *"…. strategic level in the project does not think about waste minimisation. Waste minimisation responsibility is always with the contractor and it is very rare to see waste minimisation clauses in the brief. During my experience, I have never seen waste minimisation clauses in briefs...." (A1).*

Clients, however, held a contrasting view to the above and stated that waste minimisation is implied during the pre-design phase. They believed that it is not necessary to 'embed waste minimisation clauses' into the brief. Also, they believed that contractors are good at managing waste at site level even if it is not expressly stated in the brief. One client stated:

> *"…. waste minimisation in the pre-design is implied. Even if we don't expressly mention it, contractors and designers know that they should think of waste generation, energy minimisation etc. etc. Other than that, contractors are better in managing waste at site. Therefore, I don't think that not embedding waste clauses into the brief can make a huge impact on waste generation. Most of our current healthcare projects have partnering agreements and therefore all the project partners have equal responsibilities and they all get the benefits of minimising waste, energy etc. So they all work towards it…." (C3).*

Given the large number of project partners usually involved in the healthcare construction process, all the architects and contractors stated that healthcare projects have to handle a large number of documents, they thus revealed that they have experienced 'inconsistencies in contract documents' during their past projects. One contractor stated:

> *"…. a lot of people are involved in the healthcare process. It has large number of drawings, contract agreements, waste plans etc. Therefore, it is very difficult to cross check each document with others. Sometimes we forget to update all the documents when there is a change. In such cases we experienced waste due to inconsistent details…." (B1).*

However, clients stated that it is very rare to find 'inconsistencies in contract documents' in healthcare projects because of the use of partnering agreements where all the project partners have access to the latest information through back-to-back relationships and extranets between project partners.

> *"…. P21 and LIFT contracts have very few chances for inconsistencies. Project partners have back-to-back relationships, extranets to get latest information from the designers, contractors have access to the core data etc. Therefore, inconsistencies are very much less…." (C3).*

In addition to the above, all the architects and contractors agreed that 'the type of contract' affect waste generation in healthcare as it influenced different levels of responsibility towards waste. One contractor reported:

> *"…. I don't think there is a big difference. PFI might do that because the contractor is responsible for lifecycle maintenance. But, in P21 when the guaranteed maximum price is set up there is no incentive to minimise waste. In any contract, they give waste minimisation responsibility to the contractor either way. I think in traditional contracts like JCT, there is higher influence than P21 in terms of waste minimisation…." (B1)*

Views from the majority of the respondents (8 of 9) regarding the 'types of tendering' as a cause of waste in healthcare projects confirmed that it does not significantly impact on construction waste generation in healthcare projects. Respondents emphasised the use of integrated procurement agreements instead of traditional procurement methods as the main reason for not being a significant cause of waste in healthcare projects. A client illustrated the above as follows:

> *"…. healthcare projects do not normally use traditional tendering method. Therefore, percentage allowance doesn't matter in many healthcare projects as allowance for waste percentage is not critical during the bidding stage…." (C2).*

In addition to the above-mentioned causes of waste, two interviewees (of 9) stated that 'lack of concentration on adaptability and flexibility by the clients'; 'clients not willing to change their requirements to standard sizes'; and 'clients lack of knowledge about the materials available' significantly affect waste generation in healthcare projects.

4.6.2 Design Phase

As shown in Table 4.4, all the respondents (9 of 9) agreed that a 'lack of knowledge of alternative materials' very often leads to the generation of waste in healthcare projects. They also pointed out the extensive use of HBNs and HTMs to select materials in healthcare buildings as the major reason for the lack of use of alternative materials in healthcare projects to minimise waste generation. Confirming the above, one architect reported:

> *"There are a lot of health HBNs and HTMs published by the Department of Health. Designers have a lack of freedom to select alternative materials. On some occasions, these limit the chances to minimise waste selecting alternative materials ...." (A2).*

Healthcare project requirements are vast and complex; all the respondents stated that there are more opportunities to experience 'incorrect drawing details' in healthcare projects compared to other building projects. A contractor reported:

> *"…. healthcare requirements are very high. As a result, we have experienced wrong drawing details a number of times in some projects. But, most of the time we were able to avoid complications through early identification.…" (B1).*

As interviewees believed most of the healthcare buildings have many non-standardised interfaces, almost all of them (8 of 9) confirmed that healthcare projects generate considerably high amounts of waste due to the substantial amount of off-cuts within interfaces. During the interview one respondent declared:

> *"Healthcare buildings are very complex. Complex means that most of the areas cannot be standardised because of strict building regulations. This creates more waste due to off-cuts between different interfaces.…" (B3).*

Furthermore, most of the respondents (8 of 9) stated that they have experienced over-/under-specification since healthcare projects have to use a diverse range of materials to satisfy varying requirements within a building, which increases the difficulties in specifying all the material details completely at the very beginning of the project. Revealing examples for over-/under-specification in healthcare projects, one architect stated:

> *"We use a lot of materials in healthcare projects. Requirements are very different from one room to another in some buildings. Sometimes, clients don't have a proper idea about their requirements when starting the project. These kinds of situations more often result in over-/under-specifying materials.…" (A2).*

Additionally, except for one client, all the other respondents agreed that 'inefficiencies in the communication and coordination' during the design phase were a cause of waste in healthcare projects since significant amounts of design details have to be managed within a large number of design partners. Explaining the issues related to waste generation due to communication inefficiencies in healthcare projects, one architect reported:

> *"Communication problems are very common in healthcare projects. The project process has a very complicated system. We are not getting direct chances to communicate with end-users. So we get fewer opportunities to share their own ideas directly. This sometimes leads to inefficient design information sharing, resulting in incorrect drawing details, design changes etc.…" (A3).*

Other than the causes of waste mentioned above, most of the respondents (7 of 9) also stated 'design changes', 'delays in drawings causing time pressure during construction' and 'lack of awareness about the waste generation in construction' as causes of waste in healthcare projects.

From the interviewees' point of view, 'design changes' could be experienced in healthcare projects either due to later changes of mind by the clients or the large number of design partners involved in the process, which increases complications in identifying and communicating all the project requirements. During the interview, one contractor explained the above as follows.

> *"…. different people require different things in healthcare design. They all cannot be related and achieved. Also, when the construction proceeds, clients change their minds. In some cases, these changes are very critical. As an example, in one project, they have changed the purpose of the building. This was a very serious change and we had to investigate very carefully on the matter. It is really a big challenge to control design changes …" (B2).*

Even though most of the respondents agreed that there could be delays in submitting drawings in healthcare projects due to the bulky nature of healthcare design information and substantial amount of drawings used, the majority of them (6 of 7) emphasised that they have experienced very little waste due to the above fact. During the interview one contractor explained:

> *"…. there are lot of grey architectural frames in healthcare. We cannot proceed without them. Our work relies highly on their information supply. Any delay in their drawings could hit the programme overall. But we experienced waste very few times due to drawing delays…." (B1).*

Explaining the reasons for agreeing a 'lack of awareness about the waste generation in the construction process' as a cause of waste in healthcare projects, the respondents highlighted the unique nature of healthcare buildings and the low priority given by the

project partners to minimising waste as major reasons. Following are some of the quotations taken from the interview transcriptions.

> *"..... Healthcare project requirements vary from project to project. It is very difficult to judge one project based on previous experiences. Sometimes, the process is totally different. In such cases, it is very difficult to plan waste generation in advance…." (A1).*

> *"…. designers and consultants don't look at waste as a factor. They have knowledge. But they try to minimise waste only if client asked. Otherwise they only try to do the design within the set budget…." (B3).*

Other than the above, respondents pointed out causes of waste such as: 'not coordinating dimensions and sizes', 'wrong materials selection in the lifecycle', and 'not thinking about the best ways in design' as other relevant causes of waste in the design phase of a healthcare project. Illustrating the reasons for the above, interviewees highlighted the involvement of a large design team in a healthcare project as follows.

> *"…. healthcare design is a very complex thing. A large number of designers with several specialities get involved and need to communicate dimensions and sizes appropriately. In a few projects I have experienced inconsistent drawing details that create some waste. The root cause was inappropriate coordination of dimensions and sizes in the design team…." (A1).*

4.6.3 Construction Phase

According to the pre-interview questionnaire results shown in Table 4.4, most of the respondents (6 of 9) confirmed that 'poor workmanship causing rework', 'inadequate communication and coordination', 'lack of site waste management plans for every project', 'material handling and storage facilities on-site', 'damage to materials during transportation',' ordering wrong materials' and 'equipment malfunctioning causing rework' could cause waste in healthcare construction/renovation phases. However, they also highlighted that the above causes of waste generation vary tremendously from site to site and project to project depending on site conditions, project partner relationships and the level of priority given to waste minimisation in the project. Explaining the above during the interview, one client said:

> *"…. healthcare sites are different from one to another. Some sites have existing healthcare facilities. Site complications are high in those projects because operating a healthcare facility in a construction site is not like an office building or school building. They are very complicated. Waste*

> *minimisation in these projects depends on project partner attitudes and their level of priority towards waste minimisation ....” (C3).*

Since healthcare designs are complex and require high quality standards to be maintained as specified in healthcare building regulations, some interviewees (3 of 9) stated that healthcare creates significant waste quantities compared to other building projects due to ‘poor workmanship causing rework’. Confirming the above, one respondent stated:

> *“Healthcare buildings have to maintain certain quality standards as specified by the healthcare building regulations. Maintaining these standards is very important during healthcare construction. However, if these standards are not satisfied during the construction of the facility, we should re-do it until the required quality is achieved. This makes huge quantities of waste if work done at site not inspected appropriately .....” (B2)*

Additionally, almost half of the respondents (4 of 9) declared that in healthcare projects poor workmanship could occur due to ‘inefficiencies in communication and coordination’ during the construction/renovation phase. As a reason for the above, they emphasised the involvement of a large number of trades in a single site thereby limiting communication opportunities with and between trades and argued that this might increase rework due to clashes between trades. During the interview, one contractor reported:

> *“Inefficiencies in communication and coordination also increase rework in healthcare projects. In our projects, we sometimes experienced clashes between trades due to inadequate communication between trade contractors. Sometimes this happened because of the hurry to complete work…” (B3).*

Even though eight (of 9) respondents agreed ‘lack of site waste management plans’ causes waste in healthcare projects, they believed that its impact on waste generation would be minimal in future projects as government made it compulsory to prepare site waste management plans for projects exceeding a budget of £300,000.

Since healthcare projects have to use a large number of materials, almost all the interviewees (7 of 9) believed that waste generation is considerable in healthcare projects due to inefficiencies in materials procurement, transportation, handling and storing on-site. Confirming the above, respondents have made the following statements during the interviews.

"When the numbers of materials increase, damage during transportation and handling also increase gradually…" (B1).

"Extra attention should be given in healthcare projects to avoid wrong and over-ordering of materials because we have to deal with a large number of materials. Ordering the right material at the right time with the right quantity is a challenge always.…" (B3).

"… in a live hospital site, materials handling and storing should be given extra attention. Storage facilities should be planned well ahead considering emergency access roads, noise and dust levels etc. This sometimes encourages using offsite storing facilities in healthcare projects more commonly…." (A3).

Other than the causes of waste described above, some interviewees (4 of 9) highlighted 'lack of planning and organisation of site activities' and 'care and quality of trades used' as other major reasons for generating waste in healthcare projects.
Moreover, interviewees commonly believed that there is no significant difference between cause of waste in the construction and renovation phases of a healthcare project and stated that all the causes of waste mentioned above could occur in both construction and renovation projects. Nevertheless, four respondents acknowledged that in a renovation project, waste quantities due to the above causes of waste depend on the project stakeholders' awareness of the type and nature of the building, interfaces and materials in existing buildings and the potential for reusing materials.

4.7 Construction Waste Minimisation Practices in Healthcare Projects

In the preliminary data collection study, attempts have been made to identify the most appropriate waste minimisation practices for healthcare projects. With the aim of identifying waste minimisation best practices in healthcare, the respondents were asked to tick the waste minimisation practices used in their previous healthcare projects. Additionally, during the interview, the respondents were asked to mention the effectiveness of these waste minimisation practices based on their experience.

Table 4.5: Waste minimisation practices use in healthcare projects

Waste minimisation practices	Number of respondents
Pre-design and contract agreement phase	
Insert contractual clauses to enforce waste minimisation	5
Embed waste minimisation requirements to the brief.	3
Design	
Avoid late design changes	9
Early supply chain integration	7
Effective communication and coordination	6
Usage of offsite products and components	6
Adoption of low-waste modern building technologies.	6
Change management to reduce waste	3
Construction/ Renovation	
Adequate site supervision and control	9
Effective communication and coordination	8
Waste segregation, reuse and recycling	7
Regular site inspection for waste minimisation	7
Training and education on waste concepts to all staff	7
Effective materials control schemes.	5
Sub-contractors responsible for waste disposal.	5
Proper documentation of waste incidences on site.	4
Adequate planning and organisation of work process on site.	4

As shown in Table 4.5, the pre-interview questionnaire results clearly indicate that waste minimisation practices are not very commonly used in the pre-design and contract agreement phase of healthcare projects. Furthermore, a wide disparity among the views of clients and architects regarding the use of waste minimisation practices in the early stage of a healthcare project can be noticed with clients saying that "they often do it" whilst architects said that "they have never seen it". However, contractors believed that waste minimisation is an implied action in the pre-design and contract agreement stage. One contractor reported:

> *".... most clients don't say it directly in this stage. Generally, every client mentions automatically that you must be environmentally aware. So it is considered even if it is not mentioned directly in the contract or the brief…." (B1).*

Confirming the importance of avoiding late changes in the project as a very good way of minimising waste in healthcare projects, one architect reported:

> *".... as much as possible we try to avoid late changes in critical stages. I think in a healthcare project this is very important because its requirements*

are very high. So, if we failed to complete the requirements and the design before site activities it'll be a mess and generate a lot of waste…." (A2).

Most of the respondents (7 of 9) confirmed that they obtained early supply chain integration in healthcare projects where possible with the aim of customising products for the project. In explaining the above, an architect reported:

"..... we always try to get product manufacturers on board early because then we can customise products as required for the project. This helps a lot in minimising off-cuts etc. In healthcare projects, this is very easy to do because of contractor-lead procurement methods such as PFI, Procure 21 etc. Contractors already have their own suppliers and product manufacturers. This is very easy to implement in healthcare projects and I believe this is a very effective practice in terms of minimising waste …." (A1).

Additionally, they have stated the use of off-site products and low-waste modern technologies, such as modular construction, to be very effective methods of minimising construction waste in healthcare projects. They further believed these practices to be very good solutions to minimise waste generation due to complexities in shapes, sizes and services in healthcare designs, which increase off-cuts and clashes between elements. During the interview, one respondent noted:

".... healthcare buildings comprise complex shapes and sizes of elements and a large number of services. This makes healthcare construction very complex and increases off-cuts and clashes between elements. So use of modular construction units or off-site products would be a better solution …" (B3).

However, more than half of the respondents stated that they do not frequently practice 'change management procedures' to reduce construction waste in healthcare projects as healthcare requirements change rapidly throughout the building lifecycle limiting future predictions about user requirements.

"Very difficult to predict future changes in healthcare buildings because user requirements change rapidly throughout the building lifecycle. No experience about use of change management in healthcare projects. But of course we tried our best to reduce cost and waste as much as possible according to the situation. We don't plan this early…." (B3).

According to the pre-interview questionnaire results, it can be judged that waste minimisation practices are more commonly used in the construction/renovation phase

of healthcare projects as most of the respondents confirmed that they have used ‘effective communication’, ‘waste segregation’, ‘regular site inspection and supervision’, ‘training and education of staff’, and 'effective material procurement methods' to reduce waste generation in their previous healthcare projects. Moreover, the interviewees highlighted the importance of a proper coordination system among project partners throughout the project process to avoid sharing wrong information, as healthcare requirements are vast and very complex.

> *“Effective communication is very essential in healthcare not only in the construction phase but also from the beginning of the project because it has to handle a massive amount of detail within project partnerships. Any single miscommunication incident could lead to a huge amount of waste generation ….” (A2).*

Since healthcare projects require a large number of materials to satisfy healthcare building regulations as specified in HBNs and HTMs, interviewees declared ‘waste segregation into different categories’, and ‘effective material procurement methods’ to be very useful practices to minimise construction waste generation from healthcare projects. Furthermore, interviewees believed ‘regular site inspection and supervision’ is also an effective waste minimisation practice for healthcare construction sites to manage waste in a live hospital sites.

Other than the above, most of the interviewees believed that waste could be effectively reduced through enhancing the knowledge and morale of site staff with the use of training and education programmes. Most (6 of 9) of the respondents further argued that implementation of waste minimisation practices and their effectiveness varies from project to project depending on the project constraints. They also suggested further studies based on real-life projects to recognise the best places in healthcare projects to use each waste minimisation practice effectively.

4.8 Summary

This chapter has presented the findings of the preliminary data collection study. The preliminary study results disclosed that waste generation in healthcare buildings is higher than other building projects and confirmed that all the types of healthcare projects generate considerably high amounts of waste. The findings also revealed special functional and operational features such as: complex shapes and sizes of rooms; complex M & E services; large number of user requirements; high density of

materials use; special materials requirements; unique nature of healthcare projects; continuous operation of other live buildings on the site; high wear and tear of the building; and frequent changes required to facilitate future requirements, all increase waste generation in healthcare projects compared to other building projects.

According to the preliminary study findings, causes of construction waste in healthcare projects span over all the project lifecycle stages and are mostly similar to causes of waste discussed in the literature. However, findings disclosed some waste causes stated in the literature (i.e. type of contract, method of tendering) are not significant in healthcare projects in generation of construction; whereas, some waste causes (i.e. wrong materials selection, lack of adaptability and flexibility) tend to generate more waste over the building lifecycle stages. Also, the findings of the preliminary study showed a need for further data collection to identify the impact of waste generation from each cause of waste due to the complexities in healthcare buildings.

The findings indicated that the current healthcare construction projects more commonly use construction waste minimisation practices in the design and construction phases. However, the preliminary data collection demonstrated the need for implementing waste minimisation practices from the start of the project until completion highlighting the appropriateness of a lifecycle approach to reduce construction waste generation from healthcare projects. The next chapter presents the findings from the case studies.

5

CASE STUDY RESULTS AND ANALYSIS

5.1 Introduction

This chapter presents the data collected from the case studies. It begins with a brief introduction to the case studies including type of construction, nature of construction activities, procurement method, budget, construction period and importance for construction waste minimisation. The next section illustrates the causes of waste in the pre-design and contract agreement, design, and the construction/renovation phases in a healthcare project lifecycle, including their impact on waste generation based on the selected case studies. Thereafter, the chapter describes special functional and operational features in healthcare buildings which affect the construction waste generation illustrating the high-impact, functional and operational features which generate the causes of waste in each phase of the whole project lifecycle of a healthcare project. Finally, this chapter presents the waste minimisation strategies used in the pre-design and contract agreement, design and construction/renovation phases in selected case studies.

5.2 Overview of Case Studies

In this research, interviews were conducted based on four case studies, two were acute-care buildings and two primary care buildings. In each case study, three interviews were conducted with the client representative, architect and the contractor representative. The overwhelming majority of the client representatives were project leaders who were responsible for delivering the project within the budget. Architects were selected to represent the design phase, as they were responsible for leading other design partners to ensure lower-waste designs in these case studies. Contractor representatives were either site managers or project managers who were responsible for managing on-site waste in the selected case studies. The interviewees were asked

about the awareness of lifecycle waste generation in a particular healthcare project to identify their familiarity with the pre-design and contract agreement, design and construction/renovation phases. According to the results, it is important to note that all the respondents from each case study were either ‘very familiar’ or ‘familiar’ with waste generation in all lifecycle phases of the selected case studies.

The following sections briefly explain the background of each case study and Table 5.1 shows the characteristics of each case study.

5.2.1 CS1 Project

This project consists of two building programmes: development of a new acute hospital and the redevelopment of a cancer and cardiac centre. Overall, the building programme includes both new-build buildings and refurbishments to existing buildings. It is known as the largest hospital redevelopment project in the UK. Both of these sites are located in a very congested London city area. The redevelopment project has three phases:

- Completion of seven storey cancer services centre (2010);
- Completion of cardiac facilities and injuries unit (2014); and
- Completion of new car park, energy centre and refurbishment of existing areas (2016).

Similarly, the acute care project also has three phases:

- Completion of a seventeen storey tower to include clinical services (2012);
- Refurbishment of the wards (2014); and
- Completion of new medical records facility and multi-storey car park (2016).

5.2.2 CS2 Project

This project was an extension to an existing hospital located in Birmingham city centre including refurbishments to the existing wards. The new facility comprised a five storey building including an education centre on the ground floor, a burns unit on the third floor linked with the existing burns theatre, a plant room on the top floor and patient accommodation facilities on other floors.

5.2.3 CS3 Project

This project was a totally new-build healthcare facility in the Leicester city area which was built to accommodate primary care facilities such as GP centres, dental care centres, operating theatres, general consultation departments, mental healthcare

departments and restaurants under one roof. The total building has 6,100m^2 of internal floor area.

5.2.4 CS4 Project

This project was a totally new-build healthcare facility in Retford. The facility includes GP practices, community nursing, community mental health services, dietetics, minor-surgery facilities, counselling, physiotherapy, social services and pharmacies. Total internal floor area of the building is 5,241m^2.

Table 5.1: Characteristics of the case studies

Characteristics	CS1	CS2	CS3	CS4
Type of Healthcare	Acute care	Acute care	Primary care	Primary care
Nature of construction site	Live hospital site	Live hospital site	New site	New site (adjacent to a live hospital)
Procurement method	PFI	Procure 21	LIFT	LIFT
Budget	£1.2 billion	£12 million	£12.8 million	£10.5 million
Construction period	10 years (another 10 for Planning)	2 years	2 years	2 years

Results obtained from case-study-based interviews are presented in the following sections of this chapter. In order to maintain the confidentiality of the case studies, informants and their organisations, the following pseudonyms have been used within the texts (See Table 5.2). It is also important to note that all the interviewees participated in this study were exclusive from the preliminary study interviewees.

Table 5.2: Pseudonyms used for the respondents

Case study	CS1	CS2	CS3	CS4
Client	C1	C2	C3	C4
Architect	A1	A2	A3	A4
Contractor	B1	B2	B3	B4

5.3 Causes of Construction Waste in the Healthcare Project Lifecycle

Previously conducted preliminary data collection interviews identified those causes of waste which are particular to healthcare projects. One objective of this study was to identify causes of waste which impacted significantly on generating waste in these case studies, therefore, during the interviews, interviewees were asked to rank the causes of waste according to their impact on waste generation in the particular case study. Since no significant difference was noticed among the rankings given by the interviewees for causes of waste in the pre design and contract agreement phase, design phase and construction phase within acute care and primary care projects, a separate analysis was not conducted to identify similarities and dissimilarities within acute care and primary care projects. These findings were consistent with the findings of the preliminary data collection study where respondents argued that no great distinction could be noticed among the acute care and primary care facilities since complex features in healthcare facilities are common for all types of projects. Subsequent sections of this chapter describe the causes of waste in the pre-design and contract agreement; design and construction/renovation phases in a healthcare building lifecycle, together with their impact on the generation of waste (see Section 4.4).

5.3.1 Pre-design and Contract Agreement Phase

Findings from the preliminary data collection study highlighted nine causes of waste in the pre-design and contract agreement phase of healthcare projects. Thus, the interviewees were asked to rank the causes of waste according to the impact on waste generation in the particular case study (1 = highest impact on waste generation, 9 = lowest impact on waste generation). Based on the rankings given by the respondents during the interviews, a mean rank value for each cause of waste was calculated in all four case studies (CS1, CS2, CS3 and CS4 as shown in Table 5.3.

Results indicate that the impact on causes of waste such as ‘inefficiencies in communication and coordination’ and ‘incomplete briefing’ was extremely high in terms of waste generation in healthcare projects; whereas ‘waste minimisation issues not embedded in contractual clauses’ and ‘type of contract varying responsibility for waste generation’ have a considerably lower impact in the pre-design and contract agreement

phase of an acute or primary care facility. Subsequent sections illustrate the interviewees' rationales for ranking the above causes of waste.

Table 5.3: Causes of waste analysis in pre-design and contract agreement phase

Causes of waste – Pre-design and contract agreement	Mean Rank CS1	Mean Rank CS2	Mean Rank CS3	Mean Rank CS4	Mean Rank-Total
Inefficiencies in communication and coordination	1	1	1	1	1
Incomplete briefing	2	2	2	2	2
Clients are not willing to change their requirements to standard sizes	3	4	5	3	3
Clients' lack of awareness of the construction process	4	5	4	4	4
Lack of concentration on adaptability and flexibility by clients	6	3	2	6	5
Clients' lack of knowledge about the materials available	5	8	5	5	6
Inconsistencies in the contract documents	7	6	8	7	7
Waste minimisation clauses not embedded in contracts	8	9	7	8	8
Type of contract	8	7	9	9	9

5.3.1.1 Inefficiencies in Communication and Coordination

All the interviewees from all the case studies agreed that they have very commonly experienced inefficiencies in communication and coordination of briefing changes in these projects. As the reason for these inefficiencies, over half of them (7 of 12) highlighted the large number of users involved in the briefing process. Moreover, architects argued that they have had very limited opportunities to directly communicate with facility end-users to discover their requirements. This was mainly due to the selected procurement route (i.e. PFI, Procure 21 and LIFT) where the design team was appointed and given instructions by the principal contractor. Explaining the above, one architect stated:

> *"…in this project we were given instructions by the contractor. We did get very limited chances to directly communicate with the end-users of the facility. I could say that this intermediate involvement is a very ineffective method, especially when we are dealing with very complex buildings like healthcare where we, as architects, have to satisfy different end-user requirements..." (A2).*

Other than the above, most respondents (9 of 12) held the view that inefficient communication and coordination among parties in the decision-making process is

complex in healthcare projects due to the large number of partners involved. Explaining the complexities in the healthcare pre-design phase, one interviewee stated:

> *"…decision making is very difficult when the numbers of project partners are high. This makes the process complicated. If an important decision was not conveyed to all the relevant parties, there could be conflicts where some could generate waste. For an example, in this project there was a conflict between the contractor and the hospital management team due to waste storage on the site. The root cause is inefficient communication during the contract agreement process. However, we were able to come to an amicable settlement later..." (C4).*

Referring to the above complexities in healthcare projects, interviewees agreed that inefficiencies in communication and coordination during the pre-design and contract agreement phase have a great impact on the waste generation in healthcare projects**.**

5.3.1.2 Incomplete Briefing

The interview results clearly show that incomplete briefing is a very common cause that generates considerably high construction waste rates in healthcare projects. Almost all the interviewees (11 of 12) emphasised the difficulties in the task of capturing all the user requirements in the healthcare briefing process when the number of project partners with various requirements is high. In reporting this, one respondent stated:

> *"…in the case of a hospital there are nurses, doctors, patients, public etc. who specify the requirements of the design during the briefing stage. Different user groups have different requirements. Capturing all their requirements is not possible in the first instance and therefore we won't get complete briefs all the time. This is a common reality in most of the healthcare projects. When it comes to this project, I believe the briefing process is very good in the macro sense. But when it comes to the micro level, the detailed level, it was a little lacking…" (B1).*

5.3.1.3 Clients' Lack of Interest to Change Requirements to Standard Sizes

Even though very little difference can be noticed among the rankings in acute care and primary care projects, all the respondents specified that 'clients are not willing to change their requirements to standard sizes' has a considerably high impact on waste generation in healthcare projects. Eight of them (of 12) considered that clients are not given any real responsibility for waste minimisation by the legislation/contract, which reduces their interest in waste minimisation. This was illustrated by a contractor representative explaining:

> *"…As the principal contractor in this project, we were responsible for minimising construction waste. Clients are always interested in the budget not waste. They don't have any responsibility to do so as per the contract. Therefore, sometimes we found it difficult to convince them about less-waste techniques when the cost is high ..." (B3).*

Two respondents held a different view to the above and pointed out the complexities in the healthcare briefing process due to the different interests and different priorities among the client team over construction waste minimisation as the major barrier to them changing their minds about standardisation. For example, they have mentioned that the client's high expectations of the "aesthetic appearance" of the building lessen the chances for standardisation.

Other than the above, some architects (2 of 4) mentioned that healthcare designs are difficult to standardise due to the NHS design regulations such as HBNs and HTMs.

> *"…the standard sizes are set up in the design guides HBNS and HTMs. So these things come into the briefing process. Therefore, healthcare buildings are quite difficult to standardise…" (A4).*

Nevertheless, in the CS1 project, the project team had decided to allow 1% change to the critical dimensions given by HTMs and HBNs to optimise the use of standard sizes in the design.

5.3.1.4 Clients' Lack of Awareness of the Construction Process

Respondents had different views regarding the 'clients' awareness about the construction process'. Most of them (10 of 12) believed that the clients were not knowledgeable about the construction process and thus gave a considerably high ranking. A contractor representative reported:

> *"…Yes, I believe that clients are not that educated about the construction process. They are not even interested in how we are building it. They want it to be finished on time within budget. Some of their activities create waste ..." (B4).*

Two respondents held a totally opposite view to the above and declared that clients were aware about the construction process. Presenting a different argument to the above, an architect (A1) stated:

> *"….Actually, our client is the contractor of this project so they had good experience in construction. They actually looked at how efficiently they can*

do their work and how efficiently they can reduce the generation of waste in terms of time and material. Even through the client is not that experienced, the consortium directed us very well with their experience..." (A1).

5.3.1.5 Clients' Lack of Concentration on Adaptability and Flexibility

It is widely accepted in the literature and in the preliminary data collection findings that healthcare buildings need to be adaptable and flexible to facilitate future management and user requirements required by advances in medical technology. Hence, the preliminary data suggests that 'lack of concentration on adaptability and flexibility by the clients' is a cause of waste when constructing healthcare buildings. According to the findings from this study regarding the impact on waste generation, a slight disparity of views can be recognised within the same cluster: acute care projects and primary care projects. In one case study, it was ranked as being a high impact cause of waste whereas in the other case study it was given a very low ranking. The CS3 project architect, who ranked this as a high-impact waste cause stated that:

"…obviously healthcare facilities should be flexible and adaptable to cater for future changes. If these are not considered initially, there will be a high chance of generating waste throughout the building lifecycle …" (A3).

Illustrating the reasons for ranking 'lack of concentration on adaptability and flexibility by clients' as having less impact on the causes of waste in the CS1 project, all the three interviewees agreed it was an advantage of using the PFI procurement method. Since the principal contractor is responsible for maintaining the facility for an agreed period after construction, they believed that it is not necessary for the clients to concentrate on adaptability and flexibility. An interviewee reported:

"…This is a PFI project where the principal contractor is responsible for maintaining the facility for a certain period after construction. Our contractor is well-reputed in waste minimisation and they are very good in predicting lifecycle waste generation with their past experiences. Therefore, I don't believe that we should be aware of these…" (C1).

5.3.1.6 Clients' Lack of Knowledge about the Available Materials

This was identified as a lower-impact cause of waste by all the interviewees. Respondents stated that healthcare projects use contractor-oriented procurement routes most of the time, where the contractor, with his expertise and knowledge, has the opportunity to advise the other team members to select low-waste materials. A client representative illustrated this:

> *"…We get our supply chain early on through the main contractor. They were very good in selecting less wasteful materials. We didn't worry that much about materials selection ..." (C4).*

However, some interviewees believed that it was better to make clients knowledgeable about less wasteful materials because it is easy to convince clients about the selected materials. This was explained by an architect:

> *"…When the clients are knowledgeable about less wasteful materials and benefits of minimising waste, it is easy to convince them about our selections. Mutual understanding among team members is very important in complex projects like healthcare to smoothly run the project … Even I could say that the impact of waste generation is less because of early contractor involvement in healthcare projects, I suggest that it is important to make clients knowledgeable about less wasteful materials..." (A4).*

5.3.1.7 Inconsistencies in the Contract Documents

Respondents held contrasting views regarding the impact of 'inconsistencies in the contract documents' as a cause of waste in healthcare projects. Four respondents (of 12) stated that this had a considerably high impact. Illustrating their answers, respondents explained the difficulties of following contract documents all the time due to the use of standard contract documents that had not been customised for the particular project. They strongly believed that the use of standard documents increases discrepancies among project partners when the procedures are not expressly stated in the contract documents. Explaining the above, a contractor representative reported:

> *"…Inconsistencies in the contract documents is one of the biggest issues and it happens frequently. The main reason behind this is using standard contract documents without customising them to suit the project. In this project, we also used standard contract documents. Therefore, we took some decisions by ourselves when the contract was tacit. This is an obvious reason for waste generation…" (B3).*

Additionally, some respondents (5 of 12) pointed out the use of a large number of contractual documents (i.e. project brief, drawings and specifications, contract agreements) among large number of stakeholders in a healthcare project as root causes for inconsistencies in contract documents.

However, three respondents (of 12) explained this from a different point of view stating that there were no significant discrepancies in the contract documents since most of

the project partners had been involved in the project during the early stages and were allowed to refer to the necessary contract documents because of the partnering agreement. An architect reported:

> *"…This project was procured through P21, which is a partnering method. In this contract, everyone shared the same set of documents. Principal supply chain partners were involved in the process quite early on. I don't think that inconsistencies in contract documents were a major issue...." (A2).*

5.3.1.8 Waste Minimisation Clauses not Embedded in Contracts

According to the results, all the respondents gave a considerably low ranking to the cause of waste 'waste minimisation clauses not embedded in contracts'. However, they all believed that waste minimisation clauses should be integrated into the contracts between the main contractor and the trade contractors as well as the contract between the client and the principal contractor.

5.3.1.9 Type of Contract

All the respondents believed that 'type of contract' had the least impact on waste generation in healthcare projects and believed this impact to be inconsiderable. Since healthcare projects use contractor-lead agreements, all the respondents believed that the whole project team has the same responsibility towards waste minimisation. A client representative noted:

> *"…this is a partnering contract. The whole project team had the same responsibility to minimise construction waste. I don't think this had an effect at all in healthcare projects…" (C2).*

5.3.1.10 Affordability

Other than the above causes of waste, five interviewees (of 12) emphasised affordability as a cause of waste in healthcare projects. They highlighted that the clients do not give priority to minimising construction waste unless they can obtain a financial benefit. A contractor representative stated that:

> *"…I don't think that clients will say that I want a design which generates less waste. They are interested in all the clinical details and the budget because the risk of not minimising waste entirely lies with the contractor. We bear the cost. Therefore, unless waste minimisation is financially beneficial to the clients they won't be interested…" (B1).*

5.3.2 Design

According to the results of the preliminary study, eleven major causes of waste were identified in the design phase of healthcare buildings. During the interview, interviewees were asked to rank the causes of waste according to the impact on waste generation based on the particular case study (1 = highest impact on waste generation… 11 = lowest impact on waste generation). As discussed in section 5.3.1, the mean rank value for each cause of waste was calculated in all four case studies (CS1, CS2, CS3 and CS4). Table 5.4 shows the rankings of each cause of waste based on their impact on construction waste generation.

Table 5.4: Causes of waste analysis in design phase

Causes of waste –Design	Mean Rank CS1	Mean Rank CS2	Mean Rank CS3	Mean Rank CS4	Mean Rank-Total
Complex designs generating a lot of off-cuts	2	2	1	1	1
Design changes	1	3	2	4	2
Incorrect drawing details	3	4	3	2	3
Not coordinating dimensions and sizes	3	6	6	3	4
Inefficiencies in communication and coordination	5	1	4	6	5
Inappropriate selection of materials to lifecycle requirements	6	5	5	5	6
Over-/under-specification	7	9	7	7	7
Delays in drawings causing time pressure during construction	8	8	10	9	7
Lack of awareness about the waste generation in construction process	9	10	11	7	9
Not thinking about the best ways to design	10	11	9	10	10
Lack of knowledge of alternative materials	11	7	8	11	11

Even though rankings for the impact of these causes of waste on waste generation in selected case studies are very similar, it seems clear that ‘complex designs generating a lot of off-cuts’; ‘design changes’; and ‘incorrect drawing details’ are the high-impact causes of waste in the design phase in all four case studies. Interviewees gave considerably high rankings for the causes of waste such as ‘not coordinating dimensions and sizes’; ‘inefficiencies in communication and coordination’; ‘inappropriate selection of materials to lifecycle requirements’; ‘over-/under-specification’; and ‘delays in drawings causing time pressure during construction’.

Comparatively low rankings were given for the causes of waste such as 'lack of awareness about the waste generation in construction processes'; 'not thinking about the best ways in design' and 'lack of knowledge of alternative materials'. Interviewees' justifications for allocating these rankings were discussed in detail during the interview and are reported in the following sections.

5.3.2.1 Complex Designs Generating a Lot of Off-Cuts

Healthcare design complexities are widely discussed in the literature and this was further proven by the preliminary interviews as a high-impact cause of waste in healthcare projects. Moreover, all the interviewees ranked this among one of the highest, in terms of waste generation impact in healthcare projects. Several interviewees mentioned that the complex shapes and sizes required in healthcare buildings to fulfil building regulations as per HTMs and HBNs increases the number of off-cuts. In explaining this, an architect stated:

> *"…when designing a healthcare facility, we should strictly follow regulations published by the DH. The most difficult part in there is design standardisation. As you may know in healthcare even two adjacent rooms have to perform different functions, require different shapes, heights, finishes, services etc.." (A4).*

Respondents illustrated the complexities in healthcare sites due to existing buildings as another main reason for the increase in off-cuts, as new building designs have to fit with the existing buildings. In reporting this, a client representative stated:

> *"…The footprint of the site is very important in healthcare buildings because new buildings have to fit with the existing buildings in the site. Therefore, there were fewer opportunities to get the best design with minimum off-cuts..." (C4).*

While confirming the above argument, another client representative pointed out that designing buildings with irregular shapes and sizes was a major reason for increasing off-cuts. Further illustrating this with an example from the CS3 project, the interviewee explained:

> *"…The shape of the building actually generates more waste. According to my opinion, square is the best design shape for any building. This particular project had two wings. They were mostly square. But there were some rooms which had unusual shapes at one end of the building. This mainly happened due to the space availability on the site and the things we had done to enhance the design of the building. The balance between*

architectural shape and the waste has to be considered. The shape of the rotunda and the configuration of the roof had funny shapes and funny details and thus generated a lot of waste because of the complex details at the junctions. This building also had a number of courtyards to get natural lighting and ventilation. This makes the roof design more complex. We always like an exciting building, but not think of waste all the time…" (C3).

