# INTEGRATION OF WASTE MINIMISATION STRATEGIES INTO THE DESIGN PROCESS OF BUILDINGS

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# ABSTRACT

The construction industry is by far the greatest consumer of resources and waste producer of all industries in the UK; being responsible for 32% of total waste generation, which equates to three times the combined waste produced by all households. Consequently, construction waste management and minimisation became a priority in the EU and UK environmental policy programmes resulting in a combined plethora of government-driven waste related legislation and guidance documents to curb construction waste production. Similarly, an ever-increasing global research on construction waste has been conducted over the last decade ranging from 'soft' onsite waste auditing tools and methodologies to 'hard' material and recycling technologies. However, the current state-of-research is largely dominated by endeavours to manage waste that has already been produced.

Very few studies have been undertaken on how architects could go about minimising waste through a change in design practices. Hence, this research set out to construct and validate a Designing out Waste (DoW) Framework to assist architects in embedding design waste reduction strategies in each design stage. The research adopted a mixed-methods sequential explanatory design, which consisted of collecting and analysing quantitative and then qualitative data in two consecutive and consequential phases. Having identified the key themes from the literature on construction waste minimisation approaches and practices, two sets of postal questionnaire surveys were used to establish a general industry-wide perspective on construction waste causes; examine waste management responsibilities at project level; and capture respondents' views on current 'design waste' reduction and associated challenges. The sampling frame was confined to the top 100 architectural practices and top 100 contracting firms in the UK. Both questionnaires' results gathered a considerable amount of quantitative data on construction waste minimisation practices that led to a broad signposting of design waste parameters. However, in-depth investigation was needed to examine the underlying causal design waste generators. As such, a qualitative data was gathered through 24 follow up semi-structured interviews with 12 architects and 12 contractors from the questionnaire respondents to explore direct and indirect design waste causes and sources and their respective origins across all RIBA Plan Work stages.

A DoW Framework was then developed based on the findings of the literature review, questionnaire surveys and semi-structured interviews. The proposed DoW Framework, which was structured and developed in line with the RIBA Plan of Work 2007 stages, consists of three Levels: Level 0 presents a high level view of DoW across six key project stages; Level 1 presents a breakdown of the six key project stages into respective DoW processes, actions and milestones; and Level 2 presents a breakdown of each project stage's DoW processes into associated DoW sub-processes and actions, resulting in six Level 2 DoW Frameworks. The DoW Framework industry review process included a questionnaire and a follow-up focus group with members of the RIBA Practice Committee and the RIBA Sustainable Futures Group. This research developed a novel and comprehensive design waste reduction roadmap that should enable architects to comprehend and assess the impact of their design on onsite waste generation. It should also assist them in the formulation of informed and holistic building waste minimisation strategies in each design stage that would align with an integrated closed-loop DoW approach.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Context

Failure to consider the wider implications of economic development has led to a global environmental crisis driven by climate change and wasteful use of energy and material resources. This situation trigged attempts to develop international dimensions of global change mitigation programmes that led to the evolution of new concepts, including that of sustainable development (SD). Although SD has many different meanings and therefore provokes many different responses, it has been widely embraced during the past two decades and is now a significant constituent of policies and priorities of many governments across the world (Ciegis *et al.*, 2009). That said, Barkemeyer *et al.* (2014) reported that most of SD studies endorsed the definition of the concept pegged at the introductory statement presented by the Brundtland report over 27 years ago. In the latter, SD was defined as “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs” (WCED, 1987, p.43).

An accepted elucidation of SD relates to the ‘Triple Bottom Line’ (TBL) that aims to couple economic growth with social responsibility and environmental protection (Allen Consulting Group, 2002; Elkington, 1998). Sustainable construction takes account of SD TBL objectives to measure the sustainability performance of construction projects, including energy efficiency and waste control. As such, construction waste minimisation became a priority in an increasing number of UK environmental policy programmes, such as the UK Construction Strategy 2050 (HM Government, 2013), the Strategy for Sustainable Construction -SSC (HM Government, 2008a) and the Waste Strategy for England (DEFRA, 2007), which identified the construction industry as a significant sector in tackling waste generation. The SSC has been instrumental in promoting sustainability leadership and behavioural change in construction; yet, aspiring to deliver benefits to both the industry and the wider economy. The SSC identified 11 topics as being pivotal to delivering a sustainable construction, including: climate change mitigation; innovation; design; materials and waste. A zero waste target was debated, but concerns regarding industry fragmentation and poor engagement led to its omission. However, the SSC recognised the importance of considering construction waste minimisation during design; hence the notion of 'designing out waste', as espoused in recent design related guides (WRAP, 2009; WRAP, 2010a) and standards (BSI, 2013; BSI, 2015).

The construction industry makes a vital contribution to the competitiveness and prosperity of the UK economy; with an annual turnover in excess of £100 billion, contributes 9% of GDP and provides employment for over three million people (BUILDUK, 2014). However, it is by far the greatest consumer of resources and waste producer among all industries in the UK. Indeed, construction activities in the UK consume annually 420 million tonnes of raw materials destined for construction product manufacturing (Smith *et al.*, 2003). Furthermore, the UK construction and demolition sector is the largest contributor of waste in the UK, responsible for generating 120 million tonnes of waste every year (WRAP, 2008a). Of this, up to 13% consists of delivered but unused materials that end up in landfill sites (BRE, 2008).