5.3.2.2 Design Changes

Around half of the respondents (7 of 12) linked 'design changes' with the pre-design phase cause of waste 'incomplete briefing' mainly highlighted as the underlying reason for late design changes resulting in large quantities of construction waste. Involvement of a large number of users in the building process leading to communication and coordination inefficiencies was highlighted as another reason for design changes. This was echoed by a reply given by an architect:

"…I could say that incomplete briefing is the major reason for later design changes. As I have said earlier, in healthcare buildings we have to listen to a large number of end-users. They have different wish lists. Some users are not exactly sure about their requirements. Therefore, in healthcare buildings we commonly experience later design changes. This is obviously an element of waste generation..." (.A3).

However, three respondents (of 12) explained this differently. They believed this to be a result of poor planning. Illustrating a real example from the CS1 project, a contractor representative reported:

"…design changes are mostly commonly happening because of the complexity. In this project, we decided to change the MRI scanner which was in the first floor with the CT scanner which was in the ground floor. Even though we've taken the most efficient decision, we should have planned this early rather than changing later. It was exactly the fault of our planning…" (B1).

5.3.2.3 Incorrect Drawing Details

The majority of the respondents (10 of 12) agreed that incorrect drawing details are a high-impact waste origin in healthcare buildings. They emphasised the complexity of healthcare design and the requirement for a large number of drawings as major reasons for incorrect drawing details in healthcare projects. In reporting this, one architect illustrated a real example from CS4 project:

"…definitely, incorrect drawing details had a larger impact because of the complexity of the design. Large numbers of designers were involved in this project and we had to review hundreds of drawings. In this particular project there was one major discrepancy in the drawing which generated a huge amount of waste…" (A4).

5.3.2.4 Not Coordinating Dimensions and Sizes

Little difference can be noticed in the rankings given for the cause of waste 'not coordinating dimensions and sizes' within the four case studies, two-thirds of the interviewees (8 of 12) declared that it is a frequently occurring cause of waste in healthcare projects. Explaining this, interviewees mainly highlighted the involvement of large design teams in the process, since this increases communication difficulties within the design team. Furthermore, one contractor representative linked this with the cause of waste 'inefficiencies in communication and coordination' and stated that:

"… in projects like healthcare, where the design team is huge, there should be a proper communication and coordination procedure between the design partners to coordinate design information effectively. Otherwise, a small mistake can lead to the generation of huge amount of waste…" (B2).

5.3.2.5 Inefficiencies in Communication and Coordination

In all the case studies, interviewees believed that 'inefficiencies in communication and coordination' impacted considerably on the generation of construction waste; indeed, in CS2 project it was given the highest rank. As discussed in section 5.3.2.4, nearly half of the respondents (5 of 12) strongly believed that inefficiencies in communication and coordination increase conflicts among design partners when sharing design information, which eventually results in incorrect drawing details, as explained by an architect:

"…communication issues are very common in healthcare projects because of the large number of design partners. We have experienced conflicts in design information when the design information sharing process is ineffective..." (A2).

However, three respondents (of 12), especially primary care respondents, had a different view to the above; they stated that communication and coordination inefficiencies are fewer in healthcare projects despite the large numbers of design partners involved. Respondents mainly highlighted the use of integrated procurement agreements like LIFT for reducing communication and coordination inefficiencies in healthcare projects. An architect stated:

"…I believe we had a very good communication procedure with other design members. We worked as a team from the beginning of the project. We met regularly. We had a lot of opportunities to share information…" (A3).

5.3.2.6 Inappropriate Selection of Materials to Lifecycle Requirements

Respondents gave a considerably high ranking to the cause of waste 'inappropriate selection of materials to lifecycle requirements'. Most of the respondents (8 of 12) stated that lifecycle consideration when selecting materials is very important in healthcare projects to minimise unnecessary replacements to maintain required building quality standards throughout the lifecycle. They further stated that even though they did not experience unnecessary replacements in selected case studies it could be a potential cause of waste in healthcare projects due to high wear and tear if adequate consideration was not given during the materials selection process.

Furthermore, some interviewees (5 of 12) stated that the client's lack of interest, and affordability as major limitations in healthcare projects in selecting materials according to the lifecycle requirements and they considered that it could lead to the generation of waste during the operational phase in the building. Reporting the above, an architect stated:

"…Some clients give priority to the initial cost rather than lifecycle cost. In that case, preference will go to selecting cheaper materials rather its lifecycle potential. In these situations, as architects, we find it very difficult to convince clients about the benefits. But, this varies from project to project depending on the relationship between project partners and sustainability targets. However, I couldn't tell you anything based on this project because it has been in operation only few years..." (A4).

Reporting a contrasting view to the above, half the respondents (6 of 12), especially client representatives and architects, mentioned that contractor-lead procurement methods (e.g. PFI, P21, LIFT) always encourage lifecycle costing when selecting materials. This was echoed by the following statement made by a client representative during the interview.

"…in this project we always consider lifecycle costing when selecting materials. We had the principal contractor on board very early in this project. Since the contractor has to maintain the facility for a certain period of time, he always considers lifecycle aspects. Therefore, I think this will be

very low. But where lifecycle requirements were not considered, I would say that waste will be huge…" (C1).

5.3.2.7 Over-/Under-Specification

According to the majority of interviewees (9 of 12), writing specifications is a challenging task in healthcare projects because of the complexity of design details. Additionally, they all believed this to be a very important task in reducing lifecycle waste generation on healthcare projects. In proving the above, a client representative reported:

"…In healthcare, maintaining quality standards is very important, especially in infection control etc. If specifications of materials, medical equipment and finishes do not meet the facility lifecycle requirements, the building management has to replace them before the end of their expected lifetime. This increases unnecessary wastage throughout the building lifecycle…" (C2).

However, respondents had given a low ranking to this cause of waste declaring that they have had good opportunities to deal with supply chain partners very early in these projects due to partnering procurement agreements. An architect explained:

"…. our contractor had compliance with the market and had close connections with the supply chain. Since the contractor was also involved at the design stage of this project, we got appropriate specifications for materials which reduced the impact of waste generation due to over-/under-specifications…" (A1).

5.3.2.8 Delays in Drawings

Even though a majority of the respondents (8 of 12) agreed that there were late submissions of drawings in these projects due to the large amount of drawings, they affirmed that waste generation due to the above could be ignored. A contractor representative reported:

"…delays in drawings arise all the time. But I would say that it didn't create huge quantities of waste. May be a very small amount, because we sometimes started construction work before the drawings had been issued to the site to speed up the construction process. Therefore, we had to do a few changes when the designs were finalised. But it is not a big factor…" (B1).

5.3.2.9 Lack of Awareness about the Waste Generation

More than half of the respondents (7 of 12) believed that the 'lack of awareness about the waste generation in the construction process' did not heavily impact on waste generation in these healthcare projects. Their main argument was:

> *"… currently the trend in the healthcare construction is either P21 or LIFT. Unlike traditional methods the contractor is allowed to participate in these procurement processes from the very beginning of the project. Therefore, I don't think this is an issue because our contractor is very keen on minimising waste and they had enough opportunities to drive out waste in this project even though other partners are not experts in this…" (A1).*

However, just under half of the respondents (5 of 12) held a totally different view to the above and stated that architects gave priority to the aesthetic appearance of the building rather than minimising waste. Hence, they pointed out architects' lack of knowledge of waste generation in the construction process as a cause of waste. A contractor representative mentioned:

> *"…of course I think this had a high impact because architects like to design very attractive buildings and waste generation is not high in their priorities. They will specify 500 different materials where 100 would probably do it. So I think the impact is very high..." (B1).*

5.3.2.10 Not Thinking about the Best Ways to Design

All the interviewees gave a very low ranking to the causes of waste 'not thinking about the best ways to design'. They thoroughly rejected this as a cause of waste in healthcare projects stating that partnering procurement routes like P21 and LIFT always put the maximum effort into getting the best innovative design. Additionally, they have noted the aim of partnering agreements, which is to obtain the best value for money, and that construction waste minimisation is one way of securing this. In reporting this, a client representative mentioned:

> *"…I don't agree with this. We used P21 where the whole project team concentrated their maximum effort to securing value for money. Not only designers, even the contractors tried their best to design-out waste as much as possible. This was a win-win situation…" (C2).*

5.3.2.11 Lack of Knowledge of Alternative Materials

Almost all the respondents (11 of 12) revealed that the architects in their projects were knowledgeable enough to select the most suitable materials for the facility. Additionally,

a majority of them (9 of 12) highlighted the early supply chain involvement as an advantage for selecting the right materials.

> *"…we got all our supply chain partners involved early on. Therefore, we had enough time to explore materials and to select the right materials at the first instance. I think it is very important to get the right team together. In my point of view, if we use a good design team that will make sense ...." (C4)*

5.3.2.12 Use Non-Standardised Building Elements

Other than above, the majority of the respondents (9 of 12) highlighted the limitations when using standard building elements as a major cause of waste in healthcare projects since healthcare designs have to satisfy building regulations published in HBNs and HTMs. In reporting above an architect explained:

> *"…standardisation is very limited in healthcare. We should strictly follow HBNs and HTMs. As every single room is unique and has certain standards to fulfil. Finishes, medical equipment, building services etc. going into each room are difficult..." (A3)*

5.3.3 Construction Phase

The preliminary data collection study emphasised ten causes of waste that could occur in the construction/renovation phase of a healthcare project. During this study, interviewees were asked to rank the causes of waste according to the impact of waste generation based on the particular case study (1 = highest impact on waste generation…10 = lowest impact on waste generation). As discussed in Section 5.3.1, the mean rank value for each cause of waste was calculated in all four case studies (CS1, CS2, CS3 and CS4). Table 5.5 shows the rankings of each cause of waste based on their impact on generating construction waste.

Although a small disparity can be seen among the rankings given for causes of waste in the construction/renovation phase based on their impact on generating construction waste, 'lack of planning and organisation'; 'inadequate communication and coordination'; 'poor workmanship causing rework'; and 'material handling and storage facilities on site' were selected as high-impact causes of waste in all four case studies. However, respondents believed that causes of waste such as 'ordering wrong materials'; 'lack of site waste management plans'; and 'equipment malfunctioning causing rework' had an negligible effect on waste generation and thus gave them very low rankings. Respondents' rationale behind the rankings given for these causes of

waste were discussed in detail during the interview and illustrated in the following sections.

Table 5.5: Causes of waste analysis in construction/renovation phase

Causes of waste – Construction/Renovation	Mean Rank CS1	Mean Rank CS2	Mean Rank CS3	Mean Rank CS4	Mean Rank-Total
Lack of planning & organisation	1	2	3	1	1
Inadequate communication and coordination	3	1	1	2	2
Poor workmanship causing rework	3	3	1	3	3
Material handling and storage facilities on site	2	4	4	3	4
Advance ordering of material	5	5	5	7	5
Care and quality of trades used	8	7	6	5	6
Damage to materials during transportation	7	6	7	6	7
Ordering wrong/excess materials	6	8	8	8	8
Lack of a site waste management plan	9	9	9	9	9
Equipment malfunctioning causing rework	10	9	10	10	10

5.3.3.1 Lack of Planning and Organisation

Lack of planning and organisation was identified by all interviewees as a high-impact cause of waste in healthcare buildings in both acute care and primary care buildings. All the respondents argued, without doubt, that working in a live hospital site is a real challenge because of the need to plan site activities well ahead. Therefore, they pointed out 'lack of planning and organisation of site activities' as a major cause of waste in the construction/renovation phase of a healthcare project. One contractor representative clearly illustrated waste generation issues due to 'lack of planning and organisation' as follows:

> *"…we had to carry out our work on a live hospital site …which is far more complex than any other building site because we had to provide access for emergency vehicles etc. We can't plan these situations early. Access to some areas was restricted by the hospital management, which limited the use of the whole site as and when we needed it. We got limited area to maintain waste materials skips. Therefore, I could say that early planning and organisation is very complicated on this site..." (B2).*

Additionally, half the respondents (6 of 12) noted long construction durations as another main reason for the lack of site planning and organisation. An architect reported:

> *"…this project had a 10 year planning period and another 10 year construction period. Altogether, the total project will take 20 years. Early planning is very difficult in that sense because 20 years means a very long duration..." (A1).*

5.3.3.2 Inadequate Communication and Coordination among Parties

From the respondents' point of view, the number of construction partners is very high in a healthcare project compared to other building projects. The main reason for the interviewees' stating this was the large number of trades required by a healthcare construction to satisfy special building requirements, such as building services, medical equipment installations etc. Hence, almost all the interviewees (11 of 12) believed that an increase in the number of project partners increases the chances of inefficiencies in communication and coordination, which they believe to be a cause of waste. A contractor representative reported:

> *"…Communication discrepancies are very common in healthcare projects because of the number of trades. This happened very frequently and had a very high impact on waste generation. In this project this has resulted in wrong materials ordering several times…" (B3).*

5.3.3.3 Poor Workmanship Causing Rework

Since meeting quality standards, as stated in the healthcare building regulations, is a major consideration in healthcare construction, all the interviewees stated that any poor workmanship by the workers results in rework thereby generating construction waste. An architect explained:

> *"…We had instances of poor workmanship. This is a big issue. Quality and workmanship run hand in hand. In healthcare, maintaining quality standards is very important. Therefore, any poor quality work ended up as waste…" (A1).*

Additionally, respondents highlighted the extensive use of M&E services and materials for healthcare building increases the total amount of construction waste generated as a result of poor workmanship in healthcare projects.

5.3.3.4 Material Handling and Storage Facilities On-Site

Two-thirds of the respondents (8 of 12) stated that they have experienced inadequate materials handling and storage facilities on site mainly due to other live buildings. Confirming the facts, a contractor representative declared:

> *"…this is generally a real cause for high wastage. As we need to keep space clear for emergency vehicles, we got very limited space for onsite materials storage. When storage facilities are inadequate, we experience damages to materials by the trades as well as by the weather…" (B2).*

5.3.3.5 Advance Ordering of Materials

Three-quarters of the respondents (9 of 12) believed 'advance ordering of materials' to be a high-impact cause of waste in healthcare construction. Additionally, they have emphasised that this cause of waste is not peculiar to healthcare construction, but a common cause of waste for any construction project due to negligence and improper planning. In explaining this, a client representative noted:

> *"…this is a common cause of waste in any construction project. Contractors or the trade contractors are responsible for materials ordering on the site. Their negligence or poor planning can cause these effects…" (C3).*

Nevertheless, explaining the reason for categorising 'advance ordering of materials' as a high-impact cause of waste in healthcare projects, few interviewees (2 of 12) gave the large number of materials required for healthcare buildings as their rationale. This was reported by an architect stating:

> *"…healthcare buildings require a large number of materials. Sometimes contractors order materials in advance, for example in bulk quantities, to obtain discounts. But if materials are stored for long periods they could get damaged. When the numbers of materials are high, materials wastage is also high..." (A3).*

5.3.3.6 Care and Quality of Trades Used

Even though there seems little difference between the rankings given in each case study for the impact on waste generation due to 'care and quality of trades used', interviewees revealed that maintaining the required quality of trades is very important in healthcare projects, as stated in 5.3.3.3. A contractor representative explained:

> *"…Quality of trades is very essential in a healthcare project to maintain DH standards. Therefore, any inferior work would lead to rework. Rework, in other words, means waste …" (B2).*

5.3.3.7 Damage to Materials During Transportation

All the interviewees noted damages to materials during transportation as a common cause of waste in any construction project due to negligence. This was explained by a contractor representative as follows:

> *"…damage to materials during transportation are common in all the projects. This happens mainly due to negligence and improper storage or packaging of materials during transportation. In healthcare projects, waste during transportation would be high because the amount of materials going into a building is high…" (B3)*

5.3.3.8 Ordering Wrong /Excess Materials

The majority of the respondents (10 of 12) disclose this as an issue related to ineffective communication and coordination among the project partners during the construction/renovation process. However, they all agreed that ordering excess materials generates comparatively greater amounts of waste than ordering wrong materials. Illustrating the above through an example, a contractor representative reported:

> *"…Impact of materials over-ordering is relatively higher than wrong ordering of materials. We have opportunity to return materials to the suppliers if we order something wrong. But in the case of excess ordering, even if returning is possible, that will never happen. For an example, we normally pay for our plasterboard workers based on their work done. We don't pay a daily rate. So, if we order excess materials they don't consider minimisation of off-cuts because they have enough to waste. So, the material procurement system needs to be systematic...." (B1).*

5.3.3.9 Lack of Site Waste Management Plans

All the respondents believed that lack of site waste management plans will not be a cause of waste in future healthcare projects because became a requirement by law in 2008. During the interview, an architect stated:

> *"…We didn't use SWMPs for this project because it was not legislation at that time. It came as part of a BREEAM assessment in those days. But I think in future projects this won't be a problem since it's a legislation now and therefore the contractor has to submit one…"(A2).*

5.3.3.10 Equipment Malfunctioning Causing Rework

All the respondents argued that 'equipment malfunctioning causing rework' has a negligible impact on waste generation and thus gave it the lowest rank. The following is

a statement made by a contractor representative during the interview, which makes the above clearly evident:

> *"…Equipment malfunctioning is not a common mistake in any project. I could say that this had the least impact on waste because it is not frequently occurring during the process. If that happens, I could say that it is purely due to negligence. Therefore, I don't agree with this one as a cause of waste…" (B1).*

5.3.3.11 Over-Packaging

Other than the above causes of waste, almost half of the respondents (5 of 12) stated 'over-packaging of materials' as a cause of waste in healthcare projects. A contractor representative revealed:

> *"…another main reason for waste is over-packaging. A lot of cardboard and plastic materials, which aren't very necessary, are there during the put-up stage of construction. Over-packaging creates lots of volumes of waste…" (B1).*

5.4 Healthcare Complexities vs. Construction Waste Generation

In the previous preliminary study, the data collected revealed several functional and operational features which increase waste generation in healthcare projects compared to other building projects. Thus, one objective of this study was to identify the impact of these features to generate construction waste in the real-life scenarios. During this study, the interviewees were asked to select the relevant features from the list that affect waste generation in the particular case study. Table 5.6 presents the results obtained.

Table 5.6: Features in healthcare buildings that affect construction waste generation

No	Special features	Clients	Architects	Contractors	Total
Functional features					
A	Complex nature of the building due to requirements for different shapes and sizes of rooms.	C1, C2, C3, C4	A1, A3, A4	B1, B2, B3, B4	**11**
B	Complex nature of mechanical and electrical services of the building.	C1, C2,	A1,A2,A3, A4	B1, B2, B3, B4	**10**
C	Complex nature of identifying all the functional requirements of the building at an early stage.	C1, C2, C4	A1, A3, A4	B1, B2, B3, B4	**10**
D	Requirement for a high density of materials per m^2 of the building.	C2	A3, A4	B4	**04**
E	Requirement for a large number of materials to satisfy quality standards.	C1, C2, C3	A1,A2, A3, A4	B1, B2, B4	**10**
F	Changing nature of functional requirements between projects limiting the use of past experience in future construction projects.	C1, C2	A4	B2	**04**
Operational features					
A	Continuous operation of hospital buildings in construction sites.	C1, C2, C4	A1, A2	B1, B2, B4	**08**
B	Adaptable and flexible building needs to fulfil future requirements.	C1, C2, C4	A1, A4	B1, B3	**07**
C	High wear and tear of the building throughout the lifetime.	C1, C2, C4	A2, A4	B1	**06**

5.4.1 Functional Features

A- Complex nature of the building due to requirement for different shapes and sizes of rooms

The majority of respondents (11 of 12) agreed that complexities in healthcare buildings affect waste generation due to the requirement for different shapes and sizes of rooms. They argued this in several ways pointing out some of the examples from their projects. Some respondents (4 of 11) said that the designs for healthcare buildings are complex due to the limited site space availability among existing buildings. Since healthcare buildings have to comply with the healthcare building regulations (i.e. HBNs and HTMs), these respondents highlighted that designing such a complex building within a limited site space whilst complying with given standards is a challenge. Additionally, they have mentioned that this gives them limited opportunities to design-out waste through design standardisation. In reporting the above, an architect explained:

> *"…If you can design a square building with regular size rooms that is much easier. But in this project, we got a triangular building because it needed to fit with the existing buildings and spaces. So, in terms of efficiency of space, it is not effective and increases off cuts…. Complexities in healthcare buildings due to different shapes and sizes required by HTMs*

and HBNs for each space increase waste due to off-cuts. This is far more complex when site complexities are added on top of that. In CS1 project, most of the buildings have curved walls and irregular shapes of room spaces...." (A1).

However, another set of respondents (7 of 11) explained this differently. Instead of site complexities, they pointed out the requirement of multiple different functions that are required within a healthcare building as the reason for increasing off-cuts due to different shapes and sizes of rooms required to satisfy healthcare guidance notes. This can be clearly illustrated by the following statement made by a contractor representative during the interview.

"… in a healthcare building, even two adjacent rooms have to perform multiple different functions. Therefore, standardisation is very difficult. For example, the height of a theatre is different to patient accommodation rooms according to healthcare building regulations. Therefore, it is difficult to make the whole building a certain height. This has resulted in a lot of plasterboard off-cuts..." (B1).

B- Complex nature of mechanical and electrical services of the building

According to the results, 10 of 12 respondents agreed that the complex nature of the mechanical and electrical services in a healthcare building affect waste generation, therefore, they have declared that complex services in the building increased the clashes between the service connections, thereby generating waste during the fitting-out phase of the project. The following statement made by a contractor representative during the interview clearly established the above facts.

"…hospitals are normally service-heavy in terms of the number of mechanical and electrical services. Because of this nature, we have experienced a lot of clashes between services. This has sometimes resulted in rework. Obviously the waste percentage is always higher in hospital buildings than in other buildings..." (B1).

However, two client representatives held a different view to the above and stated:

"…I can classify this as a simple building. Although we have used mechanical ventilation, chillers, boilers etc. we did not use medical gases. So I can say that we did not experience waste due to this feature..." (C3).

C- Complex nature of identifying all the functional requirements of the building at an early stage

Since healthcare building requirements are vast, very complex and very precise, a majority (10 of 12) of the respondents said that identifying all the requirements at the very beginning of the project is very difficult. The way in which this has resulted in waste being generated was described by a contractor representative during the interview as follows:

> *"…The clients in a healthcare project have to specify a lot of details room by room, which is a very complicated process. In this project, clients wait 'till the last minute to specify medical equipment. They specified these after construction had been started. So when the time has come to install, the things we already had done were obsolete and therefore we had to change sizes and shapes of spaces to fit with the end-users' new requirements. This caused a huge amount of waste during the installation..." (B1).*

Other than the above, four (of 10) respondents have identified this as the result of having a large number of end-users with dissimilar interests. They mainly argued that:

> *"…we had to deal with a large number of end-users in this healthcare project. Each one had their own wish list. Some end users' requirements are vague and not defined well. They have changed them from time-to-time. This increased a lot of complexities, as we could not identify their requirements properly at the start of the project. For an example, in this project, the Burns Unit was always there. But we had to do a few later changes to the Out-Patient department as per end-user requests which generated some waste…" (A2).*

D- Requirement for a high density of materials per m^2 of the building

According to the results shown in Table 5.6, more than half of the respondents (8 of 12) disagreed that healthcare buildings need a high density of materials per m^2 of the building. In reporting this, one architect stated:

> *"…I did not notice a big difference in healthcare buildings compared to an office block or anything. I agree that some rooms need special requirements. But not the density of materials…" (A1).*

But, some respondents (4 of 12) held a totally opposite view to the above. They agreed that the use of additional building materials to satisfy medical requirements increases the density of materials per m^2 of the building. A contractor representative gave an explanation of the above during the interview, as follows:

> *"…in healthcare buildings some rooms need to be sound-proof. Therefore, we should insulate inside to make it sound-proof. Other than that, healthcare buildings obviously need more services. These additional requirements increase the number of materials going into the building. Additionally, anything like that can increase off-cuts. Packaging and segregation of materials is also difficult…" (B4).*

E- Requirement for a large number of materials or special types of materials

According to the results, most of the respondents (10 of 12) believed that healthcare buildings need a large number of materials and special types of materials. In a healthcare building, different spaces have to maintain certain quality standards as specified by the healthcare guidance notes (i.e. HTMs and HBNs). An architect explained the above by taking an example of using different flooring materials on CS1 project to facilitate different functional needs in each room.

> *"…Selection of the floor material depends on things such as functionality inside the room and hygiene requirements. We selected different flooring materials such as vinyl, or carpet or tiles to different spaces in the building as per healthcare guidance notes. Yes, I agree that if we used one type of flooring we could minimise waste because of reduced off-cuts. But the regulations don't allow us to do that..." (A1).*

Other than using different materials, in CS2 project, all the three respondents mentioned that they have used different colours for wall and floor finishes to meet the psychological needs of patients. The contractor representative of this project reported:

> *"…this is a children's ward. Most of the targeted patients would have long stays in this ward during their treatments. In order to maintain their psychological needs, we had to use different colour wall and floor finishes. We know that it increases waste. But we could not do anything…" (B2).*

Illustrating an example of using special materials in certain places in the building, an architect explained:

> *"…we had x-ray rooms and dental suites. We did change the wall construction from plaster board to a block work to increase protection from radiation..." (A3).*

The above comments made during the interviews clearly revealed the impact of waste generation due to the requirement for a large number of materials and special materials to satisfy healthcare building regulations.

F- Limited use of past hospital construction experience due to changing functional requirements

Two opposing views were recognised among the respondents regarding the 'limited use of past hospital construction experience due to the changing functional requirements from project to project' on waste generation. However, eight (of 12) of the respondents did not agree that this was a special feature in healthcare buildings that lead to the generation of construction waste. They mainly believed that the fundamentals in each healthcare design are similar and therefore there are opportunities to embed past hospital construction experience in their new projects. A contractor representative stated:

> *"…fundamentally there are a lot of similarities in hospital buildings. For an example, we always try to improve the use of plasterboard by using previous experiences. From our past projects, we know plasterboard, flooring, ceiling stripes etc. are the highest waste generators in any project. Therefore, we set strict targets on those trades in our current projects to minimise waste generation from these trades. That comes from the lessons learned from previous jobs I think…" (B1).*

Nevertheless, 4 interviewees (of 12) held a totally opposite view to the above and noted that healthcare buildings are unique and therefore direct use of past construction experience is very limited. A client representative reported:

> *"…I have worked in five hospitals. They are remarkably different. The one we are doing now has a very large site. Space is not an issue there. But in the CS2 project, we had a very small space for storage. Other than site complexities, there were a lot of complexities in the burns unit around its functionality…" (C2).*

5.4.2 Operational features

A- Continuous operation of the building

During the interview, three respondents (of 12) said that they did not have an issue in CS3 project due to the operation of other buildings on-site since it was a totally new building, however, of the remaining 9 respondents (of 12), the majority (8 of 9) agreed that waste minimisation is difficult when constructing on a live hospital site. Additionally, they have emphasised that waste removal and segregation is a challenge on a live hospital site due to insufficient space availability to segregate waste materials and due to disturbances to the adjacent live buildings. During the interview, a client representative explained:

> *"…I think the whole process is quite challenging because everything was done on an existing hospital site. Especially getting waste in and out of the building was a challenge. Knocking things down and recovering materials was challenging. We have to crush materials off-site, which we normally do on-site. So predominantly it doesn't always give the opportunity to reduce waste or segregate waste in the most economical way…" (C1).*

Some respondents (6 of 9) emphasised issues particularly related to renovation or extension to existing healthcare building projects on live healthcare sites. Their main concern was the provision of temporary accommodation for patients and staff. Since such accommodation still had to conform to the requirements stated in the healthcare guidance notes, interviewees assumed that waste generation is higher when providing temporary accommodation for healthcare buildings compared to any other building. Illustrating an example, an architect stated:

> *"…we couldn't close down the hospital when we knocked down existing buildings. Therefore, we misused some other area to perform that function before knocking down the existing building. During the design, we have to decide how much construction work is needed, how much wastage we should have to minimise and how to fit the steady state departments into the misuse stage etc. Other than that, each department is different from another. For an example, the cardiac department is different from the surgical department. So, we should try to build in as much as possible to avoid things that have to move. It's easier to build general warding units first than building specialist units. But it is difficult to do it all the time. We have to balance this in the design steady state. For an example, we should decide that this room is going to be the MRI scanning room and in the misuse stage it is going to be the scanning room etc. Therefore, we should plan the same space to perform two different functions. But finally there will be some waste when we are converting the facility for its actual function…" (A1).*

B- Adaptability and flexibility of the buildings to fulfil future management and user requirements

Respondents had different views regarding the effect of waste generation due to the requirement of future changes to the building to meet future management and user requirements. Seven (of 12) respondents mentioned that this feature impacted highly on lifecycle waste generation compared to other buildings because healthcare requirements change rapidly throughout the lifecycle due to medical improvements and

future management changes. A contractor representative illustrated his arguments regarding the above as follows:

> *"…we may need to enhance the facility during the lifecycle to meet future medical requirements. I can't specifically say anything based on CS1 project because it is still under construction. But, according to my experience in healthcare, this could happen very frequently. Another reason for change would be to satisfy future management requirements. We will hand over this facility at the end of the commissioning period. Sometimes a new management team may require some changes. Therefore, it is important to consider building adaptability and flexibility to reduce waste generation in the early stages…" (B1).*

However, all the other respondents (5 of 12) said that they did not have any idea about the future waste generation in healthcare projects. They further declared that healthcare buildings are difficult to future-proof as requirements change rapidly. Consequently, they believed that planning and designing an adaptable and flexible building is not practical for a healthcare building. Moreover, they highlighted the importance of making changes with minimum wastage rather than thinking of adaptable and flexible building. The above was explained by a contractor representative during the interview as follows:

> *"…I can't say exactly whether it will generate waste or not. In this project, we didn't consider adaptable or flexible building and it didn't encourage by the procurement method either. However, healthcare buildings are difficult to future-proof because things get changed rapidly. The most important thing, I believe, is to identify the best way of making a change rather..." (B2).*

C- High wear and tear of finishes throughout the building lifetime

According to the results shown in Table 5.6, half of the respondents (6 of 12) agreed that healthcare buildings generate large volumes of waste during the facility lifecycle. As the main reason for the high waste generation rate, interviewees pointed out the requirement for frequent renovations for facility finishes to maintain required standards due to high wear and tear. Illustrating the above, the following statement made by a client representative explained the severity of wear and tear in a healthcare building and the way it increases lifecycle waste generation.

> *"…in healthcare projects, finishes are highly subjected to wear and tear. In terms of this building, nearly 12,000 people visit every day and there are 8,000 staff. So this has an impact on floors, wall protection, lifts etc.*

> *Therefore, it is incredibly important to select proper materials. If we use any inferior material for finishes without considering lifecycle costs, we will definitely require more finishes replacements during the lifecycle than what we predict at the start of the project. In other terms this will cause huge waste..." (C1).*

The other set of respondents (6 of 12) believed that the responsibility for selecting suitable materials for the project relies on the project team and thus is not a feature of healthcare buildings. Therefore, they refused to identify high wear and tear in healthcare buildings as a healthcare-specific feature that affects waste generation. Rather, they declared that it can be totally eliminated through early maintenance planning and selecting appropriate materials for the building. An architect elaborated the above during the interview as follows:

> *"…I believe that this is not a feature in healthcare buildings. It is project partners' responsibility to select materials according to the lifecycle requirements. Of course, inferior material selection is a cause of waste in healthcare buildings; it is very critical because of wear-and-tear requirements. But this is not a healthcare feature…" (A2).*

Referring to the results shown in Table 5,6 and the statements made by the respondents during the interviews, it can be stated that functional features such as: 'complex nature of the building due to the requirement for different shapes and sizes of rooms'; 'complex nature of mechanical and electrical services of the building'; 'complex nature of identifying all the functional requirements of the building at an early stage'; and 'requirement for a large number of materials or special types of materials' have a considerably high effect on waste generation in healthcare buildings. In terms of operational features, 'continuous operation of the facility' is the most critical one.

5.5 Relationship between Special Features in Healthcare Buildings and Causes of Waste

The preceding sections of this chapter describe the causes of waste and the features of healthcare buildings in terms of their effect on construction waste generation. During the interviews, interviewees were asked to state the features in healthcare buildings related to causes of waste based on their experience in healthcare projects with the aim of identifying high-impact, waste-generating features in each lifecycle stage of the healthcare buildings. Table 5.7 shows the results obtained from the study.

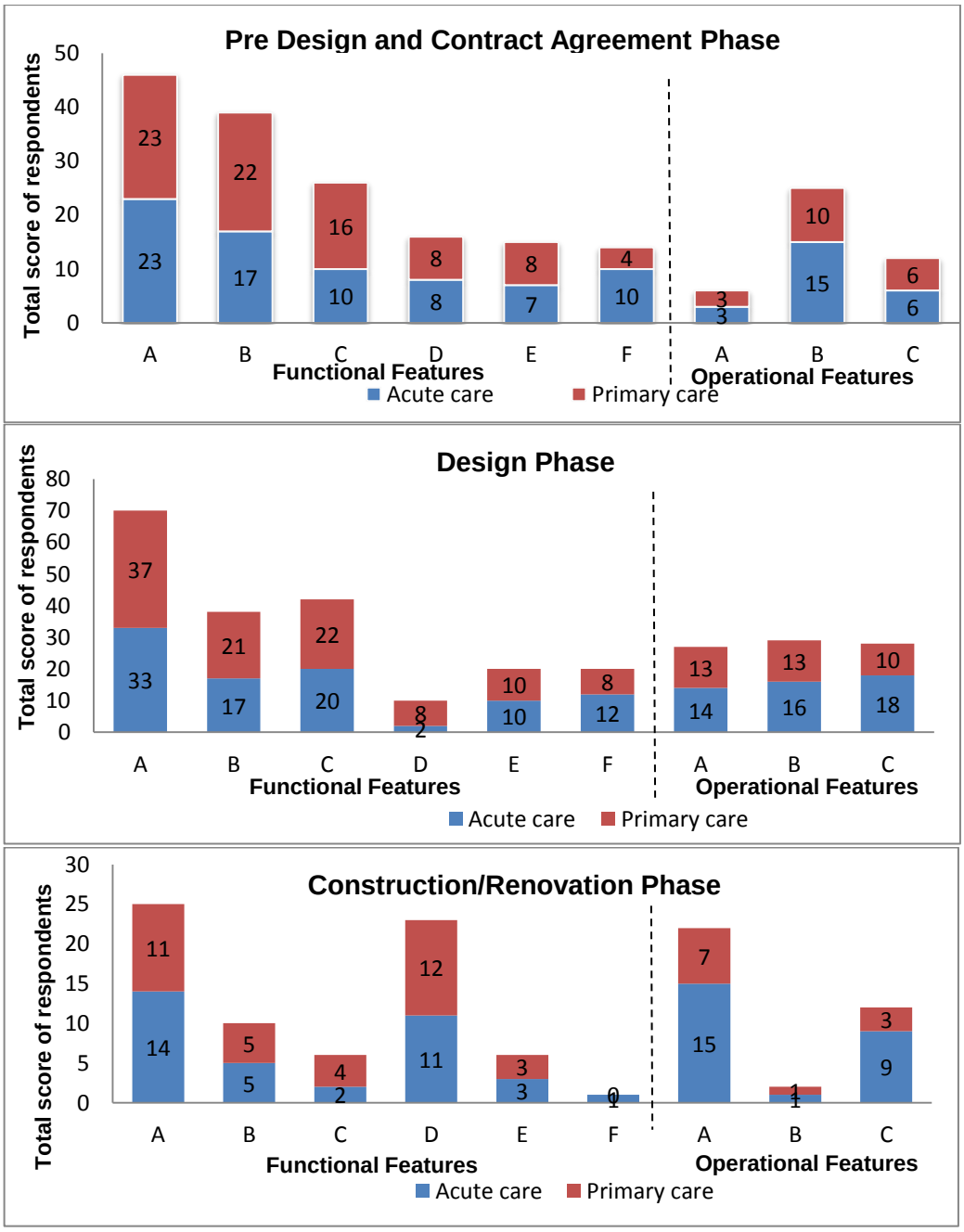
In the Table 5.7, each cell shows the number of respondents (based on the total sample) who have mentioned that the particular cause of waste could occur due to a particular feature in the healthcare building (e.g. nine respondents said that incomplete briefing could occur due to the functional feature A). In order to identify the features which most affect the generation of construction waste in each project lifecycle phase, the total number of respondents was calculated for each lifecycle stage as shown in Table 5.7. Further, the total number of respondents under each column was calculated to identify the functional and operational features that most affected the total project life cycle. Additionally, the same calculation was done based on the acute care sample and the primary care sample to find out whether there is any significant difference between the two major types of healthcare buildings. As shown in the Figure 5.1, results indicated that there was no significant difference between the impacts of healthcare complexities on construction waste causes between acute care and primary care projects. Therefore, a separate analysis was not performed within these two major healthcare project types to identify similarities and dissimilarities in generating construction waste due to healthcare related functional and operational complexities.

Table 5.7: Features in healthcare buildings vs. causes of waste (based on the total sample)

Causes of waste	Functional features						Operational features		
	A	B	C	D	E	F	A	B	C
Pre-design and Contract Agreement Phase							**Number of respondents**		
Incomplete briefing	9	10	11			8			
Clients lack of awareness of the construction process	3	10	2		1	1	2	9	6
Inefficiencies in communication and coordination	7	2	4		1			3	
Lack of concentration on adaptability and flexibility by clients	9	11	3					7	
Clients are not willing to change their requirements to standard sizes	10	2		6				2	
Clients' lack of knowledge about the materials available	2	1	1	5	7	2			6
Type of contract varying the responsibility for waste generation.				3	3	2		4	
Inconsistencies in the contract documents	6	3	5	2	3	1	4		
Pre-design and contract agreement – Total score of respondents	46	39	26	16	15	14	6	25	12

Table 5.7cont.: Features in healthcare buildings vs. causes of waste (based on the total sample)

Causes of waste	Functional features						Operational features		
	A	B	C	D	E	F	A	B	C
Design Phase	**Number of Respondents**								
Lack of knowledge of alternative materials	3				8				9
Incorrect drawing details	11	10	9	1	1		4	3	
Complex designs generating a lot of off-cuts	12	11		3			4	2	
Over-/under-specification	8	2	7	2	7			1	8
Inefficiencies in communication and coordination	8	2						4	
Design changes	10	9	9			6	4	1	
Delays in drawings causing time pressure during construction	7		5						
Wrong selection of material in the lifecycle					1	10		9	11
Not thinking about the best ways to design	6	4	6				6	6	
Not coordinating dimensions and sizes	5		6			1	5	3	
Lack of awareness about waste generation in the construction process				4	3	3	4		
Design - Total score of respondents	70	38	42	10	20	20	27	29	28
Construction/renovation Phase									
Poor workmanship causing rework	10	10		9			6	2	
Inadequate communication and coordination among parties	4		6	7	5	1			
Lack of planning & organisation	11						7		
Care and quality of trades used				7	1				12
Material handling and storage facilities on site							9		
Construction - Total score of respondents	25	10	6	23	6	1	22	2	12
Total lifecycle - Total score of respondents	**141**	**87**	**74**	**49**	**41**	**35**	**55**	**56**	**52**



No.	Functional Features	No.	Operational features
A	Complex nature of the building due to different shapes and sizes of rooms	A	Continuous operation of hospital buildings in construction sites
B	Complex nature of mechanical and electrical services of the building	B	Adaptable and flexible building needs to fulfil future requirements
C	Complex nature of identifying all the functional requirements of the building	C	High wear and tear of the building throughout the lifetime
D	Requirement for high density of materials per m^2 of the building		
E	Requirement for a large number of materials to satisfy quality standards		
F	Changing nature of functional requirements between projects		

Figure 5.1: Features in healthcare buildings vs. causes of waste

Results clearly indicate that functional features such as A, B, C and operational feature B affect, significantly, the generation of pre-design and contract agreement phase causes of waste. Moreover, a significant difference cannot be noticed between the answers given by the acute care respondents and the primary care respondents. From the results, it is interesting to note that most of the pre-design and contract agreement phase causes of waste occur due to the complexities in healthcare buildings.

In the design phase, a large number of respondents said that functional features A, B, and C could give rise to causes of waste, such as, design changes, incorrect drawing details and complex designs. Additionally, it is interesting to note that these three causes of waste are the high-impact causes of waste in the design phase of a healthcare project as discussed in the Section 5.3.2. However, referring to the total number of respondents in the design phase (Table 5.8), functional feature A generates most of the design phase causes of waste compared to functional features B and C. Similar to the pre-design and contract agreement phase, no significant difference has been identified in the acute care sample and the primary care sample. Moreover, the above results imply that operational features have less impact on design phase causes of waste compared to the functional features.

Results indicate that, functional and operational features in a healthcare facility have less impact on the construction/renovation phase causes of waste. However, comparatively, functional features A and D and operational features A and C have a high impact on the generation of some construction phase cause of waste such as: poor workmanship causing rework; lack of planning and organisation; and care and quality of trades used. Depending on the total number of respondents shown in Table 5.8, it can be stated that there is no significant difference between the views of acute care and primary care respondents.

Additionally, referring to the figures shown in Table 5.8, it can be stated that functional features A, B and C are the mostly likely to generate causes of waste throughout the healthcare building lifecycle while others have comparatively less impact. Also, it can be noticed that those features significantly influence the pre-design and contract agreement and design phase causes of waste.

The next section of this chapter describes waste minimisation strategies suggested by the respondents to minimise lifecycle waste generation from healthcare projects.

5.6 Waste Minimisation Practices

5.6.1 Project-Level Waste Minimisation Practices

During the interview, respondents were asked about the measures they have taken to minimise construction waste in the particular projects and potential improvement measures that can be taken to increase waste minimisation effectiveness.

5.6.1.1 Pre-Design and Contract Agreement Phase

Table 5.8 illustrates the best-practice, waste-minimisation strategies used in the pre-design and contract agreement phases in these healthcare projects and their potential improvement opportunities.

Table 5.8: Waste minimisation practices used in the pre-design and contract agreement phase

Waste minimisation practices: Pre-design and contract agreement phase		
	Current practices	**Potential improvement opportunities**
Effective communication and coordination between project partners	• Conduct effective meetings (i.e. face-to-face, e-discussions etc.) to share project requirements with project stakeholders (i.e. end-users, design team, contractors, suppliers etc.) to avoid miscommunications (N=8).	• Circulate all the project information by sharing documents (i.e. meeting minutes, e-mails, memorandums, project reports etc.) with all the relevant stakeholders (N=1). • Conduct initial meetings with project stakeholders (i.e. end-users, design team, contractors, suppliers etc.) to plan project waste minimisation procedures (N=4).
Enhance end-users' involvement in the briefing process	• Produce a complete brief for the design team to eliminate late changes (N=5). • Early planning and identification of hospital functions required by end-users (N=3). • Identify critical adjacencies within different departments through discussions with some key personnel from each department (N=1).	• Made efforts to capture end user requirements as much as possible and obtain consent from end-users before finalising the project requirements (N=2) • Complete the brief before starting detail designing and obtain approval from the client team once the brief finalised (N=1)
Develop and update a database to maintain project requirements	• Compile all the project requirement documents (i.e. room data, M & E requirements, medical equipment, finishes etc.) into a database (i.e. Activity Data Base) (N=4)	• Share the database with project partners (i.e. end-users, design team etc.) (N=3). • Update the database frequently to facilitate the sharing of project requirement changes immediately with the project team (N=2).

Table 5.8 cont.: Waste minimisation practices used in the pre-design and contract agreement phase

Waste minimisation practices: Pre-design and contract agreement phase		
	Current practices	**Potential improvement opportunities**
Develop a project change-management procedure		• Agree a procedure to manage change (i.e. change identification, communication, evaluation, approval, implementation, review etc.) (N=4).
Insert waste minimisation responsibilities into the contract documents		• Clearly allocate waste minimisation responsibilities to the all the project stakeholders necessarily through customised contractual clauses (N=4)
Set up waste reduction targets for each trade		• Measure waste upfront and set up waste reduction targets and incentives for minimising construction waste for each trade (N=3). • Specify waste reduction targets and incentives for keeping waste levels below the targets in the contract documents (N=2).
Early appointment of supply chain partners		• Get the supply chain involvement into the process very early to build strong relationships, to communicate effectively and to share information quickly from the start of the project (N=2).
Conduct waste awareness programmes to project stakeholders		• Conduct waste awareness programmes with project stakeholders (i.e. clients, end users etc.) to increase their interest in reducing construction waste from the project (N=4).

During the interviews, majority of the respondents (9 of 12) stated that little attention had been paid to reducing construction waste generation during the pre-design and contract agreement phase. However, some respondents believed that they were able to reduce construction waste sources through effective communication and coordination between project partners and end-users during the pre-design and contract agreement phase. Furthermore, they have pointed out a number of potential waste minimisation opportunities within healthcare pre-design and contract agreement phase reduce construction waste generation (see Table 5.8). Most of these potential improvement measures highlighted the opportunities available to plan and organise waste minimisation and management activities from the start of the project (i.e. prepare

a complete brief, develop a comprehensive change management procedure) through contracts between project partners (i.e. set up waste targets, insert waste minimisation clauses) to effectively address causes of construction waste. Also, some of the respondents (4 of 12) believed the need for increasing awareness and allocating waste minimisation responsibilities to clients to be a significant factor in successfully implementing waste reduction targets in the early project stages. In reporting the above, an architect stated:

> *"….I strongly agree in saying that waste minimisation should be considered from the start of a project to reduce waste levels. But this should come from the clients. If clients require a building with funny shapes we have no other options than satisfying their requirements. We always try our best to keep them at minimum levels. But we couldn't go for the best available option when clients have different priorities. I would recommend making them aware of the benefits and their responsibilities of reducing construction waste…" (A3)*

5.6.1.2 Design Phase

Respondents' views clearly indicated that the design phase is one of the most significant phases in healthcare construction projects for reducing construction waste generation because "design satisfies all the client demands". They have pointed out a number of the more commonly used construction waste reduction practices employed at the design phase in the case studies such as: early involvement of contractors and supply chain partners; effective communication and coordination; and use of low waste technologies in the designs (i.e. modular construction, off-site pre-fabrication). Also, some respondents (4 of 12) believed that there are more opportunities available within the healthcare design phase to integrate construction waste minimisation practices more effectively than in current projects. A contractor representative stated:

> *"…I think design is the best place to consider construction waste minimisation especially in healthcare projects because of complexities. We always advise our design teams to use low waste techniques. But still there are more…" (B3)*

Considering the above, interviewees recommended potential opportunities within healthcare design phases to reduce construction waste generation (see Table 5.9).

Table 5.9: Waste minimisation practices used in the design phase

Waste minimisation practices: Design phase		
	Current practices	**Potential improvement opportunities**
Enhance contractors' involvement in the design process	• Obtain contractor's advice to avoid design faults, select suitable product manufacturers, avoid incorrect drawing details, select appropriate materials etc. (N=9)	
Enhance supply chain involvement in the design	• Obtain advice to select the most appropriate material in the first instance to avoid over-/under-specifications (N=6). • Obtain customised products (i.e. off-site products, modular units etc.) for the project to minimise off-cuts due to complex shapes and sizes in the design (N=3). • Obtain ideas when selecting materials about materials maintenance, quality, durability etc. (N=1)	• Reduce the number of suppliers as much as possible (N=2)
Effective communication and coordination between project partners	• Conduct effective meetings (i.e. face-to-face meetings, e-discussions etc.) with design team members to share design information accurately, coordinate shapes and sizes of the design etc. (N=8)	• Conduct effective meetings (i.e. face-to-face meetings, e-discussions etc.) with contractors, supply chain partners, clients etc. to share necessary project information related to waste generation and minimisation (i.e. requirement changes, low-waste building materials, new building technologies etc.) (N=4) • Circulate all the project information by sharing documents (i.e. meeting minutes, e-mails, memorandums, project reports etc.) with all the relevant stakeholders.(N=1)
Design standardisation	• Keep the design as simple as possible (i.e. avoid complex shapes etc.) to avoid off-cuts etc. (N=3) • Design the building with standard sizes as much as possible (i.e. same height for the whole building etc.) (N=1)	• Reduce the number of variations when selecting materials as much as possible to reduce off-cuts, leftovers etc. (N=1)

Table 5.9 cont.: Waste minimisation practices used in the design phase

Waste minimisation practices: Design phase		
	Current practices	**Potential improvement opportunities**
Complete and review the design before issuing to the site		• Complete design details (i.e. architectural, structural, M & E, medical equipment etc.) to avoid incorrect drawing details and lack of design information (N=4). • Review designs to identify buildability issues (i.e. clashes between elements, incorrect drawing details etc.) using 3D modelling, simulation etc.(N=2)
Design adaptable and flexible buildings	• Consider future expansion and changes and keep allocations appropriate (i.e. allow large and flexible spaces, additional service connections etc.) (N=5).	
Consider building lifecycle requirements when selecting materials		• Select materials to suit the building's long-term requirements (i.e. maintenance, quality, durability etc.) to avoid unnecessary replacement costs (N=2)
Use low-waste modern building technologies	• Use off-site pre-fabricated units, modular construction units (i.e. M & E services etc.), steel frames etc. to reduce on-site waste generation due to rework, insufficient materials storage facilities, clashes between elements etc. (N=6)	
Conduct waste-awareness programmes with project stakeholders		• Conduct waste awareness programmes with project stakeholders (i.e. design team partners etc.) to increase their interest to design out waste (N=2)
Design change management		• Evaluate changes thoroughly and identify the best ways of implementing changes (i.e. how to redesign with minimum waste, cost and time etc.) (N=1). • Coordinate changes efficiently with relevant project partners (N=1).

5.6.1.3 Construction Phase

The majority of the respondents (8 of 12) confirmed that the construction waste minimisation practices were more commonly used during the construction/renovation phase even though they agreed that there were a number of potential opportunities available in the early project lifecycle stages. Table 5.10 shows the waste minimisation practices used in selected case studies to reduce construction waste generation and their potential improvement opportunities.

Table 5.10: Waste minimisation practices used in the construction phase

Waste minimisation practices: Construction phase		
	Current practices	**Potential improvement opportunities**
Operate off-site storage facilities/ Just-in-time deliveries	• Encourage pre-planning and better organisation of site activities (N=9).	• Minimise wastage due to inadequate materials-handling and storage, over-ordering, wrong ordering and advanced ordering of materials (N=2). • Use effective methods to encourage minimum use of materials by the workers due to limited material availability on site (N=1).
Monitor trade contractor activities and waste performances	• Monitor trade contractor activities according to the project programme to avoid clashes, rework and conflicts between trades (N=8).	• Monitor trade contractor waste generation vs. waste targets and take corrective actions (N=5).
Minimise packaging waste	• Arrange with supply chain to minimise packaging waste by using reusable packaging, a take-back policy, bulk purchasing etc. (N=6)	•
Early planning and organisation of site activities	• Plan sequence of site activities and prepare a detailed project programme including trade contractor activities, materials delivery programme, details of resources allocation etc. (N=4) • Allocate site spaces for materials storage, waste materials segregation, materials reuse and recycling spaces etc.(N=4)	• Obtain prior approval from the hospital management for on-site waste handling activities (N=2)

Table 5.10 cont.: Waste minimisation practices used in the construction phase

Waste minimisation practices: Construction phase		
	Current practices	**Potential improvement opportunities**
Effective communication and coordination between project partners	• Effectively communicate construction information between project stakeholders (i.e. trade contractors, supply chain partners, designers, etc.) to avoid clashes between trades (N=4). • Conduct meetings (i.e. face-to-face, e- discussions etc.) to discuss waste minimisation performance on site (N=2).	• Circulate all the project information by sharing documents (i.e. meeting minutes, e-mails, memorandums, project reports etc.) with all the relevant stakeholders (N=1).
Waste reporting and documenting on-site	• Maintain records on waste to monitor on-site waste generation and to take corrective actions in future (i.e. waste transfer notes, check lists, waste audits, barcode systems, cost plans and material delivery forms etc.) (N=4).	•
Materials segregation, reuse and recycling	• Segregate materials onsite as much as possible (i.e. maintain separate material skips etc.) (N=1). • Appoint a waste management contractor to handle on-site waste (N=3). • Promote use of reused and recycled materials (i.e. reuse temporary materials etc.) (N=3). • Recover materials very carefully from the dismantling activities (i.e. existing buildings, temporary accommodation, temporary partitions etc.) (N=5).	•
Conduct waste-awareness programmes with project stakeholders	• Conduct waste awareness programmes with project stakeholders (i.e. site staff, trade contractors, supply-chain partners etc.) to increase their morale to minimise on-site waste generation (N=2).	

5.6.2 National-Level Waste Minimisation Practices

Other than project-level waste-minimisation strategies, some respondents highlighted a few national-level initiatives to minimise construction waste from healthcare projects

such as: implementation of site waste management plans; use of new procurement routes and allocation of waste minimisation responsibilities.

5.6.2.1 Implementation of Site Waste Management Plans (SWMPs)

All the respondents agreed that the implementation of SWMPs was a very effective waste-minimisation practice for healthcare projects. Their main basis for the above was the complex nature of healthcare sites. As one contractor representative highlighted:

> *"…I think SWMPs would do a better job in minimising waste from healthcare projects. Even though we weren't legally bound to produce a SWMP at the start of this project, we produced one, especially because of the complex nature of this site which we identified very early on. It helped a lot in minimising waste. We identified related waste issues when preparing SWMPs and we took corrective actions to eliminate waste from the process as much as possible. It helped us to set waste targets. Not only that, we planned waste segregation, reuse and recycling activities...." (B1).*

Apart from that, nearly half of the respondents (5 of 12) revealed this to be a very effective means of distributing waste targets and responsibilities among the project team. During the interview a client representative illustrated:

> *"…When the contractor prepares the SWMP for the project, all the trade contractors and supply-chain partners can get an overview about the waste targets. They can get to know their waste responsibilities. This is a very useful way of transferring waste minimisation knowledge to the project team..." (C2).*

5.6.2.2 Introduction of New Procurement Methods

Most of the healthcare projects use new procurement methods such as PFI, P21 and LIFT where the latter two methods were specially introduced by the NHS to procure healthcare projects. During the interview, a majority of the respondents (7 of 12) pointed out the advantages of using contractor-lead partnering agreements to procure healthcare buildings in terms of minimising construction waste. Some respondents (7 of 12) stated that these contracts are 'no-variation contracts' and thus provide a minimum of chances for major changes. Hence, they argued that, by using these new procurement methods, waste generation could be minimised in healthcare projects. In explaining the above, a client representative mentioned:

> *"…in PFI, Procure 21 and LIFT projects, once you sign the contract the ability to make major changes to the design by the client will automatically be limited. The contract frustrated the Trust or the end-user to do the*

changes. These are theoretically no variation contracts and there should be minimum waste..." (C3).

In addition to the above, respondents have emphasised a number of possibilities within these procurement processes to minimise construction waste such as: motivation to obtain maximum profit through waste minimisation; early involvement of the project partners (contractor, product manufacturers, trade contractor etc.); continuous improvement through previous experience, re-use temporary materials and use any over-ordered materials in later projects.

5.6.2.3 Allocation of Waste Minimisation Responsibilities to Clients

Three respondents (of 12) pointed out the importance of allocating waste minimisation responsibilities to the clients. According to their view, the waste minimisation process should be enforced by the clients, however, it is still considered to be a contractor's responsibility. Hence, these interviewees pointed out the importance of the government allocating waste minimisation obligations to the clients to increase the clients' attention to waste minimisation. The following views of a contractor representative clearly demonstrate the above:

"….clients are interested to know how much we reused and recycled and they like to hear the numbers. They are happy if we give priority to minimising waste and others issues like completion on time, on budget etc. But, this may vary if the government is pushing more responsibility onto the client to deal with waste. Also, In SWMPs, the contractor is asked to send a copy to the client. But the preparation and work on the SWMP is totally the responsibility of the contractor not the client. Even in BREEAM, the responsibility is with the contractor. The contractor has to demonstrate to the client that he has achieved BREEAM Excellent. Clients don't want to do that and demonstrate it to the government. So I'm suggesting that it is better to have some method of making clients responsible for minimising waste to make them interested…" (B1).

5.7 Summary

This chapter aimed to present the findings of the case-study-based interviews. These interviews mainly investigated causes of waste in construction in the healthcare project lifecycle and the potential waste-minimisation strategies. Since results obtained from four case studies did not significantly vary from each other, a cross case analysis has

not been performed to examine construction waste generation trends within different projects.

Results confirmed that the high impact waste causes in the pre-design and contract agreement phase of these case studies are ‘inefficiencies in communication and coordination’ and ‘incomplete briefing’. In the design phase, ‘complex designs generating a lot of off-cuts’, ‘design changes’ and ‘incorrect drawing details’ were identified as the significant causes of waste. Also, findings revealed that the causes of waste such as ‘lack of planning and organisation’, ‘inadequate communication and coordination among parties’ and ‘poor workmanship causing rework’ impact highly on waste generation during the construction/renovation phase. Additionally, it is interesting to note that ‘inefficiencies in communication and coordination’ impact highly in generating construction waste throughout the healthcare construction lifecycle stages.

The results revealed that the functional features in healthcare buildings such as: complex shapes and sizes of rooms; complex mechanical and electrical services; complex functional requirements; and the use of large and specialist types of materials impacted significantly on the generation of construction waste throughout the process. Apart from functional complexities, results revealed some operational complexities such as: continuous operation of the building; frequent changes required to facilitate future needs; and high wear and tear of the building which tend to increase construction waste generation during the facility operation.

In order to address the causes of construction waste causes and adverse waste generation issues related to functional and operational complexities within healthcare projects, interviewees outlined a number of construction waste minimisation best practices which have been used and have the potential to be implemented in healthcare construction project lifecycle stages. They suggested that waste minimisation best practices can be broadly grouped into six categories: project documents management, stakeholders waste awareness, effective communication and coordination, enhance buildability, effective materials selection and procurement, and effective management of changes. The next chapter presents the lifecycle construction waste minimisation framework for healthcare projects amalgamating the key findings of the study.

6

HEALTHCARE CONSTRUCTION WASTE MINIMISATION FRAMEWORK DEVELOPMENT AND VALIDATION

6.1 Introduction

This chapter describes the design, development and validation process of the proposed Healthcare Construction Waste Minimisation Framework (HC-WMF). The HC-WMF aims to propose a set of guidelines to follow throughout the lifecycle of a healthcare construction project to minimise construction waste generation, including a Self-Assessment Tool (SAT) to provide the means to assess the effectiveness of the guidelines implementation which will facilitate corrective actions in future projects to achieve continuous improvements in waste minimisation.

This chapter starts with an introduction to the proposed HC-WMF, which is based on the findings from the literature review (chapter 2), preliminary data collection (chapter 4) and case studies (chapter 5). This section describes the design and development methodology and components in the HC-WMF. The second section of this chapter describes the HC-WMF validation process. The third section summarises the key improvement measures that emerged from the validation process and the actions taken to improve the HC-WMF. This section also pinpoints the actions that could be conducted in future to improve and enhance the HC-WMF. The final section of this chapter presents insights into the implementation strategy of HC-WMF.

6.2 HC-WMF Design and Development

A framework is a set of beliefs, ideas and rules that is used as the basis for making judgements and decisions (Oxford Dictionary, 2005). It provides a basic structure to understand the problem and the approach for a feasible solution. After analysing the findings of this research, the themes identified were prioritised considering their

relevance and importance to reduce construction waste generation from healthcare projects. Thereafter, a comprehensive literature review was conducted to identify different framework structures and framework development methodologies to select the most suitable framework development strategy to suit to the findings of this research. The general problem solving approach was selected to develop the HC-WMF since the problem solving methodology addresses situations where "what is happening is less than desirable with the aim of rectifying the situation" (Alarcon, 1997). This approach has been successfully implemented in many sectors, including construction, to solve problems. A study conducted by Serpell and Alarcon (1998) developed a CPIM based on general problem solving methodology which helps to improve the process of waste minimisation (Figure 6.1). The same study reported that the CPIM has been very effectively used in several construction projects since it allows "a structured process to gather information about the construction process and repeatability and reliability of improvements efforts that can be fed back with experience and lessons learned from previous projects".

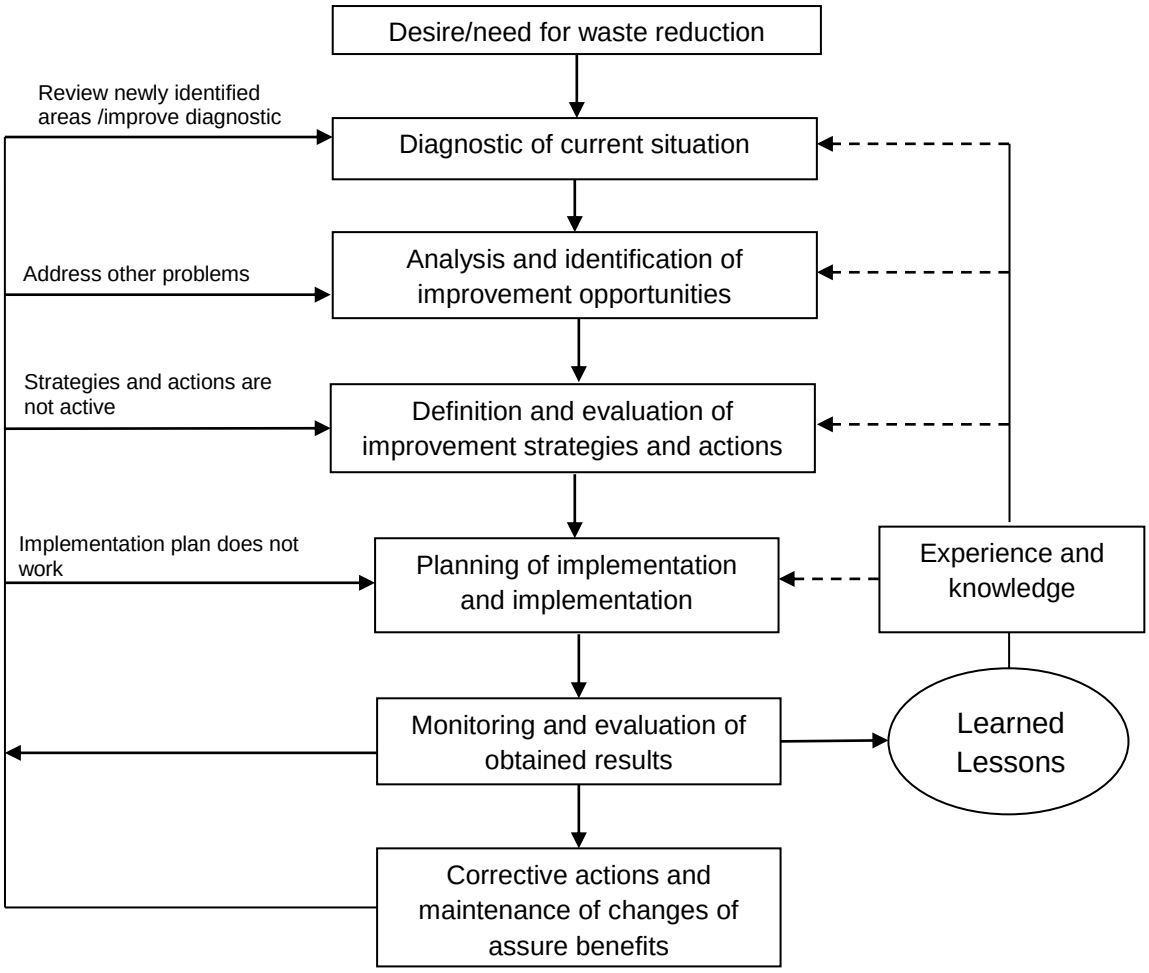


Figure 6.1: Construction Process Improvement Methodology (CPIM)

(Source: Serpell and Alarcon 1998)

The first two key steps in the CPIM: diagnosis of the current situation (to identify the present happenings that are less than desirable); and analysis and identification of improvement opportunities (recommend improvement actions to minimise waste) were used to develop the HC-WMF. Firstly, literature review and preliminary data collection study findings were arranged in a logical sequence and efforts were made to diagnose the construction waste generation issue in healthcare construction projects (First step). Findings revealed that all types of healthcare projects generate high quantities of construction waste and it is an emerging issue in the country at the moment due to the massive capital investment programme. Following the second step in the CPIM, preliminary data collection and case study results were used to analyse causes of construction waste in healthcare projects and to identify waste minimisation opportunities within the healthcare construction process. Based on these findings, the HC-WMF was developed embedding waste minimisation best practices that require implementing over the project lifecycle.

However, in order to complete the whole CPIM cycle as shown in the Figure 6.1, it is important to: evaluate the suitability of the proposed improvement suggestions; plan and implement proposed improvements; monitor and evaluate results; and take corrective actions for future improvements. Therefore, during the validation process, the contents in the HC-WMF were analysed to identify their appropriateness for reducing construction waste generation on healthcare projects and their capacity to encompass any necessary improvements (Step 3). Additionally, the validation study explored potential implementation strategies for HC-WMF even though the implementation strategy is not included as an integral part of the proposed HC-WMF (Step 4). The SAT was developed to assess the effectiveness in implementing the proposed HC-WMF (Step 5) to provide a learning platform for corrective actions in future projects for continuous improvement (Step 6).

6.2.1 Introduction to the HC-WMF

The aim of the HC-WMF is to provide a detailed guideline to use in healthcare projects to reduce lifecycle construction waste generation. The HC-WMF consists of three components: high level, low level and SAT. The contents of the HC-WMF components are linked through a coding system (numbering system and colour system), which correlates high level components, low level components and SAT. The use of a coding system provides an easy reference to waste minimisation strategies in HC-WMF at both high and low levels and also during the assessment of HC-WMF.

6.2.1.1 High level HC-WMF

The high level HC-WMF is generic and consists of two major components: waste minimisation strategies; and review and feedback (Figure 6.2).

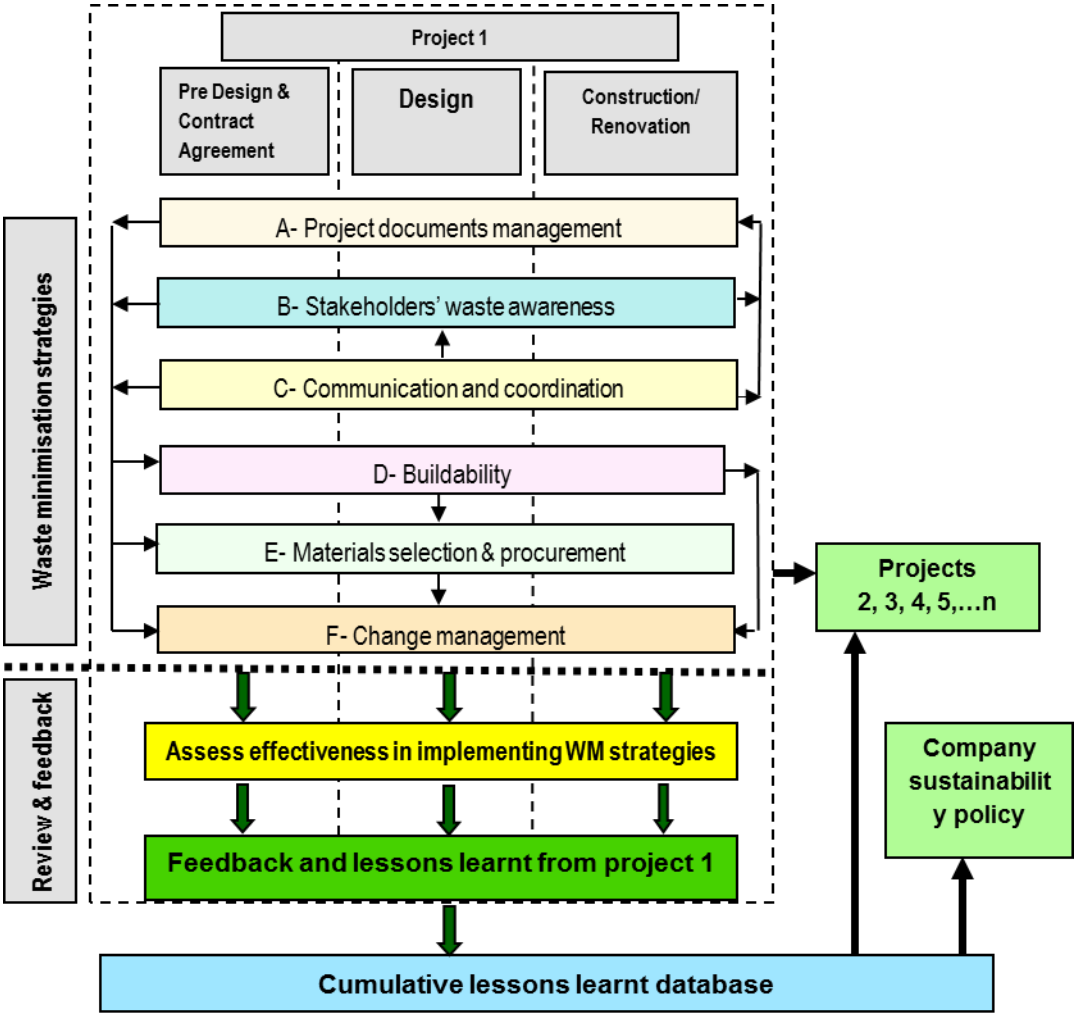


Figure 6.2: High level HC-WMF (See Appendix 6.1 for Draft HC-WMF)

Waste minimisation strategies: Six waste minimisation strategies identified from the data collection studies were proposed in the high level HC-WMF to be implemented throughout the healthcare project lifecycle. These waste minimisation strategies are: project document management; stakeholders' waste awareness; communication and coordination; buildability; materials selection and procurement; and change management. These waste minimisation strategies were placed in the vertical axis of the high level HC-WMF. The project lifecycle was divided into three phases: pre-design and contract agreement; design; construction/renovation taking into consideration the procurement systems (i.e. PFI, Procure 21, LIFT) used in healthcare projects. The project lifecycle phases were placed in the horizontal axis of the high level HC-WMF.

Moreover, particular attention was given when arranging waste minimisation strategies to ensure that they are in line with the sequence of construction activities. However, the proposed waste minimisation strategies cannot be implemented in isolation and should be considered in conjunction with other waste minimisation strategies. For instance, communication and coordination is essential to increase the awareness of stakeholders about construction waste minimisation. The interrelationships between waste minimisation strategies are shown in the high level HC-WMF using arrows that represent association links (Figure 6.2).

Review and Feedback: The high level HC-WMF aims to facilitate effective use of lessons learnt from one project to another to achieve continuous improvement through time. The effectiveness in implementing waste minimisation strategies in each lifecycle phase can be assessed using the SAT (see section 6.2.2). The learning outcomes from each healthcare construction project are expected to transfer into a cumulative lessons learnt, database. These accumulated learning outcomes can be used to enhance the company's sustainability policy and encourage the implementation of HC-WMF in future projects to gradually reduce waste.

6.2.1.2 Low level HC-WMF

Waste minimisation strategies presented in the high level HC-WMF are further detailed within the six low level HC-WMF components which specify activities to be performed in each lifecycle phase under each waste minimisation strategy (Figure 6.3). These components are: (A) Project document management; (B) Stakeholders' waste awareness; (C) Communication and coordination; (D) Buildability; (E) Materials selection and procurement; and (F) Change management. As shown in the Figure 6.3 the low level HC-WMF design also follows the same coding system and the same horizontal and vertical axis used in the high level design to maintain consistency and easy reference. All lifecycle waste minimisation activities stated under each lifecycle phase (pre-design and contract agreement; design; and construction/renovation) in the low level HC-WMF were accumulated from the findings from this research study. These are discussed below.

Waste minimisation strategies	Lifecycle implementation		
	Pre Design & Contract Agreement (PC)	Design (DE)	Construction/Renovation (CR)
A Project Documents Management	A.1.PC A.1.PC (a,b,c,d,e,f,g) A.2.PC A.3.PC	A.1.DE A.2.DE A.2.DE (a,b,c) A.3.DE	A.1.CR A.2.CR A.2.CR (a,b,c,d) A.3.CR
B Stakeholders' Waste Awareness	B.1.PC B.2.PC	B.1.DE	B.1.CR
C Communication and Coordination	A.1.PC A.2.PC	B.1.DE B.2.DE	C.1.CR C.2.CR
D Buildability	D.1.PC	D.1.DE D.2.DE D.3.DE D.4.DE	D.1.CR D.1.CR (a, b) D.2.CR D.3.CR
E Materials Selection and Procurement	E.1.PC E.2.PC	E.1.DE E.2.DE E.3.DE	E.1.CR E.2.CR E.3.CR
F Change Management	F.1.PC F.2.PC	F.1.DE F2.DE F.3.DE F.4.DE	F.1.CR

Figure 6.3: Low level HC-WMF (See Appendix 6.1 for Draft HC-WMF)

A- Project Documents Management

Findings from both the preliminary data collection and the case study revealed that inefficient use of project documents throughout the healthcare project lifecycle contributes to waste generation. For instance, the inherent complexities within the healthcare briefing process due to the large number of users' involvement and complexities in requirements; interviewees' in above studies revealed incomplete briefing is a major cause of waste in healthcare projects. Moreover, the research study results emphasised the importance of producing a complete brief during the pre-design phase to reduce waste generation due to incomplete briefing. Therefore, in the low level HC-WMF (A.1.PC (a)) it was suggested that a complete project brief was produced. Similarly, it was recommended that preliminary specification documents (A.1.PC (b)), feasibility reports of project requirement documents (A.1.PC (c)), initial site waste management plans (A.1.PC (d)), and project change management procedure documents (A.1.PC (e)) were produced at the start of the project (see

Appendix 6.1). Furthermore, the requirements specified that updating changes and finalising the above documents should occur before starting the design phase (A.1.DE). During the design phase, to avoid later design changes and delays in drawings, it was suggested that the preparation of a complete set of design information documents including: drawings (A.2.DE (a)); and project specifications (A.2.DE (b)) were updated and finalised before starting actual construction/renovation activities on site (A.1.CR). Additionally, the research study results indicate the requirement of early planning and organisation of site activities including waste minimisation and management. Respectively, recommendations were made to prepare: a complete project programme (A.1.CR (a)); site waste management plans (A.1.CR (b)); and a materials delivery programme (A.1.CR (c)) in the construction/renovation phase.

Furthermore, the research study findings highlighted causes of waste related to inconsistencies in contract documents, waste minimisation issues not embedded in contract clauses, and unclear allocation of waste responsibilities within project partners. In order to eliminate adverse waste generation effects due to the above, it was recommended that clauses be inserted into the documentation specifying waste minimisation responsibilities for each project stakeholder (A.2.PC). Additionally, to motivate project partners to reduce waste generation, incentives for reducing construction waste should be stated in the contract documents (A.2.PC) (see Appendix 6.1 for low level HC-WMF section A).

In order to reduce inconsistencies in project documents (i.e. contract documents, project requirements documents, design information, construction information documents), research study results revealed the importance of sharing the same set of documents with project partners through project document integration. As such, it was proposed to: develop a database integrating project documents; share it with project partners; and upgrade the database continuously throughout the project lifecycle (A.3.PC, A.3.DE, and A.3.CR) (see Appendix 6.1).

B- Stakeholders' Waste Awareness

The research study results revealed that involvement of a large number of project partners' is a major barrier to effectively sharing essential project information as it limits opportunities to recognise each other's requirements early. Therefore, it was proposed to appoint project stakeholders (i.e. suppliers, trade contractors, product manufacturers) to the project as early as possible to increase their awareness of the

project's requirements and the project's waste minimisation targets while increasing opportunities to build up strong relationships.

In the light of the results provided in this research study, there are a number of causes of waste associated with stakeholders' lack of awareness of waste minimisation throughout healthcare projects' lifecycle: clients are not willing to change their requirements to standard sizes; clients lack of awareness of the construction process; designers lack of awareness about waste generation in the construction process; not thinking about the best ways to design; and lack of knowledge in alternative materials (see Figure 7.2). Correspondingly, the importance of organising waste awareness programmes to project stakeholders throughout the project lifecycle was noted in the low level of HC-WMF (B.2.PC, B.1.DE, and B.1.CR) (see Appendix 6.1 for low level HC-WMF section B).

C- Communication and Coordination

Inadequate and inefficient communication and coordination between project stakeholders was highlighted as a major cause of waste in healthcare projects due to the participation of a large number of stakeholders throughout the project process. In order to facilitate effective communication and coordination between project stakeholders, it was recommended that regular meetings be held (i.e. face to face, electronic discussion forums) with stakeholder groups throughout the project lifecycle to share construction waste minimisation information, project requirement information, design information and construction information (C.1.PC, C.1.DE, and C.1.CR). Additionally, to maintain consistency when sharing project information, it was suggested that uploading project information sharing documents (i.e. meeting minutes, memorandums, e-mails, project reports, etc.) into a database for sharing between project stakeholders (C.2.PC, C.2.DE, and C.2.CR) would reduce conflicts while keeping them up-to date with changes and decisions (see Appendix 6.1 for low level HC-WMF section C).

D- Buildability

The research study results disclosed the intrinsic complexities in healthcare project requirements, designs and construction/renovation process (refer section 5.4) which results in high waste generation rates from healthcare projects. These associated complexities originate causes of waste such as: rework, increase in off cuts; clashes between building elements; difficulties in adaptability and flexibility; incorrect drawing details; and materials handling and storage difficulties.

With the complexities in healthcare requirements and site constraints, the research study results highlighted some limitations to satisfy all the project requirements specified by the end users. With the intention of reducing waste generation due to the aforesaid complexities, it was recommended that assessment of the feasibility requirements of the project take place before starting the design (D.1.PC).

Similarly, healthcare designs have to satisfy Building Regulations published by the Department of Health (HBNs and HTMs) and are required to maintain different standards for different building spaces. With the difficulties in design standardisation due to Building Regulations, the findings of this research study clearly identified the increase in waste generation from healthcare constructions. In order to reduce adverse waste generation impacts due to the above, the recommendation was to: keep designs as simple as possible by using regular shapes and standard size elements (D.1.DE); and use low waste modern building technologies (i.e. offsite construction, modular units etc.) in the design as much as possible (D.2.DE).

Equally, the low level HC-WMF put forward recommendations to facilitate future expansions and changes in healthcare designs to reduce lifecycle waste generation from healthcare projects (D.3.DE) since healthcare buildings are subjected to change frequently throughout the lifecycle (see section 5.4). Additionally, it was suggested that an assessment of the buildability of the designs be undertaken before issuing them to the site (D.4.DE) to minimise buildability issues due to complexities associate with healthcare designs. Furthermore, to ensure effective management of site activities and minimise onsite waste generation the following waste minimisation activities were recommended: management of on-site materials storage facilities (D.1.CR)); obtaining prior approval for SWMPs from the healthcare facility management team (D.2.CR); management of materials deliveries to the site (D.3.CR); and monitoring of trade contractor activities according to the project programme (D.4.CR) (see Appendix 6.1 for low level HC-WMF section D).

E- Materials Selection and Procurement

Both preliminary data collection and case study findings suggest that materials selection and procurement is complicated in healthcare projects due to the use of large number of materials. These complexities originate a number of causes of waste: lack of awareness about alternative materials; over/under specification; wrong selection of the materials in the lifecycle; and materials procurement inefficiencies.

The low level HC-WMF outlined a number of waste minimisation activities to be implemented throughout the lifecycle of healthcare projects to reduce waste generation due to materials selection and procurement inefficiencies. In the pre-design and contract agreement phase it was suggested that detailed preliminary specification requirements be prepared including building maintenance requirements (E.1.PC) and that initial discussions take place with supply chain partners to arrange specific materials requirements (E.2.PC).

It is recommended that, to ensure an appropriate selection of materials to suit healthcare building lifecycle requirements, it is necessary to minimise unnecessary differentiation (E.1.DE), to consider long term building requirements when selecting materials (D.2.DE); and to obtain advice/input from project partners (E.2.DE) during the design phase.

Additionally, during the construction phase, a recommendation was proposed to minimise packaging waste (E.1.CR); and purchase customised materials to the project to reduce off cuts (E.2.CR) (see Appendix 6.1 for low level HC-WMF section E).

F- Change Management

In the light of the results provided in this research study, healthcare buildings are subjected to frequent changes throughout the building lifecycle to meet future users' and management needs. The low level HC-WMF proposed several waste minimisation activities to be implemented throughout the project lifecycle.

In order to avoid late changes in healthcare projects, it was recommended that prior approval be obtained from healthcare clients, end users and other relevant stakeholders on healthcare building requirements.(F.1.PC). Additionally, it was recommended that the development of a change management procedure at the start of the project to manage changes effectively would reduce construction waste generation (F.2.PC).

The low level HC-WMF suggested several actions for the healthcare design team to reduce waste: evaluate changes thoroughly and identify the best way of implementing those changes (F.1.DE); coordinate changes appropriately with project stakeholders (F.2.DE); redesign using minimum extra resources (F.3.DE); and obtain approval from clients before implementing changes on site (F.4.DE). Furthermore, it recommends the reuse of as much material as possible in the event of dismantling temporary or permanent parts of a building to guarantee high reuse rates (F.1.CR). This waste

minimisation activity which was especially embedded into the low level HC-WMF for renovation projects who frequently dismantle existing buildings (see Appendix 6.1 for low level HC-WMF section F).

6.2.1.3 Self-Assessment Tool

The SAT was developed to measure the effectiveness of the proposed waste minimisation activities implementation in a particular project to obtain feedback and lessons learnt for future projects to reduce construction waste generation through continuous improvements. This tool was developed using Excel Macros, which consists of seven worksheets: instructions for use; project details; assessment of strategies implementation in pre-design and contract agreement phase; assessment of strategies implementation in design phase; assessment of strategies implementation in construction/renovation phase; summary of project waste minimisation strategies implementation effectiveness; and feedback, learning outcomes and recommendations. **Instructions for use:** The first worksheet contains instructions on how to use the SAT including: aim of the SAT; the person responsible for acting; when to act; and self-assessment procedure (see Figure 6.4).

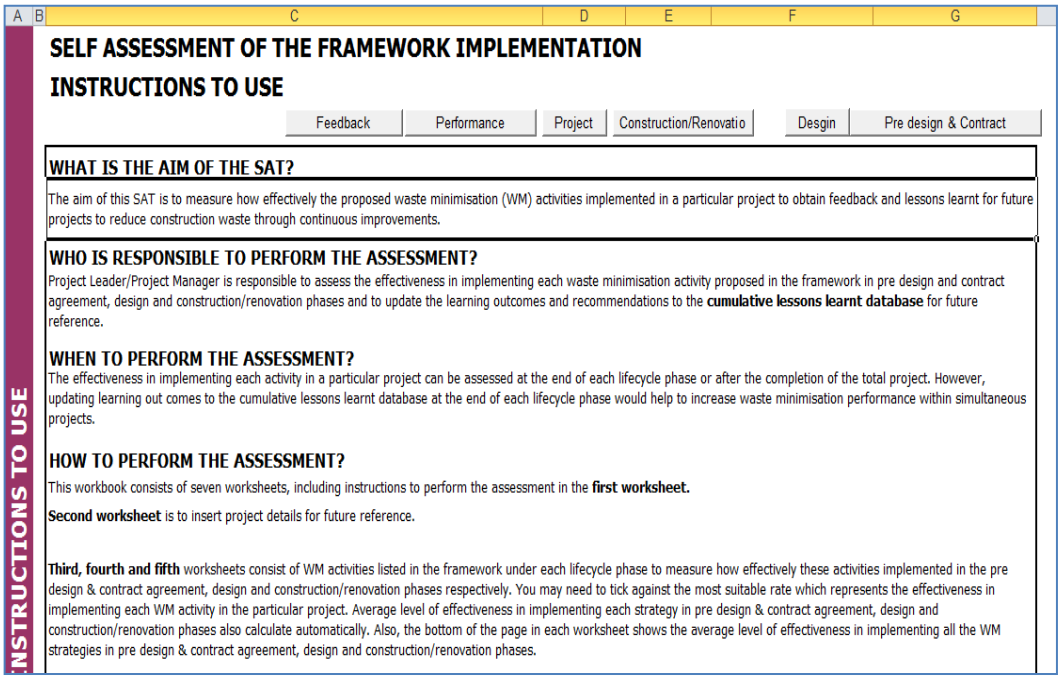


Figure 6.4: Instructions to use worksheet in SAT

Project details: This is the second worksheet in the SAT with information of the project: project name; project leader; project description; project waste generation, for future reference (see Figure 6.5).

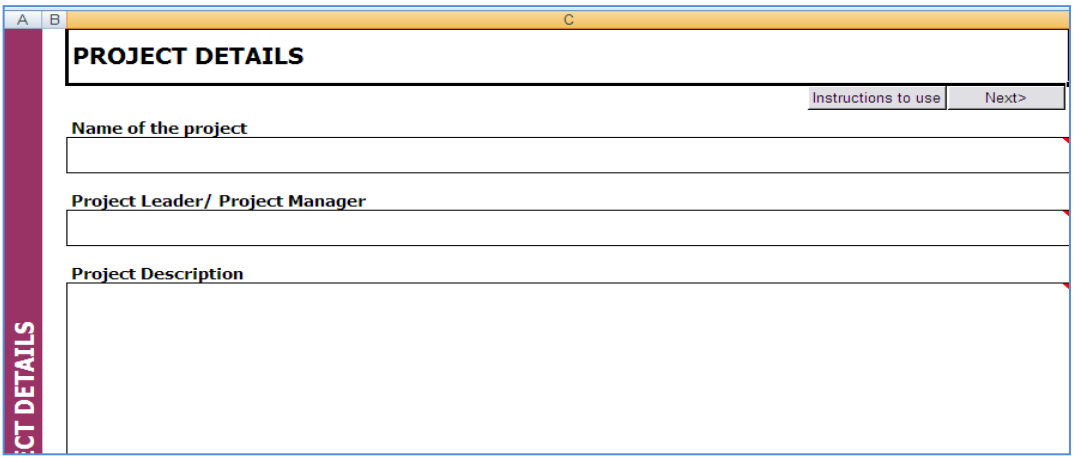


Figure 6.5: Project details worksheet in SAT

Assessment of strategies implementation in the pre-design & contract agreement, design, and construction/renovation phases: The third, fourth and fifth worksheets contain waste minimisation activities that are included in the low level HC-WMF which are needed to assess the effectiveness of HC-WMF implementation. Each waste minimisation activity is rated using a five point scale from very low to very high (see figure 6.6). A colour coding system (very low: low-red, average- yellow and high: very high- green) has been used to illustrate the level of implementation effectiveness clearly. The total score of each worksheet illustrates the overall effectiveness in implementing waste minimisation activities perticular to the project lifeycle stages (pre-design and contract agreement, deisgn, construction/renovation).

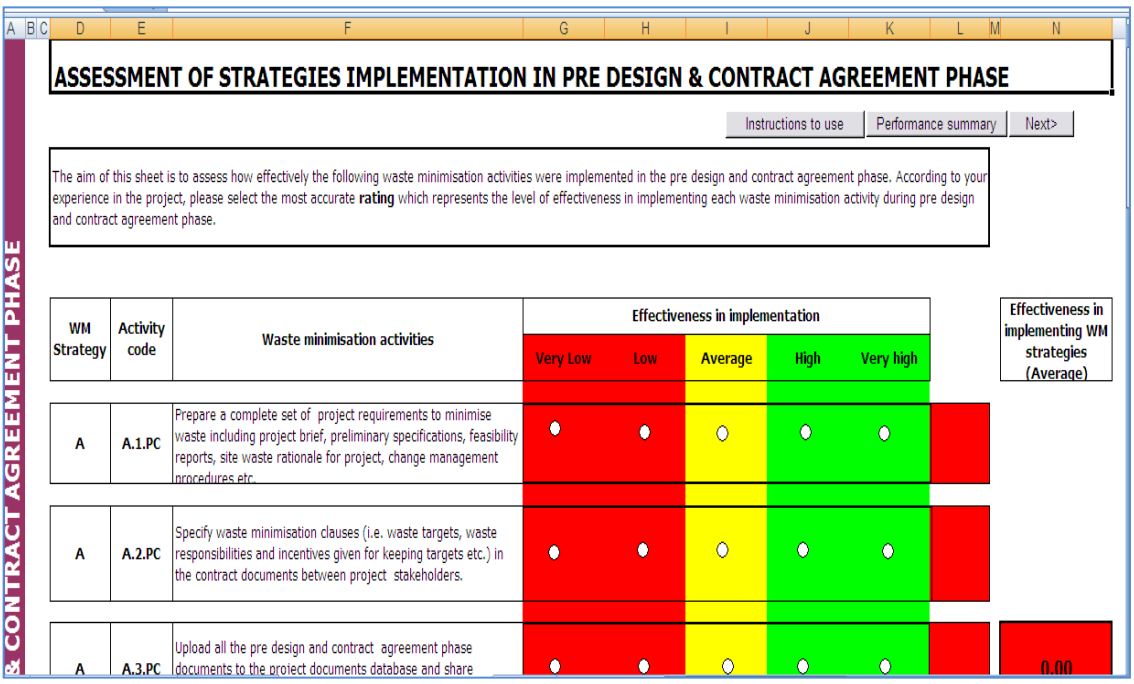
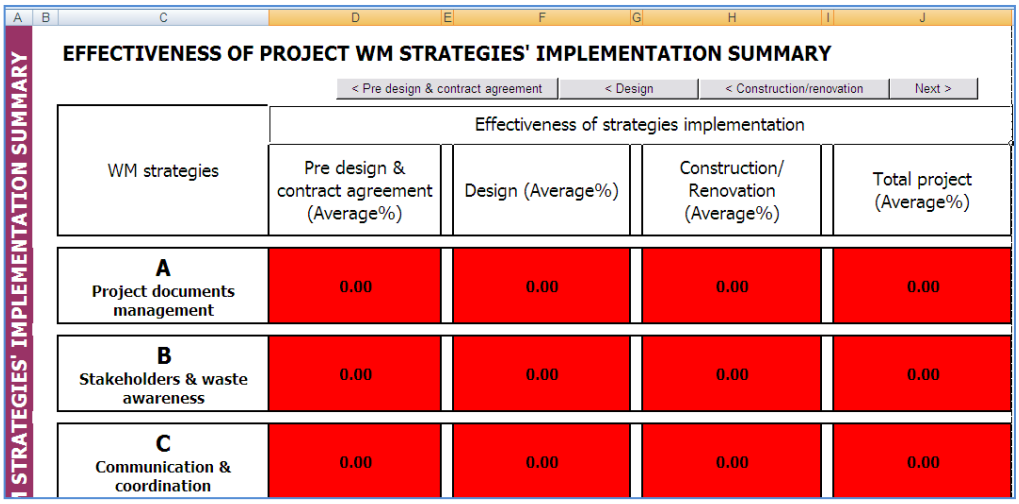


Figure 6.6: Assessment worksheet in SAT

Performance summary: The sixth worksheet in the SAT gives the overall summary of effectiveness in implementing waste minimisation strategies throughout the project lifecycle. With the use of the colour system, the project team can easily identify the level of effectiveness in implementing each waste minimisation strategy in each lifecycle phase (see Figure 6.7).



STRATEGIES' IMPLEMENTATION SUMMARY

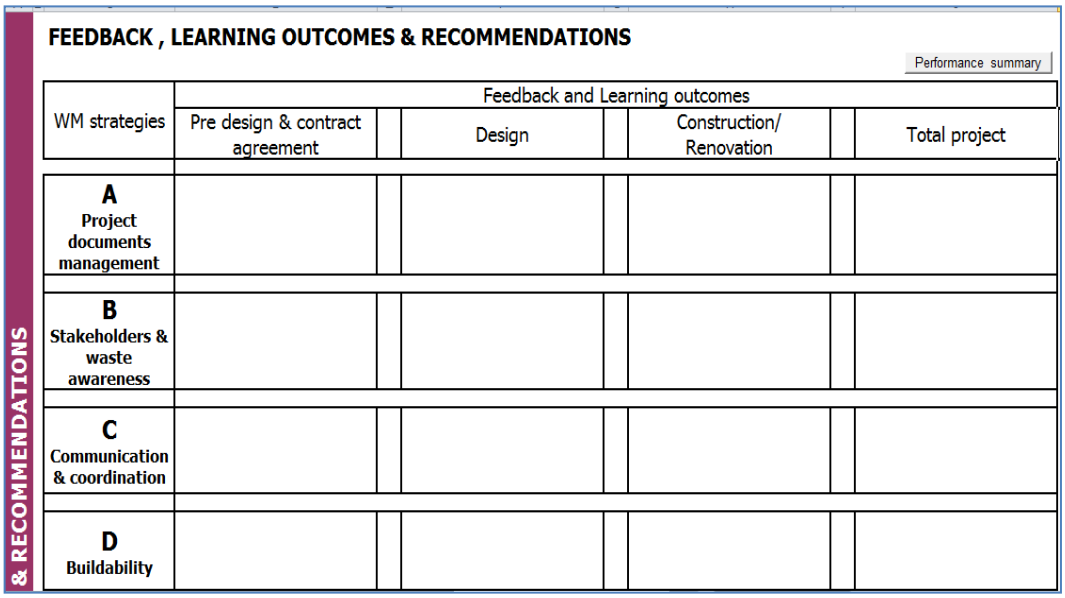
EFFECTIVENESS OF PROJECT WM STRATEGIES' IMPLEMENTATION SUMMARY

< Pre design & contract agreement | < Design | < Construction/renovation | Next >

WM strategies	Effectiveness of strategies implementation			
	Pre design & contract agreement (Average%)	Design (Average%)	Construction/ Renovation (Average%)	Total project (Average%)
A Project documents management	0.00	0.00	0.00	0.00
B Stakeholders & waste awareness	0.00	0.00	0.00	0.00
C Communication & coordination	0.00	0.00	0.00	0.00

Figure 6.7: Performance summary worksheet in SAT

Feedback and learning outcomes: The seventh worksheet in the SAT facilitates process of feedback and lessons learnt from a particular project to increase the performance in HC-WMF implementation in future projects. Additionally, these learning outcomes can be fed into a cumulative lessons learnt database to obtain sustained improvements in future projects with the use of past lessons learnt (see Figure 6.8).



& RECOMMENDATIONS

FEEDBACK , LEARNING OUTCOMES & RECOMMENDATIONS

Performance summary

WM strategies	Feedback and Learning outcomes			
	Pre design & contract agreement	Design	Construction/ Renovation	Total project
A Project documents management				
B Stakeholders & waste awareness				
C Communication & coordination				
D Buildability				

Figure 6.8: Feedback and lessons learnt worksheet in SAT

6.3 HC-WMF validation

6.3.1 HC-WMF validation process

The aim of the HC-WMF validation process is to examine the appropriateness of the proposed HC-WMF to minimise lifecycle waste generation from healthcare projects. This study consists of three stages: pre validation discussions; validation questionnaire; and validation interviews (see Figure 6.9).

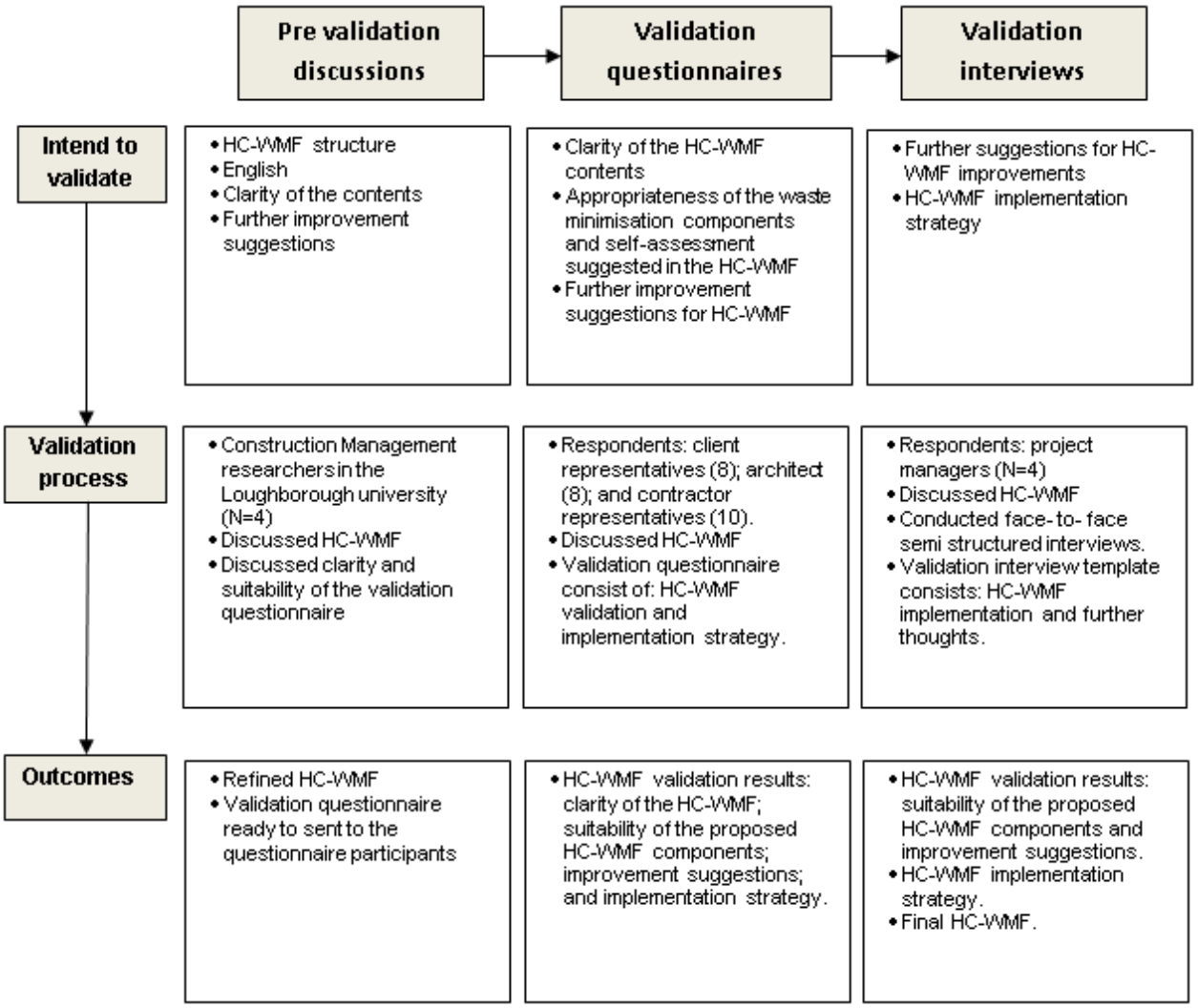


Figure 6.9: HC-WMF validation process

Pre-validation discussions: Before starting the main validation process, pre validation discussions were conducted with four construction management researchers at Loughborough University with the aim of refining the proposed HC-WMF. During the discussions, more emphasis was given to refining the HC-WMF (see Figure 6.9).

According to the participants' suggestions few changes were made to improve the clarity of the contents in the draft HC-WMF.

Validation Questionnaire: As the first step in the validation process, an electronic questionnaire was sent to twenty six respondents including: eight client representatives (General Manager, Estate Manager); eight architects and ten contractor representatives (Project/Site Managers, Project Directors), who have participated in this research study during the data collection stages (preliminary data collection and case study). The softcopies of refined HC-WMF were also sent to the respondents along with the questionnaire for the respondents' reference. Fifteen questionnaires were received representing a 58% active response rate including: five client representatives; four architects; and six contractor representatives. The aim of the validation questionnaire was to assess the components in the HC-WMF in terms of clarity and appropriateness to reduce lifecycle construction waste generation from healthcare projects. Additionally, in the questionnaire, the respondents were asked to state potential implementation strategies and further improvement suggestions for the proposed HC-WMF (see Figure 6.9).

Validation interviews: Validation interviews (semi- structured face-to-face) were conducted with four Project Managers who have experience in waste minimisation in healthcare projects. All four interviewees were participating in this study for the first time (see Section 3.5.5). The aim of the interviews was to establish external validity of the HC-WMF by assessing the appropriateness of the components in the HC-WMF and self-assessment procedure through external expertise. Also, efforts have been made during the interview to identify the best implementation strategy and improvement suggestions for the proposed HC-WMF.

The next section discusses the findings of the HC-WMF validation questionnaire and semi-structured interviews.

6.3.2 HC-WMF Validation Results

6.3.2.1 Clarity of the HC-WMF

The questionnaire respondents were asked to rate the level of agreement to statements provided on the clarity of the HC-WMF from 1 (strongly disagree) to 5 (strongly agree). The results obtained from the study are shown in the Table 6.1, which indicates that the majority of the respondents (above 90%) either 'agree' or 'strongly

agree' on the clarity of the HC-WMF in terms of its structure, contents, waste minimisation process, and relationships between waste minimisation strategies.

Table 6.1: Clarity of the HC-WMF

Clarity of the HC-WMF	**Strongly disagree 1**	**Disagree 2**	**Neither agree/ disagree 3**	**Agree 4**	**Strongly agree 5**
The structure of the proposed HC-WMF is clear.			1	11	3
The contents presented in the HC-WMF are clear.			1	13	1
The construction waste minimisation process shown in the HC-WMF is clear.				12	3
The relationships between waste minimisation strategies are clear.		1	1	12	1
The information flows between different projects to obtain continuous improvement on waste minimisation in healthcare projects is clear.			6	8	1
The instructions given to use the "SAT" are clear (Worksheet 1).			2	10	3
The assessment method proposed in the "SAT" to measure the effectiveness in			1	14	
The waste minimisation activities stated in the worksheets 3, 4 and 5 are clear to enough to do the assessment.				13	2

During the validation interviews, all the interviewees mentioned that the proposed HC-WMF structure, its contents and the waste minimisation procedure proposed is clear and logical. An interviewee mentioned:

> *"… Everything is specified and the contents are simple and very clear. Things have been arranged in a very logical order and make sense. All the waste minimisation activities are clearly stated in the framework. Anyone can easily implement this through a simple project management process…" (P2)*

Since six respondents (of 15) held a neutral view about the information flow between different projects (see Table 6.1), more emphasis was given during the validation

interviews to obtain respondents' views about the clarity of the information flow between projects in the continuous improvement process. Three interviewees stated that the arrows used in the high level HC-WMF are appropriate to indicate the relationships between waste minimisation strategies and information flows between different projects. An interviewee stated:

> *"….the arrows shown in the high level are appropriate and clear enough to indicate the related waste minimisation strategies and flow of information between project phases and other projects…" (P4)*

6.3.2.2 Appropriateness of the Selected Lifecycle Phases in the HC-WMF

The questionnaire respondents were asked to rate the level of agreement for the importance of implementing waste minimisation activities in the selected project lifecycle phases to reduce construction waste from healthcare projects from 1 (strongly disagree) to 5 (strongly agree). As shown in the Table 6.2, the majority of the respondents (above 80%) rated either "agree" or "strongly agree" confirming that the selection of the lifecycle phases in the HC-WMF are appropriate to the implementation of waste minimisation activities in healthcare projects.

Table 6.2: Appropriateness of the selected lifecycle stages in HC-WMF

Importance of selected life cycle phases	**Strongly disagree 1**	**Disagree 2**	**Neither agree/ disagree 3**	**Agree 4**	**Strongly agree 5**
Implementing waste minimisation activities in the "Pre design and Contract agreement phase (PC)" is important to minimise waste in healthcare.			3	9	3
Implementing waste minimisation activities in the "Design phase (DE)" is important to minimise waste in healthcare.			1	4	10
Implementing waste minimisation activities in the "Construction/Renovation phase (CR)" is important to minimise waste in healthcare.				8	7

All the interviewees who participated in the validation interviews also confirmed that the selection of the lifecycle phases to the HC-WMF are appropriate and illustrated the importance of implementing waste minimisation practices from the start of the project. An interviewee declared:

"…. with the use of PFI and P21 procurement methods there are overlaps in the project lifecycle phases which are difficult to differentiate. However, it is important to start implementing waste minimisation strategies from the start of the project to get actual benefits. Therefore, I think this classification is appropriate…" (P4).

6.3.2.3 Appropriateness of the Selected Waste Minimisation Strategies in the HC-WMF

The questionnaire respondents were asked to rate the level of agreement for the appropriateness of the selected waste minimisation strategies in reducing construction waste from healthcare projects from 1 (strongly disagree) to 5 (strongly agree). As shown in the Table 6.3, more than 60% of the respondents rate either "agree" or "strongly agree" confirming that the selected waste minimisation strategies in the HC-WMF are appropriate to minimise construction waste generation from healthcare projects. However, it can be noticed that 67% of the respondents rate "neither agree/disagree" for the 'change management' waste minimisation strategy. Therefore, during the validation interviews the appropriateness of the 'change management' waste minimisation strategy was specifically discussed with the interviewees.

Table 6.3: Appropriateness of the selected waste minimisation strategies in HC-WMF

Importance of selected waste minimisation strategies	Strongly disagree 1	Disagree 2	Neither agree/ disagree 3	Agree 4	Strongly agree 5
"Project documents management (A)" is important to minimise waste generation from healthcare projects.			5	8	2
"Stakeholder waste awareness (B)" is important to minimise waste generation from healthcare projects.				8	7
Adequate "Communication and coordination (C)" is important to minimise waste generation from healthcare projects.				7	8
"Buildability (D)" is important to minimise waste from healthcare projects.		1		2	12
Appropriate "Materials selection and procurement (E)" is important to minimise waste generation from healthcare projects.				9	6
"Change management (F)" is important to minimise waste generation from healthcare projects			10	2	3

All the interviewees highlighted the importance of a comprehensive change management procedure for healthcare projects to reduce lifecycle waste generation due to continuous changes. An interviewee reported:

> *"… Many buildings change in their use, especially in healthcare with changes in medical practices and technology. This may come into the pre-design phase, but should be reviewed at design and construction stage. Therefore, a comprehensive change management procedure is important to reduce construction waste generation throughout the facility lifecycle due to changes..." (P3)*

6.3.2.4 Appropriateness of the Proposed Waste Minimisation Activities in the HC-WMF

During the validation questionnaire survey, the respondents were asked to rate the importance of proposed waste minimisation activities listed in the low level HC-WMF according to their level of agreement from 1(strongly disagree) to 5 (strongly agree). As shown in the Table 6.4, the majority of the respondents accepted that all the waste minimisation activities proposed in the low level HC-WMF are important to minimise construction waste generation from healthcare projects. Even so, few respondents held opposite views to those stated above and rated some of the proposed waste minimisation practices as being unimportant in minimising construction waste from healthcare projects, although this number is comparatively insignificant. However, these contrasting results were further discussed in detail during the validation interviews and all the interviewees confirmed that they are important and relevant to healthcare projects. Following are some of the narrations taken from the interview transcriptions.

> *"… all the proposed waste minimisation activities in the HC-WMF are important…" (P1)*

> *"…. The proposed waste minimisation activities cover major waste generation issues in healthcare. It is also good to see waste minimisation activities that give emphasis on minimising lifecycle impacts…" (P2)*

> *"…. The actions to be performed under each waste minimisation strategy are comprehensively explained; actions are clearly defined. It is a good piece of work…" (P4)*

Table 6.4: Appropriateness of the proposed waste minimisation activities in HC-WMF

Importance of waste minimisation activities	Strongly disagree 1	Disagree 2	Neither agree/ disagree 3	Agree 4	Strongly agree 5
Completion of all the project requirements documents before starting the design is important (A.1.PC).	1		3	8	3
Specifying waste minimisation clauses in the contract documents is important (A.2.PC).			2	7	6
Completing all the design and construction information before starting site activities is important (A.2.DE & A.2.CR).		1	5	7	2
Integrating all the documents to a database and share with stakeholders is important (A.3.PC, A.3.DE & A.3.CR).		1	6	6	2
Appointing all the key stakeholders to the project as early as possible is important (B.1.PC).		1	3	7	4
Organising waste awareness programmes to project stakeholders is important (B.2.PC, B.2.DE & B.2.CR).			1	10	4
Conducting regular communication with stakeholders to share project information is important (C.1.PC, C.1.DE & C.1.CR).			1	10	4
Sharing all the project information sharing documents with stakeholders through a database is important (C.2.PC, C.2.DE & C.2.CR).			6	8	1
Assessing the feasibility of the project requirements within project constraints is important (D.1.PC).		1	4	7	3
Keeping designs as simple as possible using standard shapes and sizes is important (D.1.DE).	1	1		6	7
Applying low waste modern technologies to the design as much as possible are important (D.2.DE).		1	2	5	7
Keeping allocations for future expansions and changes in the design is important (D.3.DE).	1		1	3	10
Assessing the buildability of the design before starting site activities is important (D.4.DE).			1	2	12
Allocating site spaces for specific activities is important (D.1.CR).			5	6	4
Obtaining approval for site waste management plans from facility managers before starting site activities is important (D.2.CR).		3	3	9	
Managing materials deliveries to the site is important (D.3.CR).			1	6	8
Monitoring trade contractor activities according to the project programme is important (D.4.CR).			2	8	5
Preparing project preliminary specifications as early as possible is important (E.1.PC).		1	4	8	2

Table 6.4 cont.: Appropriateness of the proposed waste minimisation activities in HC-WMF

Importance of waste minimisation activities	Strongly disagree 1	Disagree 2	Neither agree/ disagree 3	Agree 4	Strongly agree 5
Discussing special material requirements with supply chain partners as early as possible is important (E.2.PC).			1	11	3
Selecting minimum number of materials to the building as much as possible is important (E.1.DE).		2	6	7	
Selecting materials according to building long term requirements are important (E.2.DE).			1	5	9
Obtaining ideas/advice from supply chain partners when selecting materials is important (E.3.DE).				2	13
Minimising packaging waste when purchasing materials is important (E.1.CR).			1	9	5
Purchasing customised materials where possible is important (E.2.CR).		2	6	5	2
Obtaining prior approval for project requirements to avoid later changes is important (F.1.PC).			1	10	4
Developing a clear change management procedure for the project is important (F.2.PC).			1	12	2
Evaluating changes to identify the best method when implementing changes is important (F.1.DE).			5	6	4
Coordinating changes appropriately with relevant stakeholders is important (F.2.DE).			1	11	3
Redesigning changes with minimum extra resources is important (F.3.DE).		2	8	3	2
Obtaining approval from clients, end users etc. before implementing changes on site is important (F.4.DE).		3	4	5	3
Recovering materials as much as possible when dismantling existing elements during renovation activities is important (F.1.CR).		1	2	7	5

The questionnaire survey and validation interview results indicate that waste minimisation strategies and waste minimisation activities specified in the HC-WMF are appropriate to reduce lifecycle construction waste generation from healthcare construction projects. During the validation interviews all the interviewees explicitly mentioned that the proposed waste minimisation strategies are appropriate, as illustrated by one interviewee:

"… All the waste minimisation strategies are very important and cover major waste generation issues in healthcare construction. Waste

minimisation activities are very simply and logically described in the low level HC-WMF…." (P4)

6.3.2.5 Appropriateness of the Self-Assessment Procedure

A specific section in the pre-validation questionnaire was dedicated to the assessment of the appropriateness of the proposed self-assessment procedure in HC-WMF. The respondents were asked to rate their level of agreement about the proposed self-assessment procedure from 1 (strongly disagree) to 5 (strongly agree). As shown in Table 6.5, results indicate that the scale proposed to measure the effectiveness in implementing waste minimisation activities is appropriate (12 of 15). However, most of the respondents had given low rankings to the: easiness in assessing effectiveness of waste minimisation activities implementation; and appropriateness of calculating averages to measure effectiveness in the HC-WMF implementation. During the validation interviews, more efforts were made to ascertain the views of interviewees' regarding appropriateness of the self-assessment procedure recommended in the HC-WMF, since validation questionnaire findings gave negative insights about the self-assessment procedure. Validation interviewees also confirmed the findings from the questionnaire and recommended some improvement measures to the self-assessment procedure. However, all the interviewees accepted that the "proposed self-assessment procedure is acceptable as a concept and requires further improvements" (P2).

Table 6.5: Appropriateness of the self-assessment procedure

Appropriateness of the self-assessment procedure	Strongly disagree 1	Disagree 2	Neither agree/ disagree 3	Agree 4	Strongly agree 5
The scale proposed to measure the effectiveness of implementing waste minimisation activities in the project is suitable.			3	11	1
Waste minimisation activities stated in worksheets 3, 4 and 5 to assess the implementation effectiveness are easy to assess.		1	6	7	1
Calculating averages to measure the effectiveness of each strategy's implementation in a project is suitable.		1	12	2	
Calculating averages to measure the effectiveness of strategies implementation in each lifecycle phase is appropriate.		3	10	2	

6.3.2.6 Improvement Measures Proposed for HC-WMF

The questionnaire respondents and interviewees put forward a few recommendations to enhance: clarity of HC-WMF components; and lifecycle waste minimisation by using HC-WMF. The Table 6.6 shows the improvement suggestions and actions taken to modify the contents of HC-WMF.

Table 6.6: Improvement measures to the proposed HC-WMF

Participants' improvement suggestions	Actions taken to modify the HC-WMF
• A clear decision making process is important to be introduced at the pre design phase to avoid conflicts in the decision making process due to the large number of stakeholders involvement in healthcare projects (three interviewees)	• Inserted a new waste minimisation activity A.1.PC(f): **A.1.PC(f):** project decision making process
• It is important to increase awareness about the project change management procedure among stakeholders to obtain expected outcomes (three interviewees) i**.e.** "… change is one of the biggest sources of waste, and if not managed carefully it will undo all the other measures put in place to minimise waste. Therefore it is important to increase awareness of the project stakeholders about the change management procedure…" (P1)	• In order to make stakeholders aware of the project change management and decision making process reworded B.2.PC, B.1.DE and B.1.CR as follows: **B.2.PC:** Organise awareness programmes (i.e.SWMPs, decision making process, materials logistics programme, project programme, change management process etc.) for clients, end users, hospital staff etc. as appropriate, to increase their motivation and interest in minimising construction waste from project. **B.1.DE:** Organise awareness programmes (i.e.SWMPs, decision making process, materials logistics programme, project programme, change management process etc.) for design team partners as appropriate, to increase their motivation and interest in minimising construction waste from project. **B.1.CR:** Organise awareness programmes (i.e SWMPs, decision making process, materials logistics programme, project programme, change management process etc.) for the construction team, supply chain partners etc. as appropriate, to increase their motivation and interest in minimising construction waste from project

Table 6.6 cont.: Improvement measures to the proposed HC-WMF

Participants' improvement suggestions	Actions taken to modify the HC-WMF
• For easy reference, integrate materials ordering, delivery, storage and handling activities and propose a clear logistics control mechanism in the HC-WMF (four interviewees).	• Reworded A.2.CR (c) as follows: **A.2.CR(C):** Materials logistics plan (i.e. deliver dates, types and quantities, storage, allowances, roles stakeholders etc). • Merge D.1.CR and D.3.CR and reword as follows (new activity D.1.CR) **D.1.CR:** Manage materials deliveries and storage facilities on site according to the materials logistics control plan (A.2.CR(C)). **D.1.CR(a):** manage materials deliveries through offsite storage facilities; just in time deliveries etc. **D.1.CR(b):** allocate site spaces for materials storage, waste materials segregation, reuse and recycling before starting construction/ renovation. • Inserted a new waste minimisation activity (E.3.CR) **E.3.CR:** Follow materials logistics plan always as specified in A.2.CR (C) when purchasing materials to determine types and quantities of materials, exact delivery dates etc.
• The word 'common materials' in the E.1.DE is not very clear and not disseminate the correct meaning to the users (four questionnaire respondents).	• Reworded E.1.DE as follows: **E.1.DE:** Minimise unnecessary differentiation when selecting materials to the building where possible to minimise leftovers, off cuts etc. (i.e. use same colour from one material to all the possible places in the building etc.).
• Insert project professional team' to activities E.2.PC and E.3.DE (three interviewees). **i.e.** "…project professional team engagement is equally important during the materials selection stage. Not only supply chain partners. They can't make decisions on their own…" (P3)	• Reworded E.2.PC and E.3.DE as follows: **E.2.PC:** Conduct initial discussions about specific materials requirements (i.e.product customisation etc.) with client team, design team, construction team, supply chain partners etc. as early as possible. **E.3.DE:** Obtain ideas/advice/input from main contractor, trade contractors, product manufacturers, suppliers etc. about materials maintenance, quality, durability requirements etc. when selecting materials.

The HC-WMF, which integrated respondents' suggestions for improvements are shown in the Figure 6.10 to Figure 6.14.

The validation interviewees also proposed several improvement suggestions to the HC-WMF to facilitate wider adoption and enhance to reliability of waste minimisation outcomes. However, these were suggested as part of future work since they need additional investigation. The proposed improvement suggestions by the interviewees are as follows.

1. Develop a user guide (including definitions of terms, set of template documents and databases)
2. Integrate a section in the HC-WMF to demonstrate the possibilities of using existing tools, guidance documents, and policies and legislation to increase the usability of the HC-WMF among healthcare industry practitioners.
3. Propose a weighted score instead of averages to measure the effectiveness in implementing waste minimisation activities proposed in the HC-WMF. These weighted scores can be assigned based on the level of importance of each waste minimisation activity in terms of construction waste minimisation on healthcare projects.
4. Simplify waste minimisation activities assessment by splitting them into more specific activities and outline a list of deliverables to check during the assessment.
5. Expand this HC-WMF for different levels of users (i.e. national level, strategic level).

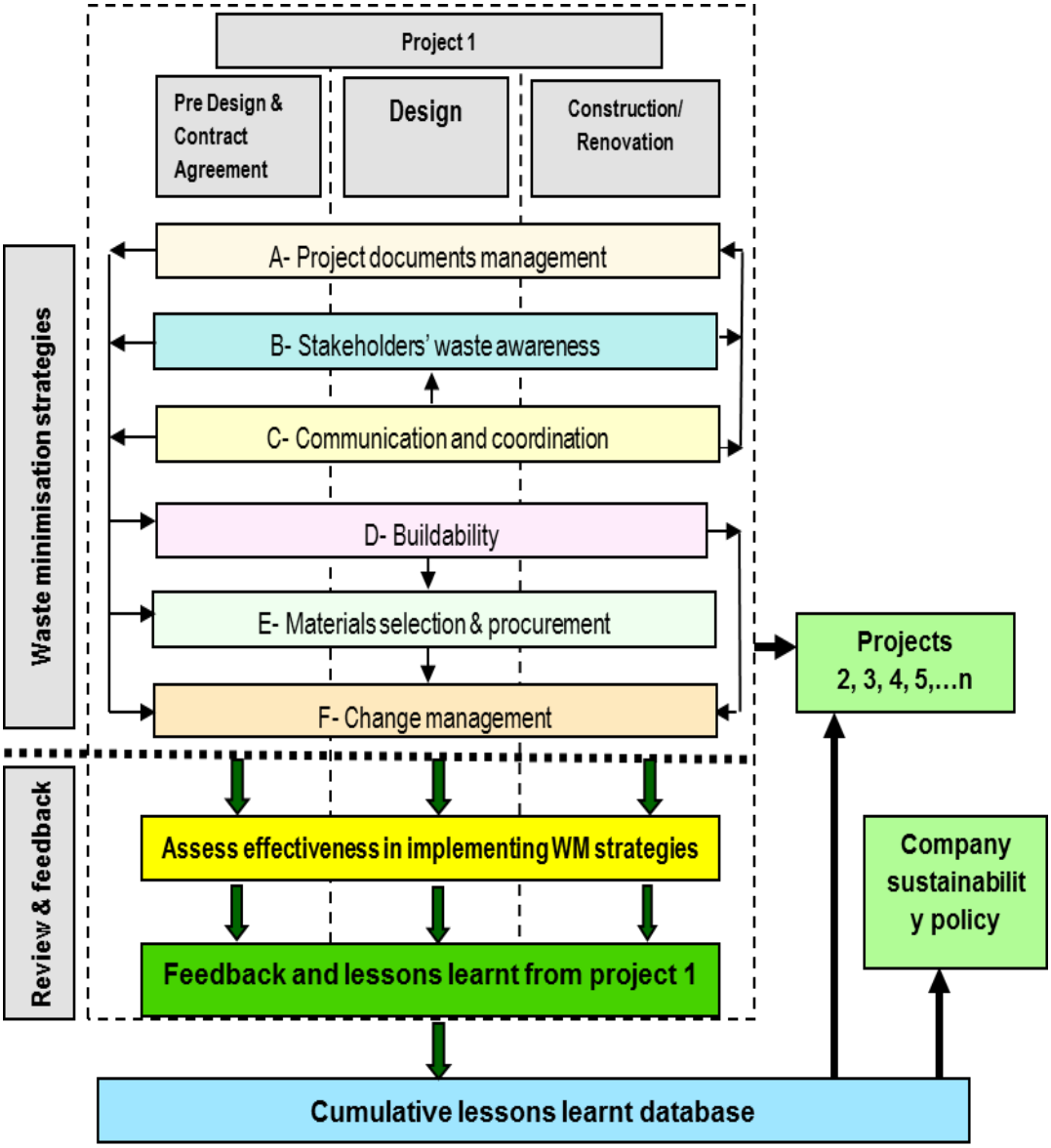


Figure 6.10: High level HC-WMF

Waste minimisation strategies	Lifecycle implementation		
	Pre Design & Contract Agreement (PC)	Design (DE)	Construction/Renovation (CR)
A Project documents management	**A.1.PC** Prepare a complete set of project requirements to minimise waste including: **A.1.PC(a)** project brief (i.e. room data, M&E requirements, finishes, medical equipment etc.); **A.1.PC(b)** preliminary specifications (i.e. requirement statements including expected life time of the building, quality requirements etc.); **A.1.PC(c)** feasibility reports of project requirements; **A.1.PC(d)** initial proposals of site waste management plans; **A.1.PC(e)** project change management process requirements; **A.1.C(f):** project decision making process; and **A.1.PC(g)** other project requirements documents as appropriate to reduce waste due to late changes.	**A.1.DE** Update changes and finalise the project requirements before starting the design.	**A.1.CR** Update changes and finalise the project design information before starting construction/renovation.
	A.2.PC Specify waste minimisation clauses (i.e. waste targets, waste responsibilities and incentives given for keeping targets etc.) in the contract documents shared between project stakeholders (i.e. project leader and main contractor, main contractor and designers etc.).	**A.2.DE** Prepare a complete set of design information documents to minimise waste including: **A.2.DE(a)** set of drawings (i.e. architectural, structural, M&E, medical equipment installations etc.); **A.2.DE(b)** set of project specifications to comply with healthcare building regulations (i.e. HBNs, HTMs etc.); and **A.2.DE(c)** other documents as appropriate to reduce waste due to lack of design information.	**A.2.CR** Prepare a complete set of construction information documents before starting site activities including: **A.2.CR(a)** project programme (i.e. sequence of site activities and trades; resource requirements etc.); **A.2.CR(b)** site waste management plans (i.e. waste segregation, reuse, recycling, waste targets etc.); **A.2.CR(c)** materials logistics plan (i.e. delivery dates, types and quantities, storage allowances, roles of stakeholders etc); and **A.2.CR(d)** other construction information documents as appropriate to reduce waste.
	A.3.PC Develop a project documents database; integrate all the pre design and contract agreement phase project documents to share between project stakeholders to obtain necessary project information; and update them frequently.	**A.3.DE** Upload all the necessary design phase project documents as appropriate to the project documents database specified in A.3.PC and update them frequently.	**A.3.CR** Upload all the necessary construction/renovation phase project documents as appropriate to the project documents database specified in A.3.PC and update them frequently.

Figure 6.11: Low level HC-WMF- Project documents management

Waste minimisation strategies	Lifecycle implementation		
	Pre Design & Contract Agreement (PC)	Design (DE)	Construction/Renovation (CR)
B Stakeholders waste awareness	**B.1.PC** Appoint key stakeholders (i.e. product manufacturers, suppliers etc.) to the project as early as possible to increase their awareness about project waste minimisation requirements. **B.2.PC** Organise awareness programmes (i.e. SWMPs, decision making process, materials logistics programme, project programme, change management process etc.)for clients, end users, hospital staff etc. as appropriate to increase their motivation and interest in minimising construction waste on the project.	**B.1.DE** Organise awareness programmes (i.e. SWMPs, decision making process, materials logistics programme, project programme, change management process etc.) for design team partners as appropriate to increase their motivation and interest in minimising construction waste on the project.	**B.1.CR** Organise awareness programmes (i.e. SWMPs, decision making process, materials logistics programme, project programme, change management process etc.) for construction team, supply chin partners etc. as appropriate to increase their motivation and interest in minimising construction waste on the project.
C Communication and coordination	**C.1.PC** Use face to face meetings, computer supported electronic discussion forums etc. to discuss best WM practices to be implemented into the project and to share project requirements with project stakeholders as appropriate. **C.2.PC** Upload all the necessary project information sharing documents (i.e. meeting minutes, e- mails, memorandums, project reports etc.) for circulation among project stakeholders during the pre design and contract agreement phase to the database specified in A.3.PC.	**C.1.DE** Use face to face meetings, computer supported electronic discussion forums etc. to share design information with project stakeholders as appropriate. **C.2.DE** Upload all the necessary project information sharing documents (i.e. meeting minutes, e- mails, memorandums, project reports etc.) for circulation among project stakeholders during design phase to the database as specified in A.3.PC.	**C.1.CR** Use face to face meetings, computer supported electronic discussion forums etc. to discuss onsite WM issues and to share construction information with project stakeholders as appropriate. **C.2.CR** Upload all the necessary project information sharing documents (i.e. meeting minutes, e- mails, memorandums, project reports etc.) for circulation among project stakeholders during the construction/renovation phase to the database specified in A.3.PC.

Figure 6.12: Low level HC-WMF- Stakeholders' waste awareness & Communication and coordination

Waste minimisation strategies	Lifecycle implementation		
	Pre Design & Contract Agreement (PC)	Design (DE)	Construction/Renovation (CR)
D Buildability	**D.1.PC** Assess the feasibility of the project requirements within the project constraints (i.e. site space availability, resource availability, skills and technology etc.) to avoid rework etc. and provide feasibility reports as required in A.1.PC(c).	**D.1.DE** Keep designs as simple as possible (i.e. use regular shapes etc.) and use standard size elements where possible to minimise off cuts etc. **D.2.DE** Apply low waste modern building technologies to the design where possible (i.e. off-site pre-fabricated elements, modular construction units), steel frames etc.). **D.3.DE** Consider future expansions and changes required to the building and keep allowances necessarily (i.e. allow large and flexible spaces, additional service connections etc.). **D.4.DE** Assess the buildability of the design before starting site activities (i.e. use clash detection techniques such as 3D modelling, simulations etc. to avoid clashes between building elements).	**D.1.CR** Manage materials deliveries and storage activities on site according to the materials logistics control plan (A.2.CR(C)). **D.1.CR(a)** manage materials deliveries through offsite storage facilities; just in time deliveries etc. **D.1.CR(b)** allocate site spaces for materials storage, waste materials segregation, reuse and recycling before starting construction/renovation. **D.2.CR** Obtain prior approval from the healthcare facility management team for site waste management plans (A.2.CR(b) before starting site works. **D.3.CR** Monitor trade contractor activities according to the project programme (A.2.CR(a)) to avoid conflicts, clashes etc. between them.
E Materials selection and procurement	**E.1.PC** Prepare preliminary specification requirements including building maintenance requirements, expected building life time, quality requirements etc. as required in A.1.PC (b). **E.2.PC** Conduct initial discussions about specific materials requirements (i.e. product customisation etc.) with client team, design team, construction team, supply chain partners etc. as early as possible.	**E.1.DE** Minimise unnecessary differentiation when selecting materials for the building where possible to minimise leftovers, off cuts etc. (i.e. use same colour from one material to all the possible places in the building etc.). **E.2.DE** Select materials according to building for long term requirements such as maintenance, quality, durability, whole life costing etc. **E.3.DE** Obtain ideas/advice/input from main contractor, trade contractors, product manufacturers, suppliers etc. about materials maintenance, quality, durability requirements etc. when selecting materials.	**E.1.CR** Minimise packaging waste when purchasing materials through early agreements with supply chain partners using reusable packaging, bulk purchasing, take back policy etc. **E.2.CR** Purchase customised materials to the project where possible through early supply chain involvement (i.e. plaster boards, off site products etc.). **E.3.CR** Follow materials logistics plan always as specified in A.2.CR (C) when purchasing materials to determine types and quantities of materials, exact delivery dates etc.

Figure 6.13: Low level HC-WMF- Buildability and Materials selection and procurement

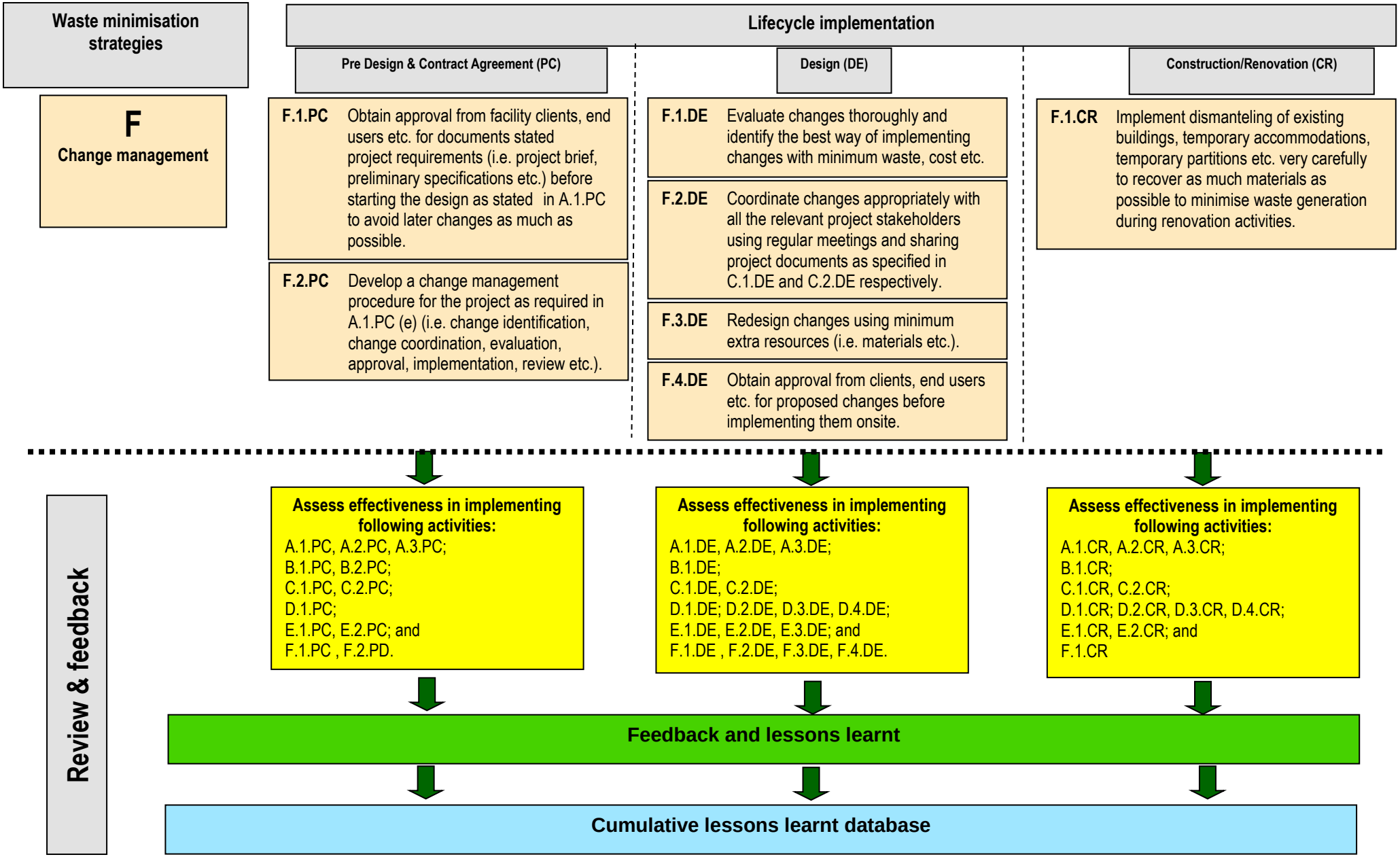


Figure 6.14: Low level HC-WMF- Change Management & Review and feedback

6.3.3 HC-WMF Implementation Strategy

The questionnaire respondents were asked to state the most suitable implementation strategy for the proposed HC-WMF. From the active respondent sample, 54% of respondents stated their views about potential implementation strategies for HC-WMF. The suggested implementation strategies are: collaborative project management approach; RIBA plan of work, WRAP guidance documents; and ISO 14001 standards (Table 6.8).

Table 6.7: HC-WMF implementation strategies

Implementation strategy	Frequency of respondents
Collaborative project management approach	6
RIBA plan of work	3
WRAP guidance documents	2
ISO 14001 standards	1

Table 6.8 suggests that the majority (6 of 8) of the respondents believe in a collaborative project management approach for implementation of the HC-WMF, which was further confirmed by the validation interviewees. Explaining their selection, they have pointed out two main reasons: consistency of contents (waste minimisation activities) presented in the HC-WMF with the project management procedures; and importance of early project partner collaboration to successfully launch lifecycle waste minimisation activities. In reporting the above one interviewee stated:

> *"…. the contents in this framework methodically align with project management procedures. Early collaboration with project partners and obtaining good knowledge about cross functional disciplines is important to successfully implement the framework…" (P2)*

Additionally, two interviewees stressed the importance of good leadership for the successful implementation of the proposed HC-WMF in healthcare projects. In describing this one interviewee declared:

> *"….leadership is the key to success in framework implementation. Initiation, implementation, management, review and completion, all should be coordinated very well throughout the project. I would say that leadership is key. Therefore I would suggest that it should be enforced by the client's side and could be coordinated through contractor's project manager…." (P4)*

Two respondents stated that the implementation of HC-WMF along with RIBA Plan of Work stages is not possible. They pointed out the overlaps in lifecycle phases due to collaborative procurement approaches as the main reason for their argument. However, two other interviewees had a totally different view to the above and collectively argued that the waste minimisation activities presented in the HC-WMF can be implemented throughout the RIBA plan of work stages once work has been appropriately assigned to the RIBA Plan Work stages. Moreover, they have emphasised the importance of analysing and arranging RIBA Work Stages to suit the healthcare project lifecycle stages before implementation.

All the interviewees agreed WRAP guidance documents are useful tools for integrating waste minimisation activities. However, they believed that the use of WRAP guidance documents alone would not give the expected outcomes due to the complex nature in healthcare project settings: particularly stakeholders; lifecycle effects; and communication.

Most of the interviewees (3 of 4) reported that there are fewer opportunities to integrate HC-WMF components with ISO 14001 as it is difficult to set exact standards for waste in healthcare projects due to the unique nature of healthcare projects.

It could be concluded that the proposed HC-WMF can be implemented through collaborative project management procedures in healthcare projects with the support of RIBA Plan of Work and WRAP guidance documents.

The interviewees were asked about steps that could be followed when implementing HC-WMF and the most appropriate individual to be responsible for its implementation. All the interviewees suggested the development of a full business case including essential details (i.e. strategic overview, stakeholders and external engagements; scope and targets; benefits and constraints; implementation plan, evaluation procedure etc.) as required by the formal project management methodologies as the first step in the HC-WMF implementation process. Interviewees (2 of 4) further mentioned that the use of a business case is very familiar within construction industry stakeholders since it is widely used in the industry. In reporting this one interviewee stated:

> *"….the first step is developing a detailed business case. The business case should demonstrate the organisation's needs how to get the support for the initiative, who is on the change team, operational people and so on. Developing a business case is common in most of the construction*

companies, and therefore I think I will be a familiar implementation process…" (P3)

Additionally, during the HC-WMF implementation stage, respondents stressed the need for continuous monitoring and corrective actions as necessary to obtain expected outcomes from the HC-WMF implementation. In that sense, all the four interviewees pointed out the requirement of one strong leader to successfully implementation HC-WMF throughout the healthcare project lifecycle. While stipulating the most suitable project partner to take the responsibility of implementation, all the interviewees mentioned *"top personnel on the site representing the main contractor"*. Additionally, they have explicitly mentioned that the responsible professional to implement the HC-WMF should be one who represents all the project lifecycle stages from start to the completion. Therefore, all the interviewees stated Project Manager/Project Director as the most suitable professional to undertake the implementation of HC-WMF and self-assessment responsibilities. Although, they suggested a key person to hold the total responsibility, it is obvious that the Contractor's Project Manager/Project Director requires support from other project stakeholders to implement the HC-WMF successfully throughout the lifecycle. In explaining this one interviewee stated:

"….A senior professional, may be project manager or project director in a large healthcare project would be ideal to hold the total responsibility. But he/she has to delegate responsibilities to the other professionals as necessary during the framework implementation. And also they can obtain essential details from other project partners to perform the self-assessment. For example, in the construction phase, site project manager/ site engineer would be suitable to collect information. But construction is just one phase. He can delegate work to a commercial manager in the pre design and contract agreement phase and contract manager in the design phase. This is a fairly natural break and I think it will work sufficiently well…" (P2)

Challenges and incentives for HCWMF implementation

The challenges and incentives for implementing the HCWMF as described by the validation interviewees are as follows:

Potential challenges for HC-WMF implementation:

1. **Integration of HC-WMF across different organisations:** The large number of stakeholders involved in healthcare projects from start to completion (i.e. end

users, hospital staff, client organisations, supply chain partners, design teams, construction organisations). Therefore, interviewees believed that at implantation of the HC-WMF working in a collaborative working environment with a large number of stakeholders and collecting relevant information from all of them during the assessment will be challenging.

2. **Commitment of stakeholders towards waste minimisation:** Stakeholders awareness and attitude towards waste minimisation greatly influences the successful HC-WMF implementation. However, interviewees pointed out that it is very unlikely to see self-motivation from all the stakeholders towards waste minimisation. Therefore, interviewees believed that these attitudes will be challenging during the HC-WMF implementation. Furthermore, they highlighted the importance of enforcing waste minimisation through contract agreements.

3. **Lack of details about waste minimisation benefits:** The HC-WMF doesn't provide clear evidence about the benefits (i.e. cost, quality, and time) that stakeholders can obtain through the HC-WMF implementation. Hence, the interviewees suggested developing a tool to facilitate measuring waste minimisation benefits to increase motivation of project partners towards waste minimisation.

4. **Complex nature of healthcare projects:** healthcare buildings have a number of associated complexities related to their functional and operation features. These features vary greatly from project to project. Therefore, interviewees pointed out that it will be challenging to implement, directly, lessons learnt from one project to another project.

Potential Incentives for HC-WMF implementation:

1. **Meet legislative requirements:** Construction waste reduction was recently given considerably high attention by the UK government who introduced several waste minimisation policies and legislations (i.e. SWMPs). As a main public sector organisation, the NHS is currently working towards delivering sustainable healthcare buildings. Therefore, interviewees believed that HC-WMF would be a useful tool to reduce construction waste generation in healthcare projects.

2. **Reduce construction cost:** Construction waste generation is a major source of increasing costs in any construction project. Since the proposed HC-WMF aims to reduce construction waste in healthcare projects; interviewees believed

that healthcare clients will be motivated to use this HC-WMF to reduce the overall budget of the project.

3. **Achieve sustainable healthcare:** The DH is currently dealing with a number of sustainability issues, including construction waste generation. Since, the healthcare industry doesn't have any tools/guidance documents to minimise lifecycle construction waste generation in healthcare construction, interviewees believed that HC-WMF will be useful once it has been tuned to be fit for purpose.

6.4 Summary

This chapter has given an account of the HC-WMF design and development processes and the components in the high level and low level HC-WMF components including the SAT.

Based on the validation questionnaire and interview results, the overall view about the clarity and appropriateness of components in the HC-WMF are positive. The HC-WMF validation results indicated that the structure and the contents in the HC-WMF are clear. Additionally, the validation results showed that the waste minimisation activities that are proposed in the HC-WMF are appropriate to minimise construction waste generation in healthcare projects. However, negative views from the respondents were recognised regarding the use of averages to measure the effectiveness in implementing waste minimisation activities as proposed in the HC-WMF. Instead, the validation results proposed using weighted averages to obtain more accurate results from the self-assessment of HC-WMF implementation.

The proposed HC-WMF has been further enhanced based on the validation study recommendations and feedback. Furthermore, some recommendations were proposed as future work (i.e. develop a user guide, integrate existing tools, guidance documents etc., assign weighted values for waste minimisation activities based on their level of importance in reduction of construction waste) to improve the HC-WMF to acquire enhanced benefits.

The validation results indicated that the collaborative project management procedures led by the main contractor as an appropriate implementation strategy for this HC-WMF. Additionally, results highlighted the potential use of RIBA Plan of Work and WRAP

guidance documents to ease the HC-WMF implementation. The next chapter presents a discussion of the research findings in the context of literature.

7

DISCUSSION

7.1 Introduction

This research set out to develop a lifecycle construction waste minimisation framework for healthcare projects. The aim of this chapter is to present a discussion of themes emerging from the results of this research as presented in the previous chapters. The first section of this chapter discusses the importance of construction waste minimisation in healthcare building construction in the UK. The second section presents a discussion of causes of waste in healthcare projects and their relationship to healthcare associated complexities under five themes: inefficiencies in project documents; stakeholder lack of awareness; inefficiencies in communication and coordination; buildability issues; and inefficiencies in materials selection and procurement. The third section examines the importance of lifecycle waste minimisation approaches in healthcare projects, and discusses waste minimisation strategies to be implemented throughout the lifecycle of healthcare projects. The final section of this chapter attempts to review the validation results of the HC-WMF and SAT.

7.2 Importance of Construction Waste Minimisation in Healthcare Projects

Literature reveals a rapid growth in the UK healthcare buildings including new constructions, renovations and extensions to existing buildings due to their current and future expansion programme (DH, 2007a; DH, 2010). This triggers an increased interest in SC to ensure reduced environmental, economical and social impacts during the capital investment programme. The “Delivering Sustainable Development DH Action Plan 2007/08” (DH, 2007b) set out targets to reduce energy consumption, water consumption, CO_2 emissions, and waste generation. In terms of construction waste minimisation, this target is in line with the call by the UK Sustainable Construction Strategy for a reduction in CD&E waste to landfill sites from the levels of 2008 to a 50%

reduction by 2012 and to achieve a zero net waste of construction waste by 2015 and zero waste to landfill sites by 2020 (HM Government, 2008).

Construction waste generation contributes almost one third of all UK waste which is more than three times that of all household wastes combined (DEFRA, 2007a). Literature provides no statistical data on construction waste generation from healthcare projects. However, as one of the largest public sector clients in the UK government, with a substantial property portfolio, the healthcare sector in the UK has a considerable responsibility to support the UK government's aim to achieve its SC targets. However, no clear evidence has been published in the literature that puts emphasis on construction waste generation issues related to healthcare building construction activities. Therefore, a preliminary data collection study was conducted with the aim of identifying the severity of construction waste generation in healthcare projects in comparison to other construction projects. The preliminary study results revealed that healthcare buildings, irrespective of their type or size, generate comparatively high rates of waste (per m^2) than other building projects due to their inherent complexities. The findings of the preliminary data collection study are in line with many other authors (Akintoye and Chinyio, 2005; Taner et al., 2007) who have mentioned that healthcare buildings are complex and different from other buildings. However, the preliminary data collection study results move a step forward to the existing research findings, enabling the link between complexities in healthcare features and construction waste generation.

7.3 Causes of Construction Waste in Healthcare Projects

Literature specifies a large number of causes of construction waste throughout the construction project lifecycle stages (see Table 2.3, Table 2.4, Table 2.5 and Table 2.6). However, no significant research has been conducted, to-date, to identify causes of waste that are particular to healthcare projects. Additionally, literature fails to propose a systematic process to address appropriate causes of construction waste depending on the characteristics of particular projects. Since the preliminary study confirms that the complexities in healthcare projects have an effect on construction waste generation in healthcare projects, further attempts have been made throughout this research to customise generic causes of construction waste on healthcare projects. The causes of waste identified from the research findings that are particular to healthcare projects can be broadly categorised into five headings: inefficiencies in

project documents; stakeholder lack of awareness; inefficiencies in communication and coordination; buildability issues; and inefficiencies in materials selection and procurement. The subsequent sections discuss the research findings on causes of waste highlighting associated healthcare complexities that tend to increase construction waste generation.

7.3.1 Inefficiencies in Project Documents

Construction projects use substantial amounts of project documents (i.e. project brief, drawings and specifications, contractual agreements, construction programme) from start to completion as a means of disseminating project information among project stakeholders. Several past researchers revealed a lack of planning and identification of client's requirements as a cause of waste in construction projects since incomplete briefs result in last minute changes, leading to construction waste generation (Kulathunga et al., 2006; Osmani et al., 2006; Tam et al., 2007b). Moreover, a study undertaken by Lima and Augenbroe (2007) identified poor scope definition as one of the biggest concerns in the pre-design phase of a healthcare project. However, the latter did not examine the impact of poor scope definition in healthcare projects on construction waste generation. Outside of the findings of the existing literature, the findings of this research confirmed that incomplete briefings were a significant cause of waste in healthcare projects and had considerable impact on the generation of construction waste due to the large numbers of project partners (i.e. end-users, NHS trusts, funders) involved at the briefing process stage with varying requirements and priorities (see Figure 7.1). Based on the above findings, there are clear grounds to argue that the construction projects with complex requirements and large numbers of project partners tend to generate more waste unless careful consideration is given during the project briefing stage to capture all the project requirements. However, since this research focused only on healthcare projects, a further study based on different types of projects would be essential to identify the ways in which complex project requirements impact on different project types in terms of construction waste generation.

In line with the findings of Bossink and Brouwers (1996), Ekanayake and Ofori (2000), Kulathunga et al. (2006), and Osmani et al. (2008), some research participants agreed that inconsistencies (i.e. errors, incomplete documents) in contract documents as a cause of waste in healthcare projects. Furthermore, the results reflected that healthcare projects have a greater propensity for inconsistencies in project documents because of the substantial amount of project documents that need to be shared among

a large number of project stakeholders. However, some respondents held contrasting views by arguing that the use of more integrated procurements systems in delivering healthcare projects should reduce inconsistencies in project documents, since project stakeholders will be able to share project documents. Even though these contrasting views limited making straightforward decisions about the impact of inconsistencies in contract documents for generating waste in healthcare projects, the results highlighted the importance of managing project documents accurately to reduce construction waste generation. Additionally, interviewees from both the preliminary data collection and the case studies stated that the type of contract and the method of tendering (allocation of waste allowance during tendering) do not have a significant impact on construction waste generation in healthcare projects due to the use of partnering procurement systems (see Figure 7.1). However, some thoughts were raised about the use of standard documents on a project without customising them to suit the project requirements (i.e. JCT contracts) and not embedding waste minimisation clauses in the contact documents as another ways of generating construction waste in healthcare projects. Results highlighted that current contractual documents are lacking clauses to guide, implement and monitor (i.e. waste targets, performance measures) waste minimisation activities throughout the project lifecycle. Participants claimed that incentives and penalties for waste minimisation performances are not adequately incorporated into the tender and contract documents. These findings are consistent with previous studies which highlighted the need for incorporating contractual clauses targeting waste minimisation requirements (Sterner, 2002; Greenwood, 2003; Dainty and Brooke, 2004; Tam et al., 2007a).

Several past research studies revealed a number of causes of waste associated with design related documents such as: design changes; incorrect drawing details; and delays in drawings (Gavailan and Bernold, 1994; Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000; Poon et al., 2004a; Kulathunga et al., 2006; Osmani et al., 2006; Tam et al., 2007b; Osmani et al., 2008). The findings of this research confirmed that these design related causes of waste are very common and contribute to significant amount of waste generation in healthcare projects mainly due to their associate complexities such as: complex project requirements; requirements to satisfy healthcare building regulations; complexities in healthcare sites; and large numbers of drawings and design information documents (see Figure 7.1).

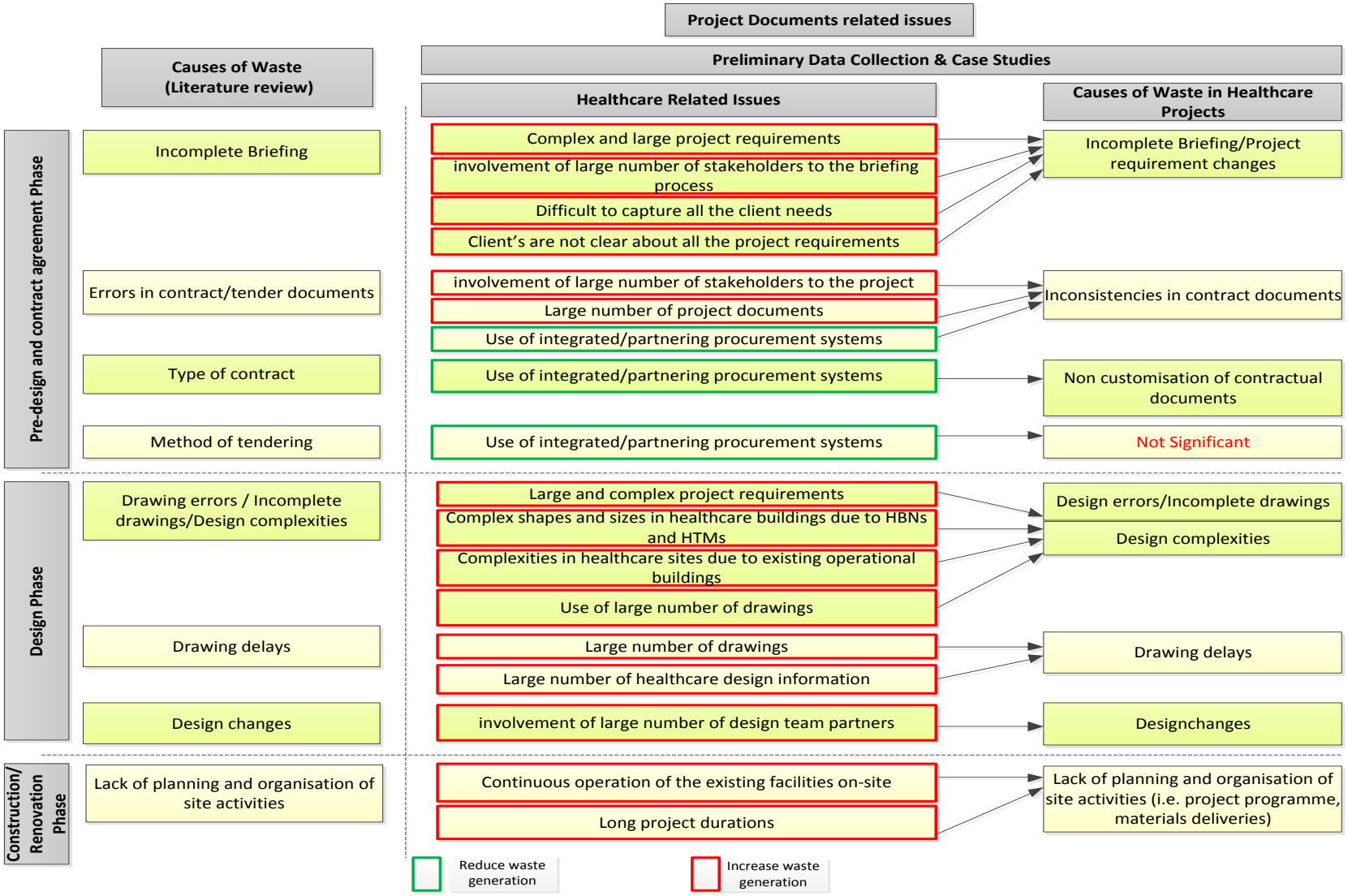


Figure 7.1: Causes of waste related to project documents in healthcare projects

Similar to the findings of Bossink and Brouwers (1996), Ekanayake and Ofori (2000), Kulathunga et al. (2006), and Osmani et al. (2008); both preliminary data collection and case study interviewees agreed that a lack of on-site management and planning causes construction waste in healthcare projects. Additionally, the research findings stressed the issues that are closely associated with healthcare construction projects such as continuous operation of existing facilities and long project duration as barriers to preparing detailed site programmes (i.e. project programmes, materials logistics programmes) for healthcare projects. These findings further widen the understanding of complexities in healthcare construction projects that limit opportunities for reducing construction waste generation.

Even though, this research specifically attempted to identify healthcare project related complexities that tend to increase construction waste generation due to inefficiencies in project documents management, there are however clear grounds in the literature to claim that most of the aforesaid complexities (i.e. complex project requirements, large number of drawings, long project durations etc.) are common for other construction projects as well. Hence, these findings could be used as the basis for future research studies to identify other project related complexities and their associated construction waste causes to plan and implement appropriate waste management strategies.

7.3.2 Stakeholder's Lack of Awareness

Albeit, existing literature did not widely discuss the consequences of clients' awareness in terms of construction waste generation, several authors highlighted designers' and construction teams' attitudes, their lack of interest and lack of awareness greatly influenced construction waste generation. For instance, Bossink and Brouwers (1996), Ekanayake and Ofori (2000; 2004) and Osmani et al. (2008) stated designers' lack of knowledge about alternative materials, standard size components, and construction sequences were causes of waste in construction projects. Similarly, Teo and Loosemore (2001) and Kulathunga et al. (2006) highlighted construction teams' negative attitudes and perceptions as having a significant impact on construction waste generation as construction is a highly labour incentive industry. It is important to note that, many of the above studies focused either on the design phase or the construction phase rather than focusing on the whole project lifecycle. However, the findings of this research viewed stakeholders' lack of awareness in a more holistic lifecycle perspective and specified lack of awareness of waste generation issues (i.e. stakeholder responsibilities, importance of waste minimisation, suitable materials, and

alternative construction methods) of any stakeholder could lead to the generation of construction waste in healthcare projects.

Some contrasting views were recognised among the respondents regarding the impact of waste generation due to stakeholder lack of awareness of this issue on healthcare projects. For instance, some case study respondents, particularly architects and contractors, pointed out that the clients' lack of knowledge and interest on: the construction process; future adoptability and flexibility needs of the building; and availability of materials as causes of waste in healthcare projects (see Figure 7.2). Even though these causes of waste were not widely discussed in the literature, Greenwood (2003), Dainty and Brooke (2004) and Poon (2007) have emphasised that waste reduction should be considered at an early stage by all the project parties including clients. Expressing contrasting arguments, some respondents pointed out that these causes of waste have less impact in healthcare projects because clients have more opportunities to obtain necessary advices with the use of partnering procurement systems.

Similarly, some respondents in both the preliminary data collection and the case studies agreed that: designers' lack of awareness of the construction process; not designing appropriately; and their lack of knowledge about alternative materials are causes of waste in healthcare construction projects. They mainly emphasised healthcare specific design and construction requirements, lack of previous healthcare design experience, and requirements to fulfil healthcare building regulations as underlying reasons for increasing construction waste generation from healthcare projects compared to other building projects. The results also confirmed construction teams' lack of awareness of construction waste generation issues as a leading cause of waste in healthcare projects due to the involvement of a large construction team (i.e. trade contractors, suppliers, labourers). However, some respondents argued differently and highlighted the enhanced opportunities available for design and construction teams within the integrated procurement systems to share necessary information and advice to lessen the impact of waste generation.

The results suggest that stakeholders' lack of awareness about construction waste generation could result in construction waste generation in healthcare projects unless stakeholders were motivated to giving appropriate consideration to waste minimisation from the start of the project.

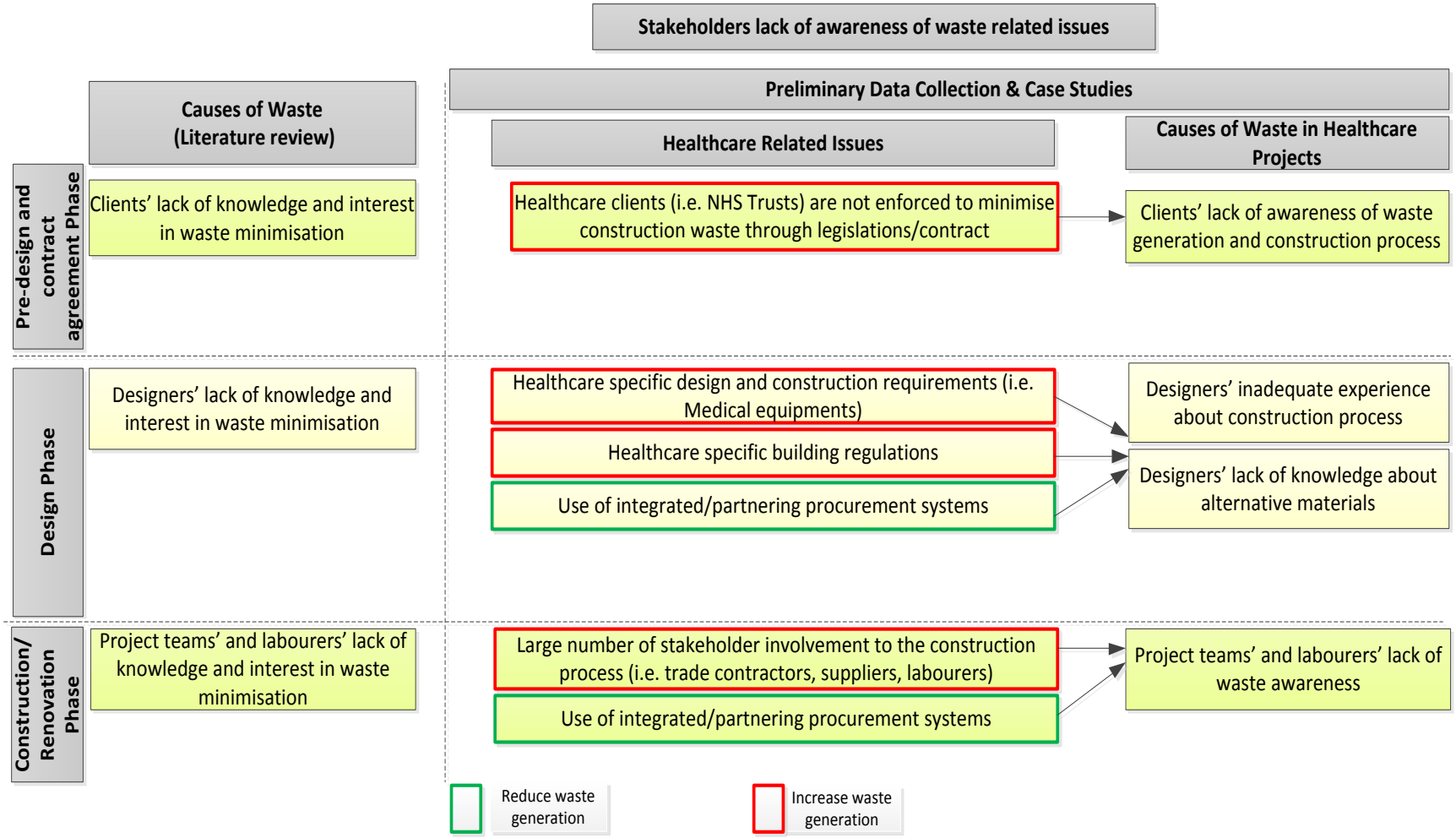


Figure 7.2: Causes of waste related to stakeholder unawareness in healthcare projects

7.3.3 Inefficiencies in Communication and Coordination

The findings of this research clearly emphasised that inefficiencies in communication and coordination among project stakeholders are a major cause of waste throughout the healthcare project lifecycle stages.

For instance, findings revealed that the involvement of large numbers of users, with varying requirements, were the main reason that frequently lead to inefficiencies in communication and coordination in the pre-design and contract agreement phase in healthcare projects (see Figure 7.3). Moreover, case study results emphasised limited opportunities available within PFI, P21 and LIFT procurement systems to directly communicate with clients and architects due to the contractor-led nature of these procurement systems as another reason that caused communication and coordination inefficiencies. Even though a study by Lima and Augenbroe (2007) mentioned ineffective communication and complex decision environments as issues in the pre-design phase of healthcare projects, no clear emphasis was given in that study to identifying the relationship between pre-design phase complexities and construction waste generation. However, the findings of this research study went a step forward from the existing literature by correlating complexities in communication and coordination in healthcare pre-design phases with construction waste generation.

Interestingly, some respondents held contrasting views to the above highlighting the benefits of using partnering procurement agreements in healthcare projects. They argued it as a good platform for the design team partners to effectively share essential information. Hence, they believed that the construction waste generation can be controlled to a certain extent in healthcare projects with the use of partnering procurement systems than in projects using traditional procurement systems.

Furthermore, the results established the view that healthcare buildings are predisposed to experience inefficiencies in communication and coordination (i.e. lack of dimensional coordination) during the design phase since healthcare design teams manage massive amounts of design details among considerably large design team (see Figure 7.3). This is not different from the findings of Ekanayake and Ofori (2000) and Osmani et al. (2008) who found poor communication and coordination during the design stage as a cause of waste in construction projects.

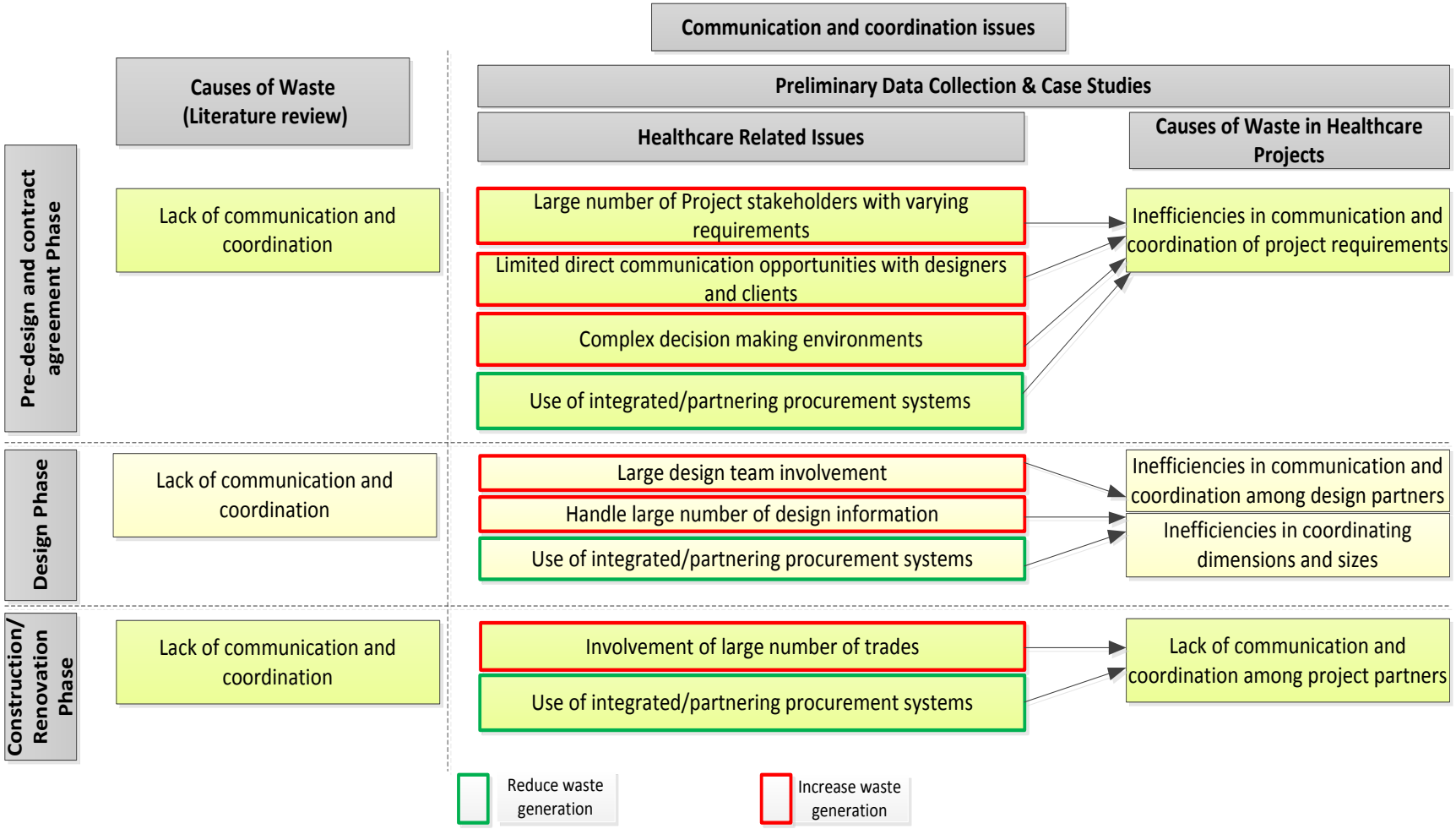


Figure 7.3: Causes of waste related to communication and coordination inefficiencies in healthcare projects

Putting forward similar arguments to the above, respondents confirmed inefficiencies in communication and coordination were a significant cause of waste generation during the healthcare construction stage due to the large number of trades involved on a healthcare site required to fulfil special building requirements (i.e. medical equipment installation).

Interestingly, a close observation of results clearly indicates that the complexities identified (i.e. involvement of large project team) are not unique to healthcare projects; but could be seen in many other construction projects. Hence, there are clear grounds to judge that construction projects involving a large number of project partners throughout the lifecycle process could generate considerably high amounts of construction waste. However, since this study only considered healthcare project scenarios, strong conclusions cannot be determined based on the results of this research study and thus require further investigation.

7.3.4 Buildability Issues

Due to the intrinsic complexities in healthcare buildings, the findings of this research study identified a number of buildability issues that lead to construction waste generation. Literature discussed the need for healthcare buildings to be adaptable and flexible to facilitate the future user and management requirements (Thomson et al., 1998). However, the findings of this research study stressed limitations to design adaptable and flexible healthcare buildings such as: lack of clients' interest due to their lack of awareness; budget limitations; and unpredictability of future requirements due to frequent developments in healthcare (i.e. medical equipment, technology changes). Therefore, the findings highlighted that the failure to design adaptable and flexible healthcare buildings has the potential to generate more waste during the facility lifecycle extending the literature review findings further to establish the link between healthcare flexibility and adaptability requirements with construction waste generation. However, respondents stressed that it is clients' responsibility to instruct the design team to consider building adaptability and flexibility.

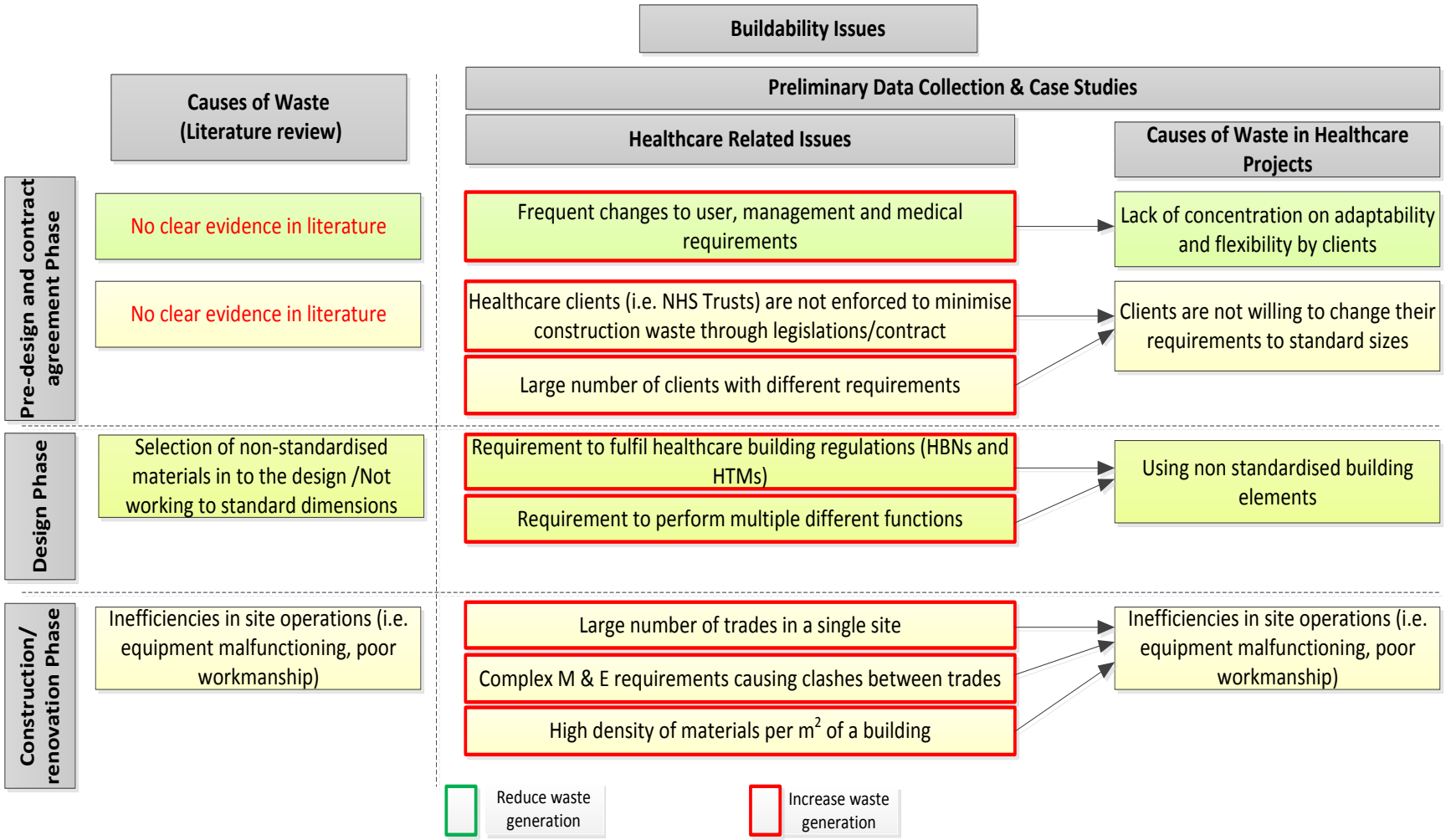


Figure 7.4: Causes of waste related to buildability issues in healthcare projects

Similarly, both preliminary data collection and case study findings revealed the use of non-standardised building elements in healthcare designs as a significant cause of waste in healthcare projects. These findings are consistent with the previous research findings (Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000; Keys et al., 2000; Kulathunga et al., 2006; Osmani et al., 2006) that have identified the selection of non-standardised materials as a cause of waste.

Further to the current findings in literature, this research related the use of non-standardised building components with healthcare complexities such as: multiple different functions performed within a single building and requirement to fulfil healthcare building regulations (HBNs and HTMs) while highlighting them as barriers to the production of simple designs integrating standardised components for healthcare buildings.

While being consistent with the findings of literature review (Gavailan and Bernold, 1994; Bossink and Brouwers, 1996; Kulathunga et al., 2006; Osmani et al., 2008), both the preliminary data collection study and the case study results confirmed that poor workmanship during the construction/renovation stage generates considerably large amounts of waste in healthcare projects. However, this research discussed issues relate to poor workmanship in healthcare sites. The findings revealed the involvement of a large number of trades, the use of a high density of materials per m^2 of the building, and complex M&E elements embedded into the buildings as fundamental healthcare construction related issues that increase waste generation due to poor workmanship (see Figure 7.4).

7.3.5 Inefficiencies in Materials Selection and Procurement

A number of authors specified causes of waste related to materials selection and procurement in construction projects such as: wrong materials specification by designers (i.e. over/under specification), inefficiencies in materials procurement (i.e. wrong ordering, excess ordering), inappropriate materials handling and storage; and damages to materials during transportation (Gavailan and Bernold, 1994; Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000; Kulathunga et al., 2006; Osmani et al., 2008). Interestingly, this research study results echoed the above findings in literature in relation to causes of waste as potential waste sources in healthcare projects.

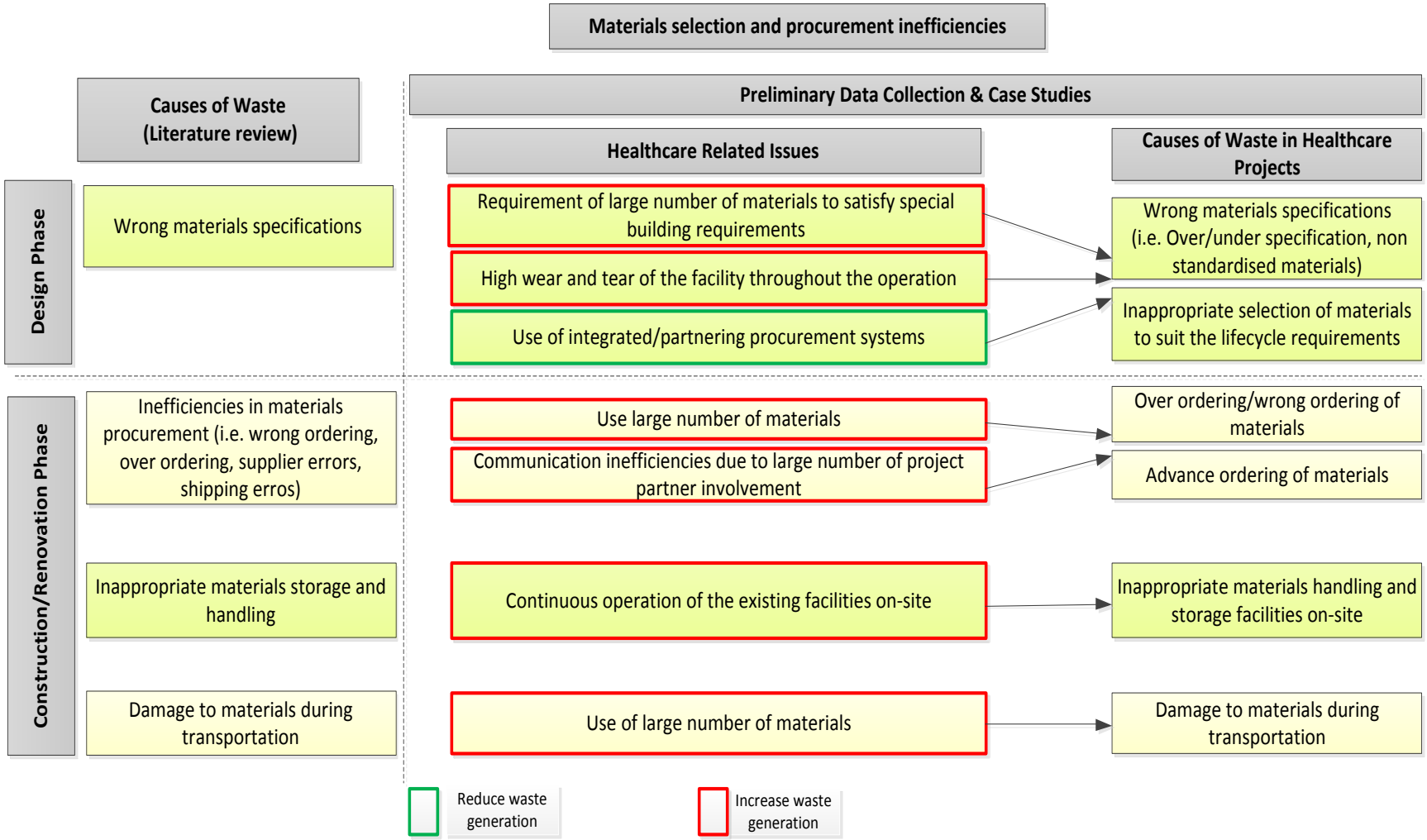


Figure 7.5: Causes of waste related to materials selection and procurement inefficiencies in healthcare

Nonetheless, highlighting the enhanced opportunities within healthcare projects to get the early supply chain integration with the use of partnering/integrated procurement arrangements, some respondents pointed out the opportunities available for design team partners to obtain necessary advice during materials specifications. Therefore, they argued that the impact of construction waste generation due to wrong materials specifications can be reduced to a certain extent in healthcare projects.

On the other hand, some respondents argued that the use of large numbers of materials; use of special materials to fulfil healthcare building quality requirements; and complexities in materials selection due to lifecycle requirements in healthcare projects often lead to wrong materials specifications in healthcare building projects. Albeit, the above arguments limited making straightforward decisions about the total waste generation impact due to wrong materials specification in healthcare buildings, it is important to note the available opportunities within healthcare construction projects to improve materials specifications with the support from supply chain partners.

In line with the findings of Gavailan and Bernold (1994), Bossink and Brouwers (1996), Ekanayake and Ofori (2000), Kulathunga et al. (2006), and Osmani et al. (2008), this research study confirmed that inefficiencies in materials ordering (i.e. over ordering, wrong ordering, advance ordering), inadequate materials handling and storage facilities onsite, and damage to materials during transportation are common causes of waste in healthcare projects. However, respondents believed that construction waste generation from healthcare projects due to the above causes of waste are significantly higher than in other building projects due to the continuous operation of other healthcare facilities on-site. Hence, the findings of this research indicated increased construction waste generation rates from healthcare sites are due to on-site complexities in materials ordering, handling and storage.

Although the results revealed that damage to materials during transportation is a potential cause of waste in healthcare projects similar to other building projects as stated in literature (Bossink and Brouwers,1996; Ekanayake and Ofori, 2000; Kulathunga et al., 2006; Osmani et al., 2008) , the findings stressed that the amount of construction waste generation would be considerably higher in healthcare projects due to the various types of materials used (i.e. different floor finishes, different M&E requirements) to satisfy healthcare building requirements.

Following the discussion of the above facts, it is important to raise attention to the fact that healthcare buildings have a higher potential to generate significant amounts of

construction waste due to inherent complexities in healthcare buildings unless properly manage from the start of the project through to completion. In order to address the aforementioned causes of waste in the healthcare project lifecycle, efforts have been made during the preliminary data collection study and the case studies to identify appropriate waste minimisation practices. The following section discusses the research findings on construction waste minimisation strategies for healthcare projects.

7.4 Construction Waste Minimisation Strategies for Healthcare Projects

Literature catalogues and discusses a number of construction waste minimisation and management approaches for construction projects of which the majority are focused on site activities; whereas, few attempts have been made recently to examine waste minimisation approaches for the design and procurement phases (Section 2.7.3). However, most of these waste minimisation and management approaches adopted a linear approach by focusing only a single phase in a construction project even though emphasis has been made in the literature for a more holistic lifecycle approach to effectively reduce construction waste generation (Dainty and Brooke, 2004; Shen et al., 2004; Hao et al., 2007).

Since causes of waste in healthcare projects span over the project lifecycle (Section 4.6 and Section 5.3), preliminary data collection interviewees confirmed that the lifecycle construction waste minimisation approach was the most suitable method for reducing construction waste generation in healthcare projects.

Results revealed various waste minimisation practices that need to be implemented throughout the healthcare project lifecycle to address causes of waste generation. These waste minimisation practices were broadly categorised into six categories: project documents management; effective communication and coordination; increased awareness of construction waste generation and minimisation; accomplished buildability; appropriate selection and procurement of materials; and change management.

7.4.1 Project Documents Management

Results highlighted a number of waste minimisation practices to be implemented in healthcare projects to reduce construction waste generation due to incomplete and inconsistent project documents (i.e. project brief, drawings and specifications;

contractual documents; planning and programming documents; waste minimisation and management documents). As such, this research mainly suggests obtaining essential information from all the relevant project stakeholders as early as possible, embedding them appropriately in to the project documents, checking and reviewing regularly to manage project documents accurately to ensure that the project documents convey accurate project information to all the necessary project partners. These findings are somewhat consistent with Faniran and Caban, (1998), Baldwin et al. (2002), and Poon et al. (2004b) who emphasised the need for planning, and preparing and reviewing project documents to reduce construction waste generation. However, the current research provides a more holistic approach than previous research since results showed the improvement measures that need to be implemented to maintain accurate project documents throughout the project lifecycle. Furthermore, to reduce inconsistencies in the project documents, the research study findings recommend compiling and sharing a set of documents with project stakeholders (i.e. through a database).

A number of past researchers highlighted the need for defining project partners' responsibility for waste minimisation, establishing waste allowances and introducing incentives into the contractual documentation for meeting waste targets as very effective practices for reducing construction waste generation (Kulathunga et al., 2006; Osmani et al., 2006; Osmani et al., 2008). Furthermore, some researchers pointed out the importance of cultivating a waste minimisation culture among clients and allocating waste minimisation responsibilities during the contractual agreements as good initiatives to motivate project partners to achieve waste minimisation goals (Ekanayake and ofori, 2000; Dainty and Brooke, 2004; Osmani et al., 2008). It is important to note that the findings of this research study also align with the aforesaid researchers, as results revealed the importance of enforcing waste minimisation among all the project stakeholders through contractual agreements. For example, the findings suggested inserting waste minimisation responsibilities for project partners, the introduction of targets for waste minimisation and incentives in the contract documents to reduce construction waste generation (Section 5.6). Additionally, by confirming the importance of inserting waste minimisation clauses into the project documents (i.e. project brief, SWMPs), the findings of this research study proved the appropriateness of the waste minimisation strategies suggested by WRAP (2010a) to the NHS Trusts.

7.4.2 Communication and Coordination

Both the preliminary data collection study and the case study results confirmed that there are several communication and coordination failures in healthcare projects throughout the project lifecycle (Section 4.6 and Section 5.3) especially due to the large number of stakeholders involved and the complex nature of the project requirements. In order to improve effectiveness in communication and coordination to reduce construction waste generation, the findings suggest a compilation of all the project information and sharing of documents by developing a mechanism (i.e. database) for dissemination of information among all the necessary stakeholders, thereby also reducing conflicts (Section 5.6). The findings also highlighted the importance of conducting regular meetings among all the relevant project stakeholders to discuss project waste performances (i.e. waste targets achievements, reuse and recycling opportunities) and to take corrective actions where necessary to maintain the desired construction waste minimisation goals. The findings of this research are in line with previous research studies that have stressed the importance of establishing effective communication and coordination mechanisms for a construction project to reduce construction waste generation (Faniran and Caban, 1998; Poon et al., 2004b; Kulathunga et al., 2006). Comparatively, the findings of this research exposed the theme to a much broader lifecycle perspective, whereas previous research studies only focused on single stages in a project lifecycle (i.e. design, construction). Moreover, the current research has given insights into potential implementation options to ensure better communication and coordination on healthcare projects.

7.4.3 Stakeholder Awareness

In healthcare projects, lack of awareness by project stakeholders (i.e. clients, end users, designers, contractors, suppliers) regarding the project requirements, project procedures (i.e. change management, decision making, communication and coordination), construction processes and project waste management targets were highlighted by the interviewees as a major cause of construction waste generation (Section 4.6 and Section 5.3). With the intention of increasing awareness, motivation and morale for waste minimisation among project stakeholders, the research results suggested appointing all the relevant stakeholders to the project as early as possible since it allows them to obtain a better understanding of the project and the waste minimisation targets. Furthermore, a waste awareness programme was suggested to stimulate and support a culture of waste minimisation among the project parties (Section 5.6). This research also pointed out the enhanced opportunities available in

healthcare projects to implement the aforementioned waste minimisation practices as an advantage of using collaborative procurement systems. These findings are fairly consistent with the findings of Ekanayake and Ofori (2000), Baldwin et al. (2002); Poon et al. (2004b); Kulathunga et al. (2006); Osmani et al. (2006), where these research studies emphasised the need for improving attitudes of project stakeholder towards waste minimisation and the desired waste minimisation outcomes. However, the findings of previous research studies focused mostly on single project phases while this study proposed a more integrated lifecycle approach. For instance, research findings such as Baldwin et al. (2002) and Osmani et al. (2006) recommended increasing the awareness of designers while Poon et al. (2004b) and Kulathunga et al. (2006) recommended increasing the awareness of site workers. Instead, the current research study highlighted measures that should be taken to increase the awareness of all the relevant stakeholders including those who are involved at the pre-design and contract agreement phase to reduce construction waste generation focusing especially on healthcare projects.

7.4.4 Buildability Enhancement

The findings of this research highlighted the complexities in healthcare projects that increase several buildability issues causing construction waste as discussed in the Section 4.5 and 5.4. Additionally, it is important to highlight that in healthcare buildings, build quality is a significant factor in establishing the smooth functioning of the building throughout its lifetime. In order to ensure the required build quality while reducing construction waste, the findings of this research study highlighted a number of waste minimisation practices that require implementing throughout the project lifecycle. For instance, the findings of this study suggested assessing the feasibility of building requirements specified by the clients to minimise later changes and rework. Even though conducting feasibility studies are common in construction projects to assess economic, environmental and social feasibility of proposed projects, no significant research has stressed the importance of considering construction waste generation as one aspect during the feasibility studies. However, this research emphasised the requirement for assessing the client’s requirements to ensure feasibility of building to the client’s requirements within the project constraints (i.e. site space availability, skills, resource availability, technology).

Additionally, during the design phase, interviewees suggested standardising the designs (i.e. use regular shapes), assessing the buildability of the designs (i.e. use 3D

modelling), using low waste modern techniques (i.e. offsite construction, modular units), and allowing for future adaptable and flexible needs to reduce waste generation due to buildability issues. The above findings are in line with the findings of the Dainty and Brooke (2004), Ekanayke and Ofori (2004), and Baldwin et al. (2006) who have recommended the use of prefabricated building elements, design standardisation and assessment of the designs (i.e. 3D visualization) to reduce construction waste generation.

The research study findings highlighted the importance of monitoring and managing site activities during the construction process to ensure appropriate quality standards in the build facility. The concept of site activities management (i.e. planning of construction process, manage trade contractor activities) is widely discussed by previous researchers to reduce construction waste generation since it allows smooth functioning of the site while guaranteeing the required quality of the build facility (Gavilan and Bernold, 1994; McDonald and Smithers, 1998; Faniran and Caban, 1998; Baldwin et al., 2002; Poon et al, 2004b). However, considering the complex nature of the operating facilities on healthcare construction sites, this study suggested obtaining prior approval for the proposed SWMPs from the healthcare facility management team before starting site works to reduce conflict and ensure the smooth functioning of the project.

7.4.5 Materials Selection and Procurement

The findings of this research brought to light a number of causes of waste in the healthcare project lifecycle related to material selection and procurement (Section 4.6 and Section 5.3) due to complex material requirements in healthcare projects. Results highlighted the need for early supply chain involvement in the project process since it increases opportunities to clearly identify project requirements, obtain necessary advice for selecting accurate materials and allows additional time to customise materials according to the project requirements. Equally, Dainty and Brooke (2004) and Guzman et al. (2009) emphasised that early supply chain involvement was good practice for reducing construction waste generation. Additionally, research findings highlighted the importance of using standard/customised products to minimise offcuts during healthcare project construction in line with the findings of Baldwin et al. (2006) who has emphasised the use of prefabricated building elements to reduce construction waste generation. Furthermore, the current research underlined the importance of

selecting materials according to the building lifecycle requirements during the design phase to avoid unnecessary maintenance during the building maintenance.

In order to reduce construction waste generation due to inefficient materials ordering, handling, storage, and transportation (Section 4.6 and Section 5.3), findings of the current study recommended operating off-site storage facilities and just-in-time deliveries of materials to the site. Additionally, requirements of packaging waste minimisation are also emphasised by the research findings which are the same as the research findings of Gavilan and Bernold (1994) and McDonald and Smithers (1998). With the aim of reducing construction waste sent to landfills, a number of researchers recommended onsite sorting of waste materials to enable reuse and recycling (McDonald and Smithers, 1998; Treloar et al., 2003; Poon et al., 2004b, Wang et al., 2010). In line with those researchers, the current research study also highlighted the importance of appointing a waste management contractor for healthcare projects and encouragement of onsite sorting of waste materials as much as possible to reduce waste sent to landfills.

7.4.6 Change Management

The literature review (Section 2.8) indicated that healthcare project requirements are subjected to frequent changes with the rapid developments in medical technology. Additionally, the findings of this research revealed that the large number of user and management requirements increased late design changes resulting in construction waste generation (Section 4.6 and Section 5.3). With the aim of reducing construction waste generation due to later changes the results stressed the importance of developing a change management procedure (including change identification, communication, evaluation, implementation and review) at the very beginning of the project and to make all the project partners aware of effective change management during the project process. These findings are in line with many other authors (CURT, 2004; Motawa et al., 2007; Hao et al., 2008b) who have emphasised the requirement for a detailed change management procedure to address causes of waste generation (i.e. design changes, client's requirement changes, poor workmanship, and rework) due to changes in the fragmented nature of construction projects. However, literature commonly discussed about managing changes during the construction process, where this research stressed the requirement of early identification and planning of potential future changes during the facility maintenance since healthcare buildings are more vulnerable to changes. Therefore, this research has specified guidelines to reduce construction waste generation due to changes in an operational healthcare building. In

that sense, the results highlighted the importance of ensuring high recovery rates when dismantling a building. Additionally, the results discussed the importance of redesigning changes to embed recovered materials to effectively reduce construction waste generation.

7.5 HC-WMF and SAT

The developed HC-WMF presents a systematic approach to reduce construction waste generation from healthcare projects. It was developed based on the general problem solving methodology and key findings that were derived from the research.

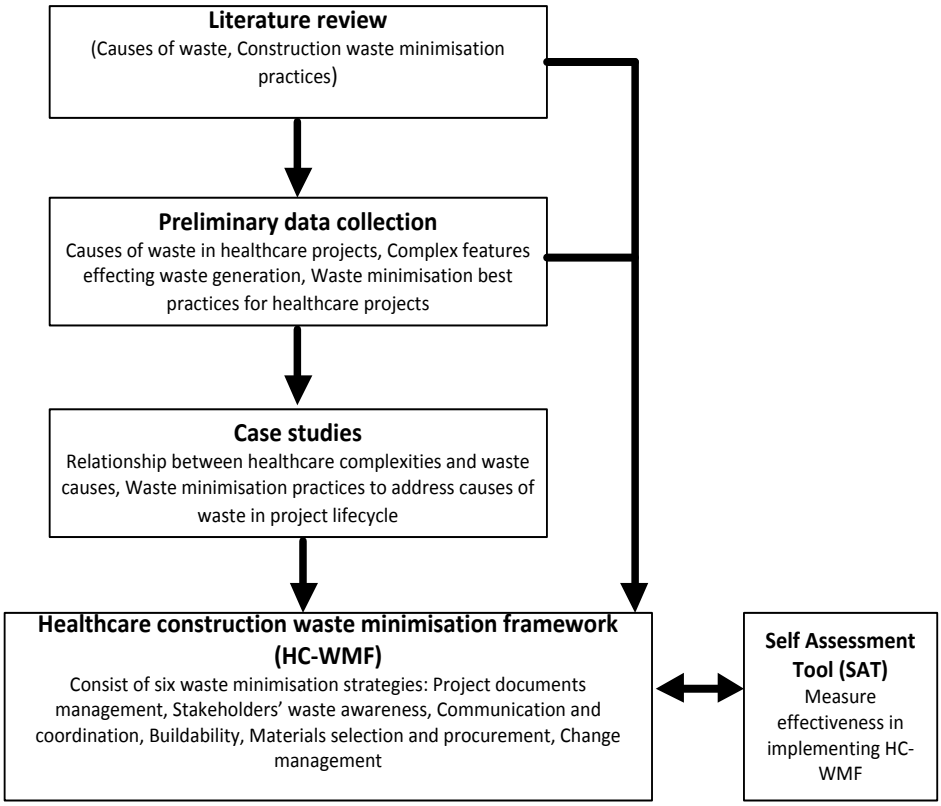


Figure 7.6: HC-WMF development process

As shown in the Figure 7.6, HC-WMF includes the findings from the literature review, preliminary data collection and case studies. The research findings revealed six main construction waste minimisation strategies (i.e. project documents management, stakeholders' waste awareness, communication and coordination, buildability, materials selection and procurement, change management) to be implemented to address the causes of waste generation throughout the healthcare project lifecycle stages, which form the main skeleton of the HC-WMF. The SAT was developed to

assess the effectiveness in implementing HC-WMF in healthcare projects, to obtain feedback and learning outcomes for future improvements.

A validation study was conducted to assess the clarity and appropriateness of the contents of the HC-WMF and self-assessment procedure proposed in the SAT. The findings showed that the HC-WMF has a clear structure and contents enabling users to view and understand links between elements of the framework. Therefore, the findings from the HC-WMF validation study gave clear indication about the appropriateness of adopting a general problem solving methodology to develop HC-WMF. In addition, there has been general agreement among the validation study participants that the waste minimisation strategies and the contents in the framework appropriately focus on minimising construction waste generation from the healthcare project lifecycle (6.3.1.1). Furthermore, the validation study results confirmed the importance of continuous learning process and agreed the underlying concepts introduced by the SAT to obtain feedback from completed projects to effectively transfer learning outcomes to future projects (6.3.1.2). However, several ways of improving the HC-WMF and SAT emerged from the validation process of which some are quick modifications within the current research study scope to improve the clarity of the HC-WMF and SAT components. But, there were some suggestions of the need for further investigations to improve HC-WMF and SAT into a practical tool that can be used directly in healthcare projects without further work.

The validation results suggested several opportunities already available that could be incorporated into the proposed HC-WMF through different methods, tools and standards already available in the construction industry (Section 6.2.6). However, the findings revealed that collaborative project management approaches would have the highest potential for implementation into the HC-WMF since lifecycle effects need to be considered during the implementation process. Additionally, the validation study results highlighted the need for strong leadership to implement HC-WMF in healthcare projects since a significant number of activities need to be implemented, monitored and reviewed throughout the project lifecycle stages to successfully implement the proposed HC-WMF. Additionally, due to the use of integrated/collaborative procurement approaches (i.e. LIFT, PFI and P21) in healthcare projects, the validation results emphasised that the responsibility for implementing the HC-WMF should be allocated to a professional who is involved in the whole construction process from start to completion. In that sense, the suitability of a contractor's representative (i.e. project

manager, programme director) who deals with the project at all activity levels was substantiated by the HC-WMF validation participants.

Several challenges and incentives for implementing the HC-WMF and SAT have been highlighted during the validation study. In terms of implementation challenges, the results highlighted the difficulties of integrating waste minimisation activities across different organisations and stakeholders since they have different attitudes towards waste minimisation. Moreover, the validation results pointed out the lack of waste minimisation benefit realisation mechanisms in the HC-WMF and the complex nature of healthcare projects as other possible challenges during the implementation stage. However, the validation results highlighted that the incentives for implementing HC-WMF and SAT would be fulfilling legislative requirements, reducing construction cost and achieving a sustainable healthcare industry.

7.6 Summary

This chapter has presented a discussion of the emerging themes from the research results. Whilst giving insights into the significance of construction waste reduction in UK healthcare construction projects, this chapter extended the discussion further to explain construction waste causes and the impact of the complexities associated with the healthcare project lifecycle has to generate construction waste. Furthermore, the chapter has discussed the developed HC-WMF based on the research results.

The discussion revealed the importance of reducing construction waste generation in the UK's rapidly developing healthcare construction industry to achieve the government's sustainability targets. Also, the discussion pointed out that healthcare construction projects tend to generate more waste compared to other building projects due to their inherent complexities.

Five main causes of waste (inefficiencies in project documents; stakeholder lack of awareness; inefficiencies in communication and coordination; buildability issues; and inefficiencies in materials selection and procurement) have been discussed highlighting underlying complexities in healthcare projects such as: complex project requirements, involvement of large numbers of stakeholder, complex site conditions, healthcare specific design guidance, special building materials requirements, complex M&E services, and frequent future changes, that tend to increase construction waste generation severity throughout the healthcare project lifecycle. Moreover, the discussion outlined some of the opportunities available within the healthcare project

lifecycle to reduce the impact on above mentioned complications by using partnering procurement arrangements. However, the discussion failed to make strong claims on the specificity of identified complexities to healthcare projects as this has research not attempted to make a comparison between complexities in healthcare project characteristics with those of other complex building types.

Later, best practice waste minimisation activities that require implementing throughout the healthcare project lifecycle have been discussed giving particular reference to the relevant findings from previous research. Earlier discussion focused on the importance of a lifecycle approach to reducing construction waste generation on healthcare projects as the causes of construction waste span all stages of the project lifecycle. Subsequently, the discussion extended further explaining potential waste minimisation practices that address the causes of waste in the project lifecycle.

Finally, the development of the HC-WMF has been discussed giving particular consideration to the development of the methodology adopted, the structure and content, and the implementation strategy. Furthermore, the discussion emphasised the requirement for further investigations to develop a practical tool to implement HC-WMF directly into healthcare projects. The next chapter discusses the conclusions, recommendations and further investigation of the current research.

8

CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH

8.1 Introduction

This chapter aims to the present conclusions and recommendations that can be drawn from the findings of this research. The first section describes the fulfilment of aim and objectives highlighting the conclusions from this research. Subsequently, the chapter outlines the key contributions of this research to the existing knowledge. Then the chapter discusses limitations of the current research. Finally, the chapter suggests recommendations to the healthcare industry and government/policy makers to reduce construction waste generation from healthcare projects while giving insights into further research opportunities.

8.2 Conclusions and Fulfilment of Research Aim and Objectives

The aim of this research was to develop a lifecycle construction waste minimisation framework for healthcare projects. Seven objectives were formulated to achieve the aforesaid aim where three objectives were related to literature review and four objectives were specific to this research. The subsequent sections describe the achievement of objectives in the process and summarise the associated conclusions.

8.2.1 Objectives Related to Literature Review

First, Second and Third Objectives

A comprehensive literature review was conducted to fulfil the objectives described in Section 3.5.2.

The first objective was to explore the relationship between SC and construction waste minimisation. Literature review findings clearly revealed the importance of construction waste minimisation in the SC context since it creates adverse environmental, economical and social issues.

The second objective was to examine construction waste minimisation drivers, causes and origins of waste, and waste minimisation approaches. In the UK, the key drivers to the reduction of construction waste generation are: environmental drivers, economic drivers, industry drivers, and legislative drivers. Literature review findings showed that the causes of construction waste span across a project lifecycle starting at the pre-design phase through to project completion. Waste minimisation approaches discussed in the literature focused, mainly, on site waste management although there is an emergent concern about waste minimisation approaches in the earlier stages of a project (i.e. design, procurement).

The third objective was to examine current and future trends in the UK healthcare industry and the importance of construction waste minimisation in sustainable healthcare construction projects. The literature review findings revealed that there is a large capital investment programme in the UK healthcare construction sector, which extends into the future. Moreover, the trend for procurement in most healthcare projects in the UK is through PFI, Procure 21 and LIFT programmes, where the latter two procurement systems were particularly introduced by the DH to construct healthcare projects. With this noteworthy investment in healthcare projects, the literature review revealed a large number of sustainability issues, including construction waste generation.

Literature also provided insights about the complex and different nature of healthcare buildings compared to other construction projects. However, to-date, no significant research has been conducted to identify construction waste generation issues particular to healthcare construction projects. This existing knowledge gaps in the

literature review established the need for a further study to investigate particular issues relate with healthcare construction projects.

8.2.2 Objectives Related to this Research

Fourth Objective

The fourth objective was to identify causes of waste perticular to healthcare projects. Using a sequential approach, causes of waste identified in the literature review were filtered using the preliminary data collection study results to identify particular causes of waste for healthcare projects. The impact of each cause of waste in generating construction waste in healthcare projects was identified using the case study results. Findings revealed several causes of waste in the pre-design and contract agreement, design, and construction/renovation phases in healthcare projects. In the pre-design and contract agreement phase, most of the causes of waste related to: a lack of planning and identification of project requirements; incomplete/inconsistence documents; inefficiencies in communication and coordination; and lack of awareness about project waste minimisation priorities. In the design phase most of the causes of waste related to drawings and materials selection and specification inefficiencies. In the construction/renovation phase most common causes of waste are: inefficiencies in materials procurement, handling and storage; inefficiencies in communication and coordination; poor workmanship; and lack of planning and organisation of site activities.

Conclusion: Five main categories of causes of construction waste and their associated sub causes were identified from the findings. Those are: inefficiencies in project documents; lack of stakeholder awareness; inefficiencies in communication and coordination; buildability issues; and inefficiencies in materials selection and procurement. Also, no significant difference has been identified in causes of waste between acute care and primary care projects.

Fifth Objective

The fifth objective was to identify complex features in healthcare projects that effect construction waste generation and their relationship to causes of waste. The findings from the literature review, preliminary data collection and case studies contributed to fulfilling this objective. The preliminary data collection results revealed complex functional and operational features in healthcare projects that increase construction waste generation. Moreover, the case study results explained the relationships between complex features in healthcare buildings and causes of waste.

Conclusion: Complex functional features in healthcare buildings such as: different shapes and size requirements for healthcare building spaces; a substantial amount of M&E services; and the many complex requirements of healthcare projects, significantly increase construction waste generation on healthcare projects. Also, the findings showed that these features impact on the causes of construction waste throughout the building lifecycle stages.

Sixth Objective

The sixth objective was to examine the most suitable waste minimisation strategies to reduce construction waste generation in healthcare projects. Appropriate waste minimisation strategies to reduce construction waste generation from healthcare projects were identified from the literature review and preliminary data collection studies. With support from case study interviewees, the most suitable waste minimisation activities to address each individual cause of waste generation in the lifecycle of healthcare projects was identified.

Conclusion: Six main waste minimisation strategies (i.e. project documents management; efficient communication and coordination; project stakeholders' waste awareness; enhanced buildability; effective materials selection and procurement; and effective change management procedures) were identified as the most important waste minimisation strategies that need to be implemented in an holistic approach to reduce construction waste generation in healthcare projects.

Seventh Objective

The seventh objective was to develop and validate the HC-WMF, which was developed based on the CPIM adopted from the general problem solving methodology. The key findings emerging from the research were embedded into the HC-WMF. The proposed HC-WMF consists of two levels: high level; and low level. This provides guidelines to reduce construction waste generation in healthcare projects. Additionally, a SAT was developed to measure the effectiveness in implementing HC-WMF and to obtain learning outcomes for future project improvements. The validation process aimed to determine the clarity and appropriateness of the components in the HC-WMF and SAT. A combination of a questionnaire survey and validation interviews were conducted in the validation process. The questionnaire survey was undertaken among the respondents who had participated in the data collection studies, whereas; validation interviewees joined the study for the first time.

Conclusion: Key stakeholders in the healthcare construction industry held positive views on the suitability of the proposed HC-WMF and the SAT albeit, a few improvement suggestions were made by the respondents to further improve the HC-WMF and SAT to obtain enhanced benefits. Moreover, it was recognised that a collaborative project management approach would be suitable to implement the proposed HC-WMF with overall coordination through a project manager.

8.3 Contribution to knowledge

There are several key contributions made by this research, which have not been offered by previous research studies. This section outlines the key contributions from this study to the existing stock of knowledge.

- **Contribution to literature: Construction waste minimisation and healthcare construction**

This research has moved some way forward to enhancing the understanding of how construction waste generation throughout the lifecycle of a construction project. However, the findings of this research study are limited to healthcare construction projects as described in Section 8.4. The previous research studies have identified that healthcare buildings are complex and different in nature from other construction projects. This research has emphasised that associated complexities in healthcare projects increases the generation of construction waste on healthcare projects compared to other building projects. Consequently, this research identified several functional and operational features in healthcare buildings which increase waste generation during construction. Previously, no clear evidence has been discovered regarding the causes of waste perticular to healthcare projects. This research identified five key causes of waste generation and associated sub waste generation across the lifecycle stages of healthcare projects. Furthermore, this research explained how the impact of each cause of waste generation varies with the complexities inherent in healthcare projects in terms of construction waste generation. Additionally, the research proposed construction waste minimisation activities which should be implemented throughout the building lifecycle to address the causes of waste in healthcare projects. The findings of this research thus helped to develop the current state of waste minimisation practices in healthcare construction projects while facilitating the achievement of sustainable healthcare construction.

- **Healthcare waste minimisation framework for healthcare projects**

This research has developed a lifecycle construction waste minimisation framework for healthcare projects. The research findings were brought together to develop the HC-WMF, which provides guidelines for a healthcare project team to follow from the start of the project until completion to address the causes of waste that could occur in the lifecycle of a healthcare project. Therefore, the HC-WMF assists the healthcare project processes presenting waste minimisation activities to be implemented into each lifecycle phase. Additionally, the HC-WMF gives insights about the involvement of project stakeholders across the project lifecycle stages. In addition to the HC-WMF, a SAT was developed to facilitate the project team's ability to measure the effectiveness of implementing waste minimisation activities throughout the healthcare project lifecycle to obtain learning outcomes for more effective improvements in future projects.

8.4 Research Limitations

Firstly, the study mainly employed qualitative data collection methods with the use of interviews. Due to the use of face-to-face semi structured interviews in the data collection stages, issues could have arisen related to the way in which the questions were put to the interviewees since this could influence the interviewees' responses. For instance, most of the probing questions put to the interviewees during the interviews were based on respondents' own responses; and therefore were not unique to everyone. Additionally, during the interviews, some interviewees were reluctant to reveal the current waste generation issues and waste minimisation practices in their organisations even though the respondents were assured that their responses would be treated confidentially and there would no adverse impact on them or their organisations. It was, particularly, noticed that the respondents were reluctant to accept their responsibilities regarding construction waste generation and passed the fault to other project stakeholders. Furthermore, the choice of case study based interviews limited the generalisation of the research findings since respondents' answers were based on one particular project, however, it is difficult to determine the impacts of the above on the research results. Hence, the outcomes of this research are not free from adverse methodological effects like research bias.

Secondly, from the beginning of this research, the sampling population represented healthcare clients, architects and contractors since they are the key representatives of healthcare project lifecycle phases; however, there are other stakeholders involved in

the healthcare construction process; therefore, it can be assumed that the outcomes might have changed if opinions were gathered from other stakeholders participating in healthcare projects. Additionally, the research outcomes were mainly based on nine preliminary interviews and four case studies. Even though the current study attempted to draw the best possible sample for the research, a much larger sample size and a different sample frame may have been given different results. However, difficulties in reaching respondents for face-to-face interviews, accessibility to interviewees due to geographical dispersion, availability of time, and availability of resources in this research limited the selection of the study sample size to the above figures.

Thirdly, even though there is a requirement to develop a lifecycle approach to reduce construction waste generation in the UK, the framework that was developed focused only on healthcare projects. Additionally, with the inherent complexities in healthcare projects, there could be certain limitations when using the HC-WMF directly on other construction projects, since there is a risk of not achieving the required waste minimisation outcomes.

Fourthly, during the HC-WMF validation stage, the validation questionnaire survey was conducted among the participants of the preliminary data collection studies and case studies. Other than validation interviewees, the validation sample was limited to previous interviewees who had participated during the data collection stages. Hence, generalisation of the HC-WMF and SAT was limited as the validation process did not consider a wider population. Additionally, due to the long duration of healthcare construction projects, the HC-WMF and SAT were not implemented in an actual project during the validation process to identify outcomes in real life scenarios.

Finally, this research has attempted to minimise only materials waste in healthcare projects even though some authors defined construction waste in a much broader perspective including machinery waste and labour waste other than materials waste. Also, this research did not consider the demolition stage in the healthcare project lifecycle considering different characteristics between construction waste and demolition waste.

8.5 Recommendations

Considering the findings and conclusions of this research several recommendations can be made to the healthcare construction industry as well as government/policy makers to improve construction waste minimisation in healthcare projects.

8.5.1 Healthcare construction industry

This study emphasised that the causes of construction waste in healthcare projects emerge throughout the project lifecycle stages. The findings also highlighted that the complexities in healthcare construction projects increase waste generation due to associated causes of waste from the start of the project (i.e. large and complex project requirements increase construction waste generation due to incomplete briefing). Therefore, the research recommends healthcare project stakeholders consider waste minimisation as a priority from the beginning of the project until completion to obtain actual construction waste reduction benefits.

In the UK, the current and future trends in procurement of healthcare construction projects are through PFI, P21 and LIFT programmes. All these procurement systems have the characteristic of early project stakeholder involvement in the project, therefore, this research recommends ensuring participation of all the necessary project stakeholders from the start of the project to effectively communicate project information among project stakeholders while enhancing their awareness about project waste minimisation requirements.

According to the current research study results, waste minimisation in healthcare projects is still considered a responsibility of the contractor. This research emphasises the requirement of a client driven initiative to enforce construction waste minimisation practices effectively from the start of the project because the client's interest and attitudes towards construction waste minimisation greatly impact on the project's waste minimisation priorities. Additionally, the study recommends assigning waste minimisation responsibilities and targets to other project stakeholders, as appropriate, to enhance their interest in waste minimisation. Furthermore, when the client driven commitment is not significant in any project, other professionals engaged in the project (especially contractors) are required to take the initiative (i.e. maintain effective communication and coordination, clearly identify and allocate waste minimisation responsibilities to stakeholders) to encourage waste minimisation among stakeholders.

This study recommends incorporating waste minimisation requirements into project documentation at all levels (i.e. client's brief, tender and contract documents, drawings and specifications). It also recommends that steps are taken to ensure effective coordination of the documentation process to help reduce inconsistencies and errors when sharing project information.

Furthermore, this study pointed out that construction companies have paid very little attention to developing internal policies to reduce construction waste minimisation. Hence, this research recommends development of company internal policies focusing on SC and construction waste minimisation.

8.5.2 Government/policy makers

This study clearly emphasised the need for reviewing government policies and legislations relating to sustainable healthcare construction to encourage construction waste minimisation. As discussed in this research, clients' commitment and interest is significant to reducing construction waste generation in healthcare projects. Therefore, this research recommends introducing or revising government policies and legislations to encourage healthcare client organisations (i.e. DH, NHS Trusts and Primary care Trusts) to give priority to waste minimisation strategies in their projects.

Also, this research highlighted a number of construction waste generation issues in healthcare projects related to stakeholders' attitudes, and, interest and knowledge of construction waste minimisation. Therefore, policy makers should consider wider cultural changes among healthcare industry stakeholders to increase their motivation and morale towards construction waste minimisation. Furthermore, this research highlighted positive commitment from all the project stakeholders as a key factor to reducing construction waste generation in healthcare projects and thus suggested to adoption of collaborative project procurement systems. Therefore, it is recommended that the DH, and the NHS take the necessary initiatives to embed construction waste minimisation responsibilities, waste minimisation targets and incentives, and relevant contractual clauses into P21 and LIFT procurement systems that were specifically introduced to procure healthcare buildings. Such initiatives could help to disseminate best construction waste minimisation practices among healthcare project stakeholders and would establish much needed cultural changes as well.

This research recommends healthcare project teams consider construction waste minimisation from the start of the project. However, most of the construction waste minimisation policies, guides and legislations published by the UK government focused on the design and construction phase (SWMPs, design waste minimisation guides). Therefore, it is recommended that a review of the existing waste minimisation guides/policies/legislations or the introduction of new waste minimisation guides/policies/legislations to the pre-design and contract agreement phase are implemented to consider waste minimisation from the start of the project.

8.5.3 Further Research

There are opportunities to extend the outcomes of this research through further investigations. In terms of construction waste minimisation in the UK, the HC-WMF is a guide to only healthcare construction projects. However, in the UK, there are large numbers of other building projects and infrastructure development programmes which contribute to significant quantities of construction waste generation. To achieve zero waste to landfill as part of the Sustainable Construction Strategy in the UK, it is necessary to consider waste minimisation from a more holistic view point rather than focusing only on healthcare projects. It would be useful to extend this research further to develop a lifecycle construction waste minimisation mechanism to cover the issues pertaining to the whole construction industry.

The findings of this research are not robust enough to differentiate the specificity and exclusivity of the complexities identified in healthcare projects in relation to the complexities inherent in the generation of construction waste in other complex buildings, since the findings were limited to healthcare construction projects. However, a close examination of the findings provides reasonable grounds to accept that many of these complexities are common in other complex building projects as well. Therefore, a further study comparing different complex building types would be an important area for further research to effectively reduce construction waste generation in all complex building projects.

Even though the literature review specified the requirement for reducing process waste (i.e. machinery waste, labour waste) to increase efficiency in the construction process, this research study has focused on only materials waste minimisation in healthcare construction projects as discussed in the Section 8.4, it is important to extend this research further to examine a suitable process waste minimisation mechanism to increase efficiency in the healthcare construction process to secure best value for money.

The selection of the research design for this study to find answers to the research questions was subjected to a few limitations as discussed in the Section 8.4 due to the limited availability of time and resources. For instance, opinions on the causes of construction waste, complexities in healthcare projects and waste minimisation good practices were gathered through interviews with healthcare clients, architects and contractors. However, it is well known that other stakeholders involved in healthcare projects from start to completion also significantly influence construction waste

generation. Additionally, the impact of the causes of waste on waste generation and best waste minimisation strategies may change depending on the project size, location, project duration and stakeholders' commitment to reducing construction waste generation. It could be argued that the findings may have been different if selection of the sampling population and projects had been wider. Also, other than interviews and case studies, the use of any other research design methods (i.e. questionnaires, focus groups) would have been given different results. Hence, it is recommended that future studies consider different stakeholder groups, different projects and different research designs to investigate causes of waste, complexities in healthcare facilities and waste minimisation best practices.

In order to facilitate a wider adoption of the HC-WMF, a number of future studies can be recommended. The HC-WMF did not include a user guide, and it is suggested a further study to develop a user guide. Additionally, it will be useful to develop draft formats of the documents and databases to use along with the framework to more easily implement the guidelines proposed in the HC-WMF. Also, the HC-WMF does not demonstrate the possibilities of using existing tools, guidance documents and policies and legislations to increase the usability of the framework among healthcare industry practitioners. This study recommends a further research to map existing tools, guidance documents, policies and legislation for incorporation into the HC-WMF. Moreover, further research can be focused on a detailed implementation strategy for the proposed HC-WMF.

As discussed in the Section 6.2.5.3, the use of weightage instead of averages in the SAT to measure the effectiveness of implementing waste minimisation activities would be more appropriate. Hence, this research recommends a further study to assign weightings based on the level of importance of each waste minimisation activity in terms of construction waste minimisation in healthcare projects. It is also recommended that a check-list of deliverables be outlined within the assessment to simplify the assessment procedure.

The HC-WMF addresses the causes of waste at the project level. However, it would be appropriate to expand the use of HC-WMF to higher levels (i.e. strategic level, national level) to deliver a holistic approach to reducing construction waste generation in healthcare projects. In that sense, the SAT could be customised accordingly to assess the contribution of higher level stakeholders towards waste minimisation.

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APPENDIX 1: LIST OF PUBLICATIONS

1. Domingo, N., Osmani, M., Price, A. (2009) Construction waste minimisation in the UK healthcare industry, *Proceedings: Association of Researchers in Construction Management (ARCOM) Conference*, Albert Hall, Nottingham, United Kingdom, pp. 1021-1030.

2. Domingo, N., Osmani, M., Price, A. (2008) Reducing construction waste in healthcare facilities: A project lifecycle Approach, *Proceedings: Association of Researchers in Construction Management (ARCOM) Conference*, Cardiff, Wales, United Kingdom, Volume 2, pp. 201-209.

APPENDIX 3.1: PRE-INTERVIEW QUESTIONNAIRE

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PRE INTERVIEW QUESTIONNAIRE

REDUCING CONSTRUCTION WASTE IN HEALTHCARE FACILITIES:
A PROJECT LIFECYCLE STRATEGY.

AIM

This pre interview questionnaire is part of a PhD study aimed at developing a lifecycle construction waste minimisation framework for healthcare facilities in UK. It is part of funded project by Health and Care Infrastructure Research and Innovation Centre (HaCIRIC).

The aim of this pre interview questionnaire is to obtain information on construction waste causes and waste minimisation practices in the healthcare construction projects to elaborate in detail during the interview. This questionnaire seeks to gather information from respondents based on their expertise knowledge and experience to identify precise needs in the UK healthcare constructions in terms of waste minimisation.

Please fill the questionnaire before starting the interview. **All the information provided will be held in strict confidence and used for academic and research purposes only.**

If you have any queries at all, please contact me at 07588589157 or by email D.D.A.N.Domingo@lboro.ac.uk.

SECTION 1: BACKGROUND INFORMATION

1.1 **Please provide the following information.**

Name: .....

Company: .....

Position in the company: .....

Total work experience (Years) .....

Total construction experience in the UK (years): .....

Healthcare construction experience in the UK (years): .....

1.2 Please state the number of years you have been working in the following building projects (Please state all that apply).

Commercial buildings .....

Educational buildings .....

Healthcare buildings .....

Hotel buildings .....

Industrial buildings .....

Residential buildings .....

1.3 Based on your experience, please rate from 1 to 5, the severity of construction waste generation of the following building types. (1= No waste generation, 2=Very low waste generation, 3=Low waste generation, 4=High waste generation, 5=Very high waste generation). (Please tick one selection by building type/ if you don't have experience on the building type please tick N/A.

Type of building	**Waste generation severity**					
	1	**2**	**3**	**4**	**5**	**N/A**
Commercial buildings						
Educational buildings						
Healthcare buildings						
Hotel buildings						
Industrial buildings						
Residential buildings						

1.4 Do you think healthcare buildings are complex compared to other buildings? (Please tick against appropriately

Yes ☐ **No** ☐

1.4 (a) If yes, please state the reasons for your answer in the given space.

……

……

1.5 What are the types of healthcare construction projects you are involved in recently (Please tick all that apply)?

New acute hospitals ☐ New primary care hospitals ☐

Acute hospital refurbishments ☐ Primary hospitals refurbishments ☐

Extension to existing buildings ☐

Others (Please specify) ----------

1.6 Based on your experience rate the types of healthcare projects based on their waste generation severity ((H=High waste production, M=Average waste production, L=Low waste production).

Type of healthcare construction	Waste production rate		
	H	M	L
New acute hospitals			
New primary care hospitals			
Acute hospital refurbishments			
Primary hospitals refurbishments			
Extension to existing buildings			
Others (Please specify below)			

1.7 Do you have a sustainability policy for healthcare projects in your company (Please tick one box only)?

Yes ☐ No ☐ In progress ☐

1.8 If 'Yes', what are the most important environmental issues with in your sustainability policy (Please tick all that apply)?

Minimise energy consumption ☐ Minimise water consumption ☐

Minimise construction waste generation ☐ Minimise CO2 emission ☐

Others (Please specify)

SECTION 2: LIFECYCLE CONSTRUCTION WASTE MAPPING

2.1 Please identify and rate the following causes of construction waste particular to the healthcare construction projects based on your experience (H=High waste production, M=Average waste production, L=Low waste production).

Related Project stage	Related waste causes	Relevance to waste production	
		Yes	No
Pre design	Inefficiencies in communication and coordination		
	Incomplete briefing		
	Lack of client's awareness of the construction process		
	Waste minimisation issues not embedded in the brief		
	Inconsistencies in the contract documents		
	Type of contract		
	Others (Please specify below)		
Design	Lack of knowledge of alternative materials		
	Incorrect drawing details		
	Complex designs generating a lot of off-cuts		
	Over-/under-specification		
	Inefficiencies in the communication and coordination		
	Design changes		
	Delays in drawings		
	Lack of awareness about the waste generation in construction		
	Others (Please specify below		
Construction/ Renovation	Poor workmanship causing rework		
	Inefficiencies in the communication and coordination		
	Lack of a site waste management plans for every project		
	Material handling and storage facilities on site		
	Damages to materials during transportation		
	Ordering the wrong materials		
	Equipment malfunctioning causing rework		
	Others (Please specify below)		

SECTION 3: CONSTRUCTION WASTE MINIMISATION PRACTICES IN THE HEALTHCARE INDUSTRY

3.1 Which is the most prevailing procurement systems used in your current healthcare projects (Please tick all that apply)?

PFI ☐ ProCure 21 ☐ LIFT ☐

Others (Please specify) ----------

3.2. Do you have a construction waste minimisation policy for healthcare projects in your company (Please tick one box only)?

☐ Yes ☐ No ☐ In progress

3.3 Please tick against the following waste minimisation strategies that are currently implemented in your healthcare projects (Please tick all that applies).

Project Stage	Waste minimisation strategy	Implementation status	
		Yes	No
Pre design	Insert contractual clauses to enforce waste minimisation		
	Embed waste minimisation requirements to the brief.		
	Others (Please specify below)		
Design	Avoid late design changes		
	Early supply chain integration		
	Effective communication and coordination		
	Usage of offsite products and components		
	Adoption of low-waste modern building technologies.		
	Change management to reduce waste		
	Others (Please specify below)		
Construction/ Renovation	Adequate site supervision and control		
	Effective communication and coordination		
	Waste segregation, reuse and recycling		
	Regular site inspection for waste minimisation		
	Training and education on waste concepts to all staff		
	Effective materials control schemes.		
	Sub-contractors responsible for waste disposal.		
	Proper documentation of waste incidences on site.		
	Adequate planning and organisation of work process on site.		
	Others (Please specify below)		

APPENDIX 3.2: PRELIMINARY INTERVIEW SCHEDULE

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Mobile: 07588589157

PRELIMINARY INTERVIEW SCHEDULE

REDUCING CONSTRUCTION WASTE IN HEALTHCARE PROJECTS:
A PROJECT LIFECYCLE APPROACH.

AIM

This interview is part of a PhD study aimed at developing a lifecycle construction waste minimisation framework for healthcare projects in the UK. It is part of funded project by Health and Care Infrastructure Research and Innovation Centre (HaCIRIC).

The aim of this interview is to explore construction waste causes, and examine current waste minimisation practices throughout the healthcare project lifecycle. This interview seeks to gather information from respondents based on their expertise knowledge and experience to identify precise needs in the UK healthcare constructions in terms of waste minimisation.

The interview should take approximately one hour. **All the information provided will be held in strict confidence and used for academic and research purposes only.**

AGENDA

Background information	10 minutes
Lifecycle construction waste mapping	25 minutes
Construction waste minimisation practices in healthcare industry	20 minutes
Further thoughts	5 minutes
Total duration	**1 hour**

REDUCING CONSTRUCTION WASTE IN HEALTHCARE PROJECTS:
A PROJECT LIFECYCLE STRATEGY.

SECTION 1: BACKGROUND INFORMATION

The aim of this section is to identify individuals and institutional background information related to the healthcare construction industry.

1.1 How many years have you been working in the healthcare construction industry?
1.2 How important is waste minimisation in your current healthcare construction projects?
1.3 What are the types of healthcare construction projects you are involved in?
1.4 Based on your experience which healthcare projects tend to produce significant construction waste? Why?
1.5 What are the complexities in healthcare projects that effect on construction waste generation? How?
1.6 What do you think would be the most suitable approach to reduce construction waste generation from healthcare projects? Why?

SECTION 2: LIFECYCLE CONSTRUCTION WASTE MAPPING

The aim of this section is to identify causes of construction waste in healthcare construction projects.

2.1 Based on your experience, what are the causes of construction waste during **pre-design stage**? How?
2.2 Based on your experience, what are the causes of construction waste during **design stage**? How?
2.3 Based on your experience, what are the causes of construction waste during **procurement stage**? How?
2.4 Based on your experience, what are the causes of construction waste during **construction stage**? How?

SECTION 3: CONSTRUCTION WASTE MINIMISATION PRACTICES IN THE HEALTHCARE INDUSTRY

The aim of this section is to identify construction waste minimisation practices in the healthcare construction industry.

3.1 Who is responsible for construction waste minimisation in your current healthcare projects ?
3.2 Based on your experience, what are the impacts of the new procurement routs in healthcare sector (i.e. PFI, ProCure 21 and LIFT) on construction waste minimisation.
3.3 What are the waste minimisation strategies that you think are more effective to implement in your healthcare projects? why?

SECTION 4: FURTHER THOUGHTS

If there are any other issues which you feel are relevant to this research please feel free to raise them now.

Thank you very much for participating in this study.

APPENDIX 3.3: CASE STUDY INTERVIEW SCHEDULE

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CASE STUDY INTERVIEW SCHEDULE

REDUCING CONSTRUCTION WASTE IN HEALTHCARE FACILITIES:
A PROJECT LIFECYCLE APPROACH.

AIM

This interview is part of a PhD study funded by the Health and Care Infrastructure Research and Innovation Centre (HaCIRIC) aimed at developing a lifecycle construction waste minimisation framework for healthcare facilities.

The **aim of this case study is to explore relationships between causes of construction waste with the features in the hospital and to explore best waste minimisation strategies used throughout the lifecycle of the project**. An approximate breakdown of the proposed interview is shown below.

1) Background information (5 minutes)
2) Causes of construction waste and their relationship to functional/operational features in the healthcare project (30 minutes)
3) Construction waste minimisation strategies (20 minutes)
4) Further thoughts (5 Minutes).

The interview should take approximately 1 hour. All responses will remain confidential. Any information indicating your identity will be removed and will not be linked to your responses.

If you have any queries at all, please contact me at 07588589157 or by email D.D.A.N.Domingo@lboro.ac.uk.

1.0 Background information

The aim of this section is to identify the project background information and the respondent's background information.

1.1 Describe your role and responsibilities in the project?

1.2 Describe the level of importance given to construction waste minimisation in the project?

1.3 Describe your role and responsibilities to minimise construction waste in the project?

1.4 Describe challenges to construction waste minimisation including project features, partners, budget, legislations, procurement method etc.?

1.5 Rate against the project phases according to your familiarity on each phase of the project?

Project phase	**Very familiar**	**Familiar**	**Not very familiar**	**Unfamiliar**
Pre – design phase				
Design phase				
Procurement phase				
Construction/renovation phase				

2.0 Causes of construction waste and their relationship to functional/operational features in the healthcare project

The aim of this section is to identify the causes of waste and their relationships with functional and/or operational features in the project.

2.1 Select the **functional features** in hospital building which affect on construction waste generation? (Tick against appropriately).

Table 1: Functional features in hospital buildings

No	**Functional features**	**Relevant/ Not Relevant**
A	Complex nature of the building due to requirement of different shapes and sizes of rooms to satisfy various functional requirements within the building (eg: X- Ray rooms, operation theatres, ICUs etc.)	
B	Complex nature of mechanical and electrical services of the building	
C	Complex nature of identifying all the functional requirements of the building at early stage	
D	Requirement of high density of materials to the per m^2 of the building	
E	Requirement of large number of materials or special types of materials to the project to satisfy quality standards	
F	Changing nature of functional requirements from project to project limiting the use of past hospital construction experience to the project	
G H	Others • …….. • ……..	

Use Table 1 for questions:- 2.3(c), 2.5(c), 2.7(c) & 2.9(c)

2.2 Select the **operational features** in hospital building which affect on construction waste generation? (tick against appropriately).

Table 2: Operational features in hospital buildings

No	Operational features	affect on waste generation
A	24 x 7 operation of the building increase the need of less disturbances to the parts of the building which are under operation throughout the project.	
B	Building need to be adaptable and flexible to fulfil future management and user requirements	
C	Building quality should support high wear and tear to maintain required standards throughout the expected life time of the building	
D E	Others • …… • ……	

Use Table 2 for questions:- 2.3(d), 2.5(d), 2.7(d) & 2.9(d)

Pre - design and contract agreement phase

2.3 The following table shows waste causes possible to occur in the **Pre - design and contract agreement phase** of a hospital project. Form your experience on the project,

a) Rank the waste causes according to their impact on construction waste generation. (1= highest impact)

b) State the frequency occurred during the project?

c) Select the **functional features** from the **Table 1** which caused waste causes?

d) Select the **operational features** from the **Table 2** which caused waste causes?

No	Causes of waste	Rank (impact) (a)	Frequency (b)	Functional features (c)	Operational features (d)
1	Inefficiencies in communication and coordination				
2	Incomplete briefing				
3	Clients are not willing to change their requirements to standard sizes				
4	Clients' lack of awareness of the construction process				
5	Lack of concentration on adaptability and flexibility by clients				
6	Clients' lack of knowledge about the materials available				
7	Inconsistencies in the contract documents				
9	Waste minimisation clauses not embedded in contracts				
10	Type of contract				
	Others • ……				

2.4 What measures you have taken to eliminate waste causes stated in the Question 2.3?

Design phase

2.5 The following table shows waste causes possible to occur in the **design phase** of a hospital project. Form your experience on the project,

a) Rank the waste causes according to their impact on construction waste generation. (1= highest impact)

b) State the frequency occurred during the project?

c) Select the **functional features** from the **Table 1** which caused waste causes?

d) Select the **operational features** from the **Table 2** which caused waste causes?

No	Causes of causes	Rank (impact) (a)	Frequency (b)	Functional features (c)	Operational features (d)
1	Complex designs generating a lot of off-cuts				
2	Design changes				
3	Incorrect drawing details				
4	Not coordinating dimensions and sizes				
5	Inefficiencies in communication and coordination				
6	Inappropriate selection of materials to lifecycle requirements				
7	Over-/under-specification				
8	Delays in drawings causing time pressure during construction				
9	Lack of awareness about the waste generation in construction process				
10	Not thinking about the best ways to design				
11	Lack of knowledge of alternative materials				
	Others • …… • ……				

2.6 What measures you have taken to eliminate waste causes stated in the Question 2.5?

Construction/ renovation phase

2.7 The following table shows waste causes possible to occur in the **construction/renovation phase** of a hospital project. Form your experience on the project,

a) Rank the waste causes according to their impact on construction waste generation. (1= highest impact)

b) State the frequency occurred during the project?

c) Select the **functional features** from the **Table 1** which caused waste causes?

d) Select the **operational features** from the **Table 2** which caused waste causes?

No	Causes of waste	Rank (impact) (a)	Frequency (b)	Functional features (c)	Operational features (d)
1	Lack of planning & organisation				
2	Inadequate communication and coordination				
3	Poor workmanship causing rework				
4	Material handling and storage facilities on site				
5	Advance ordering of material				
6	Care and quality of trades used				
7	Damage to materials during transportation				
8	Ordering wrong/excess materials				
9	Lack of a site waste management plan				
10	Equipment malfunctioning causing rework				
11	Lack of planning & organisation				
	Others • …… • ……				

2.8 What measures you have taken to eliminate waste causes stated in the Question 2.7?

3.0 Construction Waste Minimisation Strategies

3.1 What measures you have taken during the **pre-design and contract agreement phase** to address causes of waste?

3.2 What measures you have taken during the **design phase** to address causes of waste?

3.3 What measures you have taken during the **construction/renovation phase** to address causes of waste?

4.0 Further thoughts

4.1 If there are any other issues which you feel are pertinent to this research please feel free to raise them now.

Signature …… Date ……..

Thank you very much for participating in this study.

APPENDIX 3.4: VALIDATION QUESTIONNAIRE

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Dear …….,

LIFECYCLE CONSTRUCTION WASTE MINIMISATION FRAMEWORK FOR HEALTHCARE PROJECTS.

I am pleased to inform that I have developed the **"Lifecycle construction waste minimisation framework for healthcare facilities"** based on your valuable ideas given to me during the interview which was held few months ago. Also, I like to take this as an opportunity to thank you for your contribution and your valuable time spent on my research. I hereby enclosed the hardcopies of developed framework and self-assessment tool for your kind perusal.

Framework Overview

Proposed framework consists of two components:

1. **Lifecycle construction waste minimisation framework for healthcare facilities.**

   This framework consists of six waste minimisation strategies: 1) project documents management; 2) stakeholders and waste awareness; 3) communication and coordination; 4) buildability; 5) materials selection and procurement; and 6) change management. Waste minimisation activities to implement under each of the above mentioned waste minimisation strategies listed in detail with some examples by dividing the whole project lifecycle in to three main phases: 1) pre design and contract agreement; 2) design; and 3) construction/renovation.

2. **Self-assessment tool**

   This tool helps to perform a self-assessment on the effectiveness of proposed waste minimisation strategies implementation in healthcare projects where the feedback comes from the assessment could be used to improve waste minimisation in future projects through effective use of cumulative lessons learnt from past projects.

Further, I highly appreciate if you could send me your feedback and improvement suggestions regarding the clarity and suitability of the proposed “framework” and the “self-assessment tool” by completing the electronic questionnaire which I will send to your email within next couple of days along with the softcopies of developed framework and self-assessment tool.

Thank you.
Yours truly,
Niluka Domingo
PhD student, Loughborough University.

Lifecycle construction waste minimisation framework validation

INSTRUCTIONS TO COMPLETE THE QUESTIONNAIRE

AIM OF THE QUESTIONNAIRE

The aim of this validation questionnaire is to refine and validate the developed "Lifecycle construction waste minimisation framework for healthcare facilities" and "self assessment tool" in terms of clarity, importance of framework components to minimise waste generation from healthcare projects and suitability of the self assessment procedure.

DATA PROTECTION STATEMENT

All the information provided will be treated strictly confidential and no information will be made public at anytime.

This questionnaire consists of three major sections.

SECTION 1 - FRAMEWORK VALIDATION

The aim of this section is to refine and validate the Lifecycle construction waste minimisation framework for healthcare facilities in terms of clarity and importance of framework components to minimise waste generation from healthcare projects.

(Please refer "Lifecycle construction waste minimisation framework for healthcare facilities" before completing this section of the questionnaire).

SECTION 2- SELF ASSESSMENT TOOL VALIDATION

The aim of this section is to refine and validate the "Self Assessment Tool" in terms of clarity and suitability of the assessment procedure.

(Please refer "Self assessment tool" before completing this section of the questionnaire).

SECTION 3- IMPLEMENTATION STRATEGY

The aim of this section is to obtain ideas from healthcare industry practitioners about the framework implementation strategy.

Please enter your name in the given box before moving to SECTION 1.

Name:

SECTION 1- FRAMEWORK VALIDATION

Please refer 'PAGE 1- PAGE 5' of attached framework to answer following questions.

Please rate the statements given in questions 1, 2, 3 and 4 using the following rating scale.

1= Strongly Disagree;
2= Disagree;
3= Neither Agree/Disagree;
4= Agree; and
5= Strongly Agree.

Lifecycle construction waste minimisation framework validation

1. According to your level of agreement on the "clarity of the framework", please rate the following statements. (Please tick against appropriately from 1 to 5).

	1	2	3	4	5
The structure of the proposed framework is clear.	○	○	○	○	○
The contents presented in the framework are clear.	○	○	○	○	○
The construction waste minimisation process shown in the framework is clear.	○	○	○	○	○
The relationships between waste minimisation strategies are clear.	○	○	○	○	○
The information flows between different projects to obtain continuous improvement on waste minimisation in healthcare projects is clear .	○	○	○	○	○

Please specify other comments to improve the clarity of the framework in the given space.

2. According to your level of agreement on the "importance of implementing waste minimisation activities in the following life cycle phases in a healthcare project", please rate the following statements. (Please tick against appropriately from 1 to 5).

	1	2	3	4	5
Implementing waste minimisation activities in the "Pre design and Contract agreement phase (PC)" is important to minimise waste in healthcare.	○	○	○	○	○
Implementing waste minimisation activities in the "Design phase (DE)" is important to minimise waste in healthcare.	○	○	○	○	○
Implementing waste minimisation activities in the "Construction/Renovation phase (CR)" is important to minimise waste in healthcare.	○	○	○	○	○

Please specify any other lifecycle phases which you think are important to minimise waste generation from healthcare projects in the given space.

Lifecycle construction waste minimisation framework validation

3. According to your level of agreement on the "importance of the selected waste minimisation strategies for healthcare construction waste minimisation", please rate the following statements. (Please tick against appropriately from 1 to 5).

	1	2	3	4	5
"Project documents management (A)" is important to minimise waste generation from healthcare projects.	○	○	○	○	○
"Stakeholder waste awareness (B)" is important to minimise waste generation from healthcare projects.	○	○	○	○	○
Adequate "Communication and coordination (C)" is important to minimise waste generation from healthcare projects.	○	○	○	○	○
"Buildabilty (D)" is important to minimise waste from healthcare projects.	○	○	○	○	○
Appropriate "Materials selection and procurement (E)" is important to minimise waste generation from healthcare projects.	○	○	○	○	○
"Change management (F)" is important to minimise waste generation from healthcare projects.	○	○	○	○	○

Please specify any other waste minimisation strategies which you think are important to minimise construction waste generation from healthcare facilities in the given space.

Lifecycle construction waste minimisation framework validation

4. According to your level of agreement on the "importance of implementing following waste minimisation activities to minimise construction waste from healthcare projects", please rate the following statements. (Please tick against appropriately from 1 to 5).

	1	2	3	4	5
Complete all the project requirements documents before starting the design is important (A.1.PC).	○	○	○	○	○
Specify waste minimisation clauses in the contract documents is important (A.2.PC).	○	○	○	○	○
Complete all the design and construction information before starting site activities is important (A.2.DE & A.2.CR).	○	○	○	○	○
Integrate all the documents to a database and share with stakeholders is important (A.3.PC, A.3.DE & A.3.CR).	○	○	○	○	○
Appoint all the key stakeholders to the project as early as possible is important (B.1.PC).	○	○	○	○	○
Organise waste awareness programmes to project stakeholders is important (B.2.PC, B.2.DE & B.2.CR).	○	○	○	○	○
Conduct regular communication with stakeholders to share project information is important (C.1.PC, C.1.DE & C.1.CR).	○	○	○	○	○
Share all the project information sharing documents with stakeholders through a database is important (C.2.PC, C.2.DE & C.2.CR).	○	○	○	○	○
Assess the feasibility of the project requirements within project constraints is important (D.1.PC).	○	○	○	○	○
Keep designs as simple as possible using standard shapes and sizes is important (D.1.DE).	○	○	○	○	○
Apply low waste modern technologies to the design as much as possible is important (D.2.DE).	○	○	○	○	○
Keep allocations for future expansions and changes in the deisgn is important (D.3.DE).	○	○	○	○	○
Assess the buildability of the design before starting site activities is important (D.4.DE).	○	○	○	○	○
Allocate site spaces for specific activities is important (D.1.CR).	○	○	○	○	○
Obtain approval for site waste management plans from facility managers before starting site activities is important (D.2.CR).	○	○	○	○	○
Manage materials deliveries to the site is important (D.3.CR).	○	○	○	○	○
Monitor trade contractor activities according to the project programme is important (D.4.CR).	○	○	○	○	○
Prepare project preliminary specifications as early as possible is important (E.1.PC).	○	○	○	○	○
Discuss special material requirements with supply chain partners as early as possible is important (E.2.PC).	○	○	○	○	○
Select minimum number of materials to the building as much as possible is important (E.1.DE).	○	○	○	○	○
Select materials according to building long term requirements is important (E.2.DE).	○	○	○	○	○
Obtain ideas/advices from supply chain partners when selecting materials is important (E.3.DE).	○	○	○	○	○
Minimise packaging waste when purchasing materials is important (E.1.CR).	○	○	○	○	○
Purchase customised materials where possssible is important (E.2.CR).	○	○	○	○	○
Obtain prior approval for project requirements to avoid later changes is important (F.1.PC).	○	○	○	○	○
Develop a clear change management procedure for the project is important (F.1.PC).	○	○	○	○	○
Evaluate chages to identify the best method when implementing changes is important (F.1.DE).	○	○	○	○	○
Coordinate changes appropriately with relevant stakeholders is important (F.2.DE).	○	○	○	○	○
Redesign changes with minimium extra resources is important (F.3.DE).	○	○	○	○	○
Obtain approval from clients, end users etc. before implementing changes on site is important (F.4.DE).	○	○	○	○	○
Recover materials as much as possible when dismanteling existing elements during renovation activities is important (F.1.CR).	○	○	○	○	○

Please specify any other waste minimisation activities which you think are important to minimise construction waste generation from healthcare facilities in the given space.

Lifecycle construction waste minimisation framework validation

5. Please use the space below to add your suggestions to further improve "Lifecycle construction waste minimisation framework for healthcare facilities".

SECTION 2- SELF ASSESSMENT TOOL VALIDATION

Please refer 'Worksheet 1- Worksheet 7 of attached self assessment tool to answer following questions.

Please rate the statements given in questions 6 and 7 using the following rating scale.

1= Strongly Disagree;
2= Disagree;
3= Neither Agree/Disagree;
4= Agree; and
5= Strongly Agree.

6. According to your level of agreement on the "clarity of the Self assessment tool", please rate the following statements. (Please tick against appropriately from 1 to 5).

	1	2	3	4	5
The instructions given to use the "Self assessment tool" are clear (Worksheet 1).	○	○	○	○	○
The assessment method proposed in the "Self assessment tool" to measure the effectiveness in implementing framework in healthcare projects is clear.	○	○	○	○	○
The waste minimisation activities stated in the worksheets 3, 4 and 5 are clear to enough to do the assessment.	○	○	○	○	○

Please specify other comments to improve the clarity of the self assessment tool in the given space.

Lifecycle construction waste minimisation framework validation

7. According to your level of agreement on the "Self assessment procedure", please rate the following statements. (Please tick against appropriately from 1 to 5).

	1	2	3	4	5
The scale used to measure the effectiveness of implementing waste minimisation activities in the project is suitable.	○	○	○	○	○
Waste minimisation activities stated in worksheets 3, 4 and 5 to assess the implementation effectiveness are easy to assess.	○	○	○	○	○
Calculating average to measure the effectiveness of each strategy's implemention in a project is suitable.	○	○	○	○	○
Calculating average to measure the effectiveness of strategies implementation in each lifecycle phase is appropriate.	○	○	○	○	○

Please specify other comments to improve the self assessment procedure in the given space.

8. Please use the space below to add your suggestions to further improve "Self assessment tool".

9. Please try to assess how effectively you have implemented waste minimisation activities stated in the "FRAMEWORK" in a recently completed healthcare project which you are familiar using the "SELF ASSESSMENT TOOL". (Please use the attached softcopy of SELF ASSESSMENT TOOL in the email.)

If you are happy to share your completed "SELF ASSESSMENT" please send them to the following E-mail address. D.D.A.N.Domingo@lboro.ac.uk.

SECTION 3- IMPLEMENTATION STRATEGY

10. Please specify your ideas about the most suitable implementation strategy for the proposed "Lifecycle construction waste minimisation framework for healthcare facilities". (Please state in the given box).

Thank you very much for your time and effort in completing this questionnaire.

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APPENDIX 3.5: VALIDATION INTERVIEW SCHEDULE

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REDUCING CONSTRUCTION WASTE IN HEALTHCARE PROJECTS: A PROJECT LIFECYCLE APPROACH

FRAMEWORK VALIDATION INTERVIEW SCHEDULE

AIM

This interview is part of a PhD study funded by the Health and Care Infrastructure Research and Innovation Centre (HaCIRIC) aimed at developing a lifecycle construction waste minimisation framework for healthcare facilities.

The aim of this interview is to explore the implementation strategies for the proposed Framework and the Self-Assessment Tool in the healthcare projects.

The interview will take approximately 1 hour and all the responses will remain confidential and any information indicating your identity will be removed and will not be linked to your responses.

Agenda

Section	Time
Overview of the Framework and Self-Assessment Tool	5 minutes
Framework implementation	25 minutes
Self-Assessment Tool Implementation	25 minutes
Further Thoughts	5 minutes
Total	**60 minutes**

Thank you

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Section 1- Framework Implementation

1. Please state your views about the framework to minimise lifecycle construction waste generation from healthcare projects?

2. Please state any improvement suggestions to the framework, which you think are relevant to increase the waste minimisation performance in healthcare projects?

3. If you are going to implement this framework in your company/project,

   a) What are the steps you are going to follow?

   b) Who are you going to involve in the process?

   c) What are the appropriate methods/tools/standards use to implement the framework?

   d) Who should take the responsibility of framework implementation?

   e) What are the challenges?

   f) What are the incentives?

Section 2- Self Assessment Tool Implementation

1. Please state your views about the use of a Self-Assessment Tool for continuous improvement in minimising lifecycle construction waste generation?

2. Please state any improvement suggestions to the Self-Assessment Tool, which you think are relevant to increase the effectiveness of the Assessment?

3. If you are going perform the Self-Assessment,

   a) What are the steps you are going to follow?

   b) What is the most appropriate time to perform the Assessment?

   c) What is you rationale in allocating weightage for each waste minimisation activity?

   d) Who should take the responsibility of the Assessment?

   e) How to handle the learning outcomes in future projects, in simultaneous projects and in company sustainability policy?

   f) What are the challenges?

   g) What are the incentives?

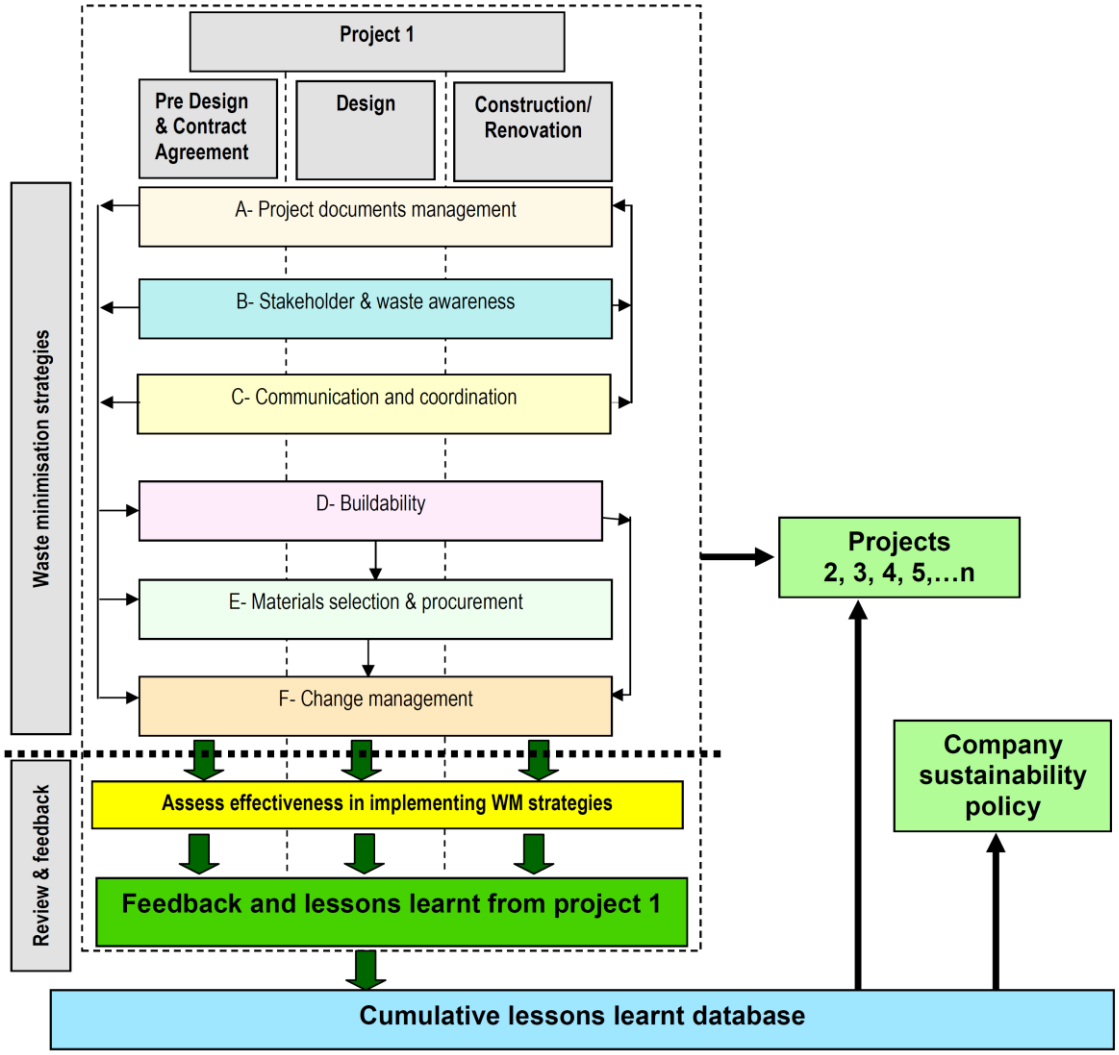
Section 3- Further thoughts

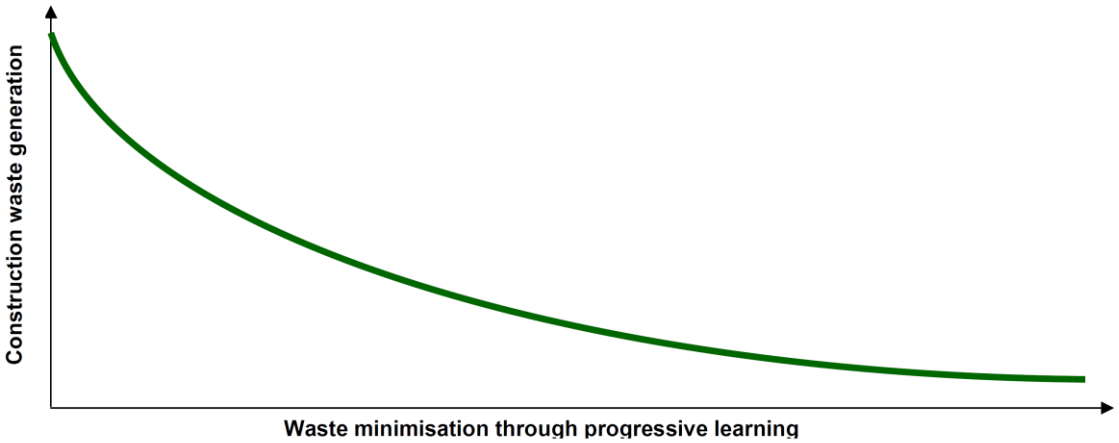
1. Please feel free to comment on any other issues/suggestions that are pertinent to this proposed framework and Self-Assessment Tool.

Thank you very much for participating in this study.

APPENDIX 6.1: HC-WMF DRAFT

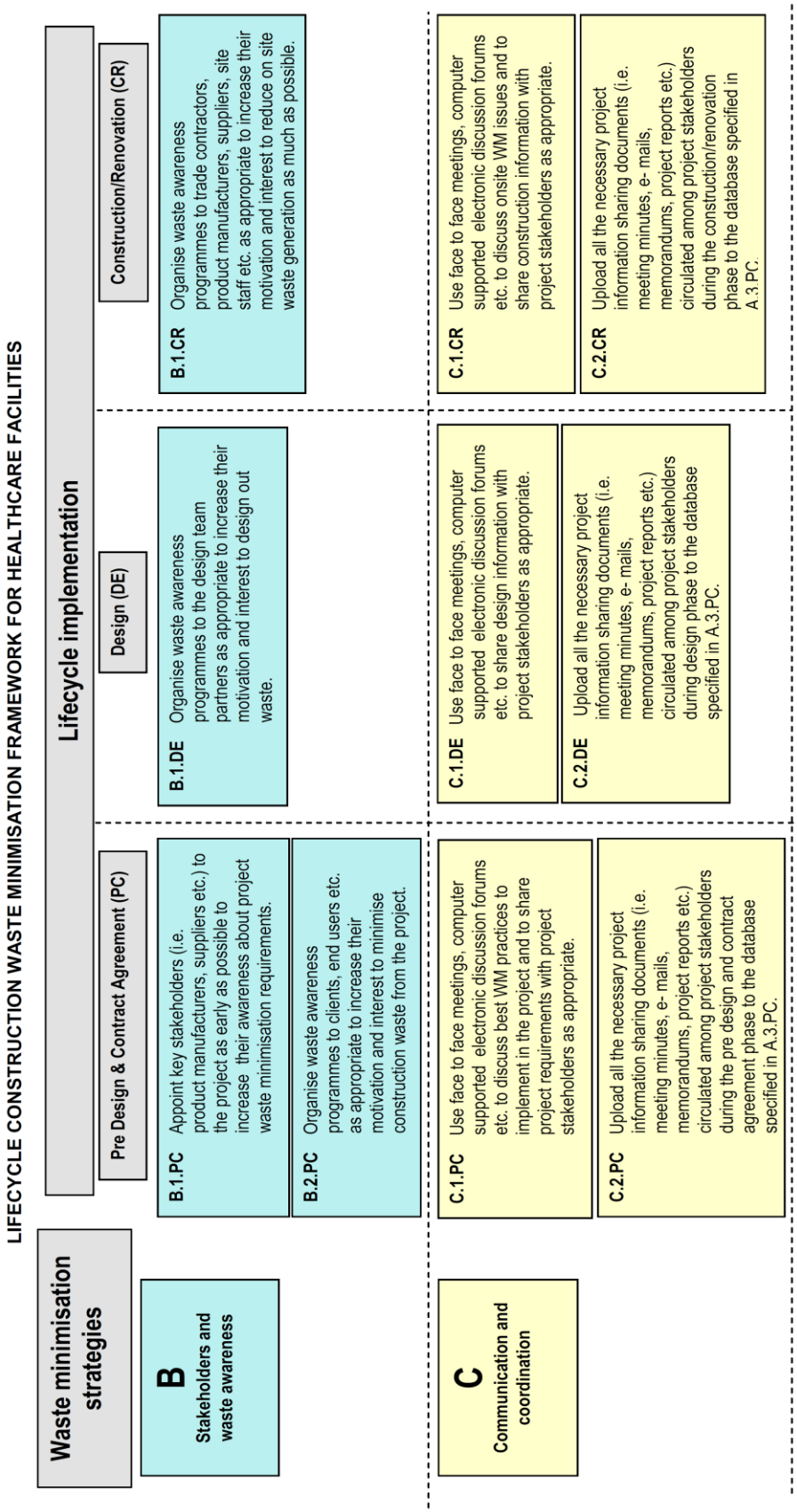
LIFECYCLE CONSTRUCTION WASTE MINIMISATION FRAMEWORK FOR HEALTHCARE FACILITIES





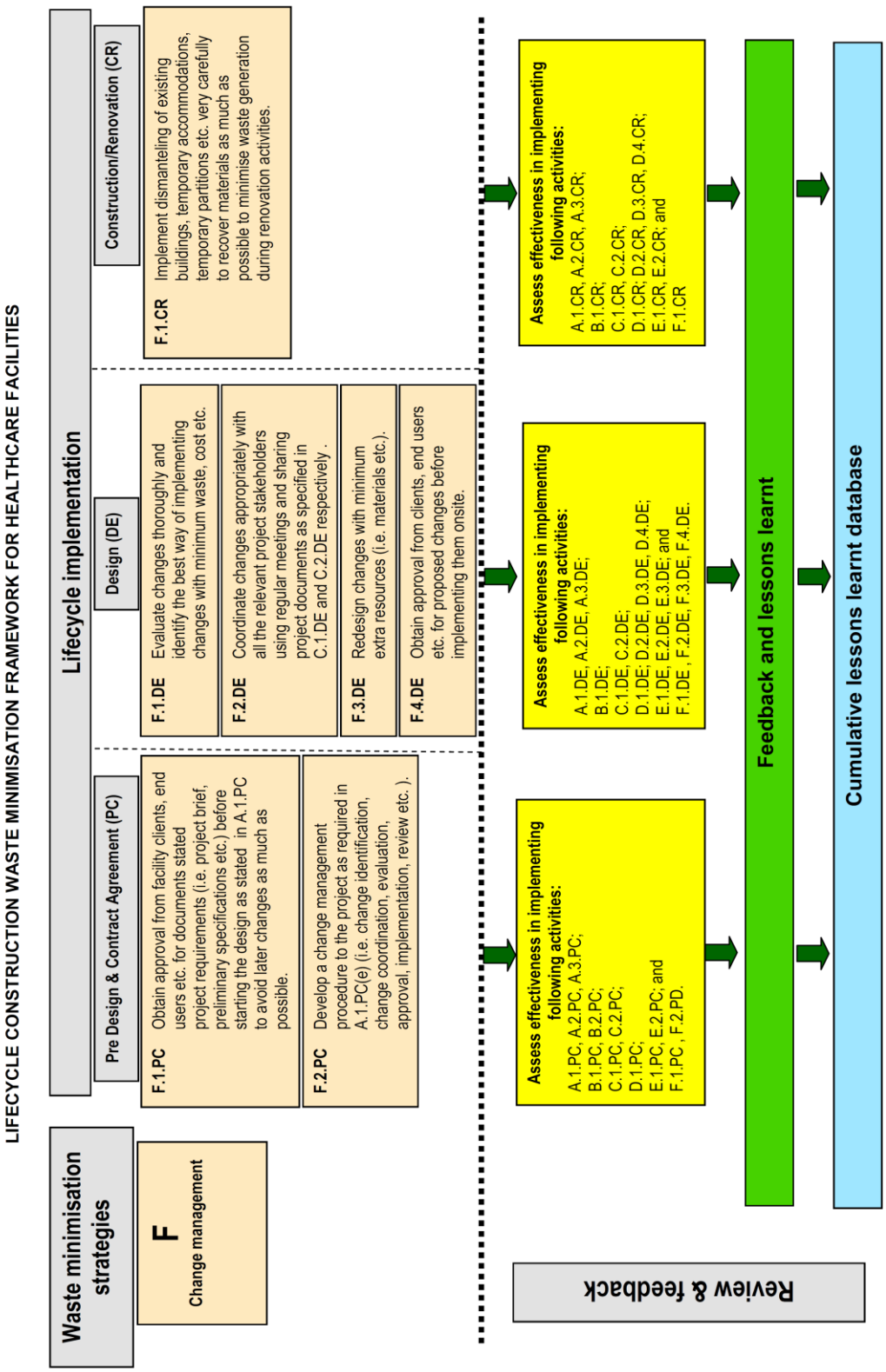
LIFECYCLE CONSTRUCTION WASTE MINIMISATION FRAMEWORK FOR HEALTHCARE FACILITIES

Waste minimisation strategies	Lifecycle implementation		
	Pre Design & Contract Agreement (PC)	Design (DE)	Construction/Renovation (CR)
A Project documents management	**A.1.PC** Prepare a complete set of project requirements to minimise waste including: **A.1.PC(a)** project brief (i.e. room data, M&E requirements, finishes, medical equipment etc.); **A.1.PC(b)** preliminary specifications (i.e. requirement statements including expected life time of the building, quality requirements etc.); **A.1.PC(c)** feasibility reports of project requirements; **A.1.PC(d)** initial proposals of site waste management plans; **A.1.PC(e)** project change management process requirements; and **A.1.PC(f)** other project requirements documents as appropriate to reduce waste due to late changes.	**A.1.DE** Update changes and finalise the project requirements before starting the design.	**A.1.CR** Update changes and finalise the project design information before starting construction/renovation.
	A.2.PC Specify waste minimisation clauses (i.e. waste targets, waste responsibilities and incentives given for keeping targets etc.) in the contract documents between project stakeholders (i.e. project leader and main contractor, main contractor and designers etc.).	**A.2.DE** Prepare a complete set of design information documents to minimise waste including: **A.2.DE(a)** set of drawings (i.e. architectural, structural, M&E, medical equipment installations etc.); **A.2.DE(b)** set of project specifications to comply with healthcare building regulations (i.e. HBNs, HTMs etc.); and **A.2.DE(c)** other documents as appropriate to reduce waste due to lack of design information.	**A.2.CR** Prepare a complete set of construction information documents before starting site activities including: **A.2.CR(a)** project programme (i.e. sequence of site activities and trades; resource requirements etc.); **A.2.CR(b)** site waste management plans (i.e. waste segregation, reuse, recycling, waste targets etc.); **A.2.CR(c)** materials delivery programme (i.e. delivery dates, type and quantities of materials etc.); and **A.2.CR(d)** other construction information documents as appropriate to reduce waste.
	A.3.PC Develop a project documents database; integrate all the pre design and contract agreement phase project documents to share between project stakeholders to obtain necessary project information; and update them frequently.	**A.3.DE** Upload all the necessary design phase project documents as appropriate to the project documints database specified in A.3.PC and update them frequently.	**A.3.CR** Upload all the necessary construction/renovation phase project documents as appropriate to the project documents database specified in A.3.PC and update them frequently.


LIFECYCLE CONSTRUCTION WASTE MINIMISATION FRAMEWORK FOR HEALTHCARE FACILITIES
Waste minimisation strategies
Lifecycle implementation
Pre Design & Contract Agreement (PC)
Design (DE)
Construction/Renovation (CR)
B
Stakeholders and waste awareness
B.1.PC Appoint key stakeholders (i.e. product manufacturers, suppliers etc.) to the project as early as possible to increase their awareness about project waste minimisation requirements.
B.2.PC Organise waste awareness programmes to clients, end users etc. as appropriate to increase their motivation and interest to minimise construction waste from the project.
B.1.DE Organise waste awareness programmes to the design team partners as appropriate to increase their motivation and interest to design out waste.
B.1.CR Organise waste awareness programmes to trade contractors, product manufacturers, suppliers, site staff etc. as appropriate to increase their motivation and interest to reduce on site waste generation as much as possible.
C
Communication and coordination
C.1.PC Use face to face meetings, computer supported electronic discussion forums etc. to discuss best WM practices to implement in the project and to share project requirements with project stakeholders as appropriate.
C.2.PC Upload all the necessary project information sharing documents (i.e. meeting minutes, e- mails, memorandums, project reports etc.) circulated among project stakeholders during the pre design and contract agreement phase to the database specified in A.3.PC.
C.1.DE Use face to face meetings, computer supported electronic discussion forums etc. to share design information with project stakeholders as appropriate.
C.2.DE Upload all the necessary project information sharing documents (i.e. meeting minutes, e- mails, memorandums, project reports etc.) circulated among project stakeholders during design phase to the database specified in A.3.PC.
C.1.CR Use face to face meetings, computer supported electronic discussion forums etc. to discuss onsite WM issues and to share construction information with project stakeholders as appropriate.
C.2.CR Upload all the necessary project information sharing documents (i.e. meeting minutes, e- mails, memorandums, project reports etc.) circulated among project stakeholders during the construction/renovation phase to the database specified in A.3.PC.

LIFECYCLE CONSTRUCTION WASTE MINIMISATION FRAMEWORK FOR HEALTHCARE FACILITIES

Waste minimisation strategies	Lifecycle implementation		
	Pre Design & Contract Agreement (PC)	Design (DE)	Construction/Renovation (CR)
D Buildability	**D.1.PC** Assess the feasibility of the project requirements within the project constraints (i.e. site space availability, resource availability, skills and technology etc.) to avoid rework etc. and provide feasibility reports as required in A.1.PC(c).	**D.1.DE** Keep designs as simple as possible (i.e. use regular shapes etc.) and use standard size elements where possible to minimise off cuts etc. **D.2.DE** Apply low waste modern building technologies to the design where possible (i.e. off site pre fabricated elements, modular construction units), steel frames etc.). **D.3.DE** Consider future expansions and changes required to the building and keep allowances necessarily (i.e. allow large and flexible spaces, additional service connections etc.). **D.4.DE** Assess the buildability of the design before starting site activities (i.e. use clash detection techniques such as 3D modelling, simulations etc. to avoid clashes between building elements).	**D.1.CR** Allocate site spaces for materials storage, waste materials segregation, waste materials reuse and recycling etc. before starting construction/renovation. **D.2.CR** Obtain prior approval from the healthcare facility management team for site waste management plans (A.2.CR(b) before starting site works. **D.3.CR** Manage materials deliveries to the site through off site storage facilities, just-in-time deliveries etc. as specified in A.2.CR(c). **D.4.CR** Monitor trade contractor activities according to the project programme (A.2.CR(a)) to avoid conflicts, clashes etc. between them.
E Materials selection and procurement	**E.1.PC** Prepare preliminary specification requirements including building maintenance requirements, expected building life time, quality requirements etc. as required in A.1.PC(b). **E.2.PC** Conduct initial discussions specific materials requirements (i.e. product customisation etc.) with supply chain partners such as product manufacturers, suppliers etc as early as possible.	**E.1.DE** Minimise differentiation when selecting materials to different places in the building where possible to minimise leftovers, off cuts etc.(i.e.use same colour from one material to all the possible places in the building etc). **E.2.DE** Select materials according to building long term requirements such as maintenance, quality, durability, whole life costing etc. **E.3.DE** Obtain ideas/advices/ inputs from trade contractors, product manufacturers, suppliers etc. about materials maintenance, quality, durability requirements etc. when selecting materials.	**E.1.CR** Minimise packaging waste when purchasing materials through early agreements with supply chain partners using reusable packaging, bulk purchasing, take back policy etc. **E.2.CR** Purchase customised materials to the project where possible through early supply chain involvement (i.e. plaster boards, off site products etc.).


LIFECYCLE CONSTRUCTION WASTE MINIMISATION FRAMEWORK FOR HEALTHCARE FACILITIES
Waste minimisation strategies
F
Change management
Lifecycle implementation
Pre Design & Contract Agreement (PC)
F.1.PC Obtain approval from facility clients, end users etc. for documents stated project requirements (i.e. project brief, preliminary specifications etc.) before starting the design as stated in A.1.PC to avoid later changes as much as possible.
F.2.PC Develop a change management procedure to the project as required in A.1.PC(e) (i.e. change identification, change coordination, evaluation, approval, implementation, review etc.).
Design (DE)
F.1.DE Evaluate changes thoroughly and identify the best way of implementing changes with minimum waste, cost etc.
F.2.DE Coordinate changes appropriately with all the relevant project stakeholders using regular meetings and sharing project documents as specified in C.1.DE and C.2.DE respectively .
F.3.DE Redesign changes with minimum extra resources (i.e. materials etc.).
F.4.DE Obtain approval from clients, end users etc. for proposed changes before implementing them onsite.
Construction/Renovation (CR)
F.1.CR Implement dismanteling of existing buildings, temporary accommodations, temporary partitions etc. very carefully to recover materials as much as possible to minimise waste generation during renovation activities.
Assess effectiveness in implementing following activities:
A.1.PC, A.2.PC, A.3.PC;
B.1.PC; B.2.PC;
C.1.PC; C.2.PC;
D.1.PC;
E.1.PC; E.2.PC; and
F.1.PC , F.2.PD.
Assess effectiveness in implementing following activities:
A.1.DE, A.2.DE, A.3.DE;
B.1.DE;
C.1.DE, C.2.DE;
D.1.DE; D.2.DE, D.3.DE, D.4.DE;
E.1.DE, E.2.DE, E.3.DE; and
F.1.DE , F.2.DE, F.3.DE, F.4.DE.
Assess effectiveness in implementing following activities:
A.1.CR, A.2.CR, A.3.CR;
B.1.CR;
C.1.CR, C.2.CR;
D.1.CR; D.2.CR, D.3.CR, D.4.CR;
E.1.CR, E.2.CR; and
F.1.CR
Feedback and lessons learnt
Cumulative lessons learnt database
Review & feedback