Although the ideal of construction waste reduction is well acknowledged and generally accepted, it is proving difficult to implement. Traditionally, wastes have been viewed by construction stakeholders as inevitable by-products (Ekanayake and Ofori, 2000). As a result, managing onsite waste was often addressed within a legislative and health and safety context. Consequently, the perception that waste is unavoidable in construction activities disallows strategic considerations, engagement and implementation attempts to manage construction waste at project level. There is anecdotal evidence that the over-ordering culture endemic across the construction sector is the result of onsite productivity issues. This has been attributed to the fact that the cost of materials excess is less than that of labour (WRAP, 2008b). On the other hand, Poon *et al*. (2004a) argued that frequent design variations during the construction stage result in unsuitable or excess materials. Hence, moving the construction industry towards a more sustainable future requires fundamental changes to current design, material procurement and construction waste management (HM Government, 2013). Consequently, diverting construction waste from landfill has a political resolve today unrivalled in recent historical times. Indeed, the past few years saw a combined plethora of European and national waste related legislation, policies, strategies and guidance documents to curb waste production and increase recycling rates across all construction sectors. Similarly, construction waste predicaments trigged a rise of research attempts to develop waste control and management methods and tools. Chapter 2 presents an examination of the state of construction waste minimisation practice, research trends and knowledge gaps.

## 1.2 Research Justification

Notwithstanding existing governmental, industrial and academic endeavours at global, national and regional levels to facilitate onsite waste management improvement and set future baselines to help divert waste from landfill, the state of construction waste management research is strongly dominated by 'end-of- pipe' issues. This is discussed in length in Chapter 2 and recapped below.

A range of studies on waste source assessment can be gleaned from literature, which reveal that construction waste is generated during design (Gavilan and Bernold, 1994; Craven *et al.*, 1994; Bossink and Brouwers, 1996; Lingard *et al.*, 2000); project procurement (Gamage *et al.*, 2009; WRAP, 2013); material procurement, storage and handling (Ekanayake and Ofori, 2000; Kulathunga *et al.*, 2005); and onsite planning and management (Gavilan and Bernold, 1994; Craven *et al.*, 1994; Bossink and Brouwers, 1996). It is widely argued in the literature that a significant amount of onsite waste is consequential to uninformed design (Bossink and Brouwers, 1996; Faniran and Caban, 1998; Rounce, 1998; Ekanayake and Ofori, 2000; Keys *et al*., 2000; Poon *et al.*, 2004a; Poon 2007; BSI, 2015). It has been suggested that up a third of a project construction waste production may be directly or indirectly impacted by design decisions (Innes, 2004). There is a consensus in the literature that a key design waste cause relates to design changes (Gavilan and Bernold, 1994; Bossink and Brouwers, 1996; Faniran and Caban, 1998; Ekanayake and Ofori, 2000; Alwi *et al.*, 2002; Polat and Ballard, 2004, Poon *et al.* 2004a and 2004b; Kulathunga *et al.*, 2005; Panos and Danai, 2012). Several authors namely Serpell *et al.* (1995); Rounce (1998); Keys *et al.* (2000), Alwi *et al.*, 2002; Poon *et al.* (2007) attributed design waste generators to inadequate stakeholders' coordination and communication; design and detailing complexity;

limited use of design standardisation and offsite construction; inadequate specification; and lack of attentions paid to material standard sizes and dimensional coordination. However, research attempts to distinctively relate design causes and sources to their respective origins across all project stages in a holistic and sequential waste mapping are absent from the literature.

Wide-ranging research has been undertaken to identify and classify onsite waste streams (Guthrie and Mallett, 1995; McGrath, 2001; Coventry *et al.*, 2001; Chen *et al.*, 2002; Emmanuel, 2014). Equally, several approaches, methods and tools were developed to assist waste producers to quantify, audit and assess onsite waste production (BRE 2001, 2007, 2009) and manage site waste management plans (WRAP, 2010b; BUILDUK, 2014). Similarly, onsite waste sorting and segregation methods and models were devised (Poon *et al.*, 2001; Wang *et al*., 2010). However and despite international academic endeavours in the past decade, design waste reduction research has been limited and piecemeal; and as such “more work is essential to investigate construction and demolition (C&D) waste issues in project design” (Lu and Yuan, 2010). Hence, there is a need for a shift from 'end-of pipe' solutions that focus on onsite waste management to an integrated source based approach, such as design waste reduction. The past few years witnessed the production of a limited; yet, increasing designing waste related guides and codes of practice that were predominantly developed by WRAP (2009 and 2010a) and BSI (2013 and 2015) to assist designers to consider material efficiency design waste minimisation principles in their projects. However, these include broad design recommendations, such as ‘design for material optimisation’ in WRAP (2009) and ‘material efficiency’ in BSI (2015). Additionally, they: do not couple and correlate the proposed principles and recommendations to well-versed and recognised design waste generators on the one hand; and do not entrench clear and sequential waste reduction strategies throughout all design stages on the other.

## 1.3 Research aim and objectives

The aim of this research is to develop and validate a Designing out Waste (DoW) Framework that would assist architects to holistically integrate waste minimisation strategies into the design process of buildings.

Seven objectives were devised to achieve the aim of this research.

1. Identify and assess construction waste minimisation pressures for change.
2. Identify and categorise existing construction waste quantification and source evaluation trends.
3. Determine and classify current and emerging research and industry construction waste minimisation approaches and tools.
4. Identify and evaluate current onsite waste management responsibilities and practices.
5. Determine the extent of the integration of waste minimisation strategies into the current architectural design practice.
6. Identify design waste root causes and sources and their associated origins across the RIBA Plan of Work stages.
7. Construct and validate a Designing out Waste (DoW) Framework to assist architects in embedding design waste reduction strategies in each RIBA Plan of Work stage.

## 1.4 Research methodology overview

The adopted methodological strategies, which are represented in Figure 1.1 and discussed in Chapter 3, involved both quantitative and qualitative strategies to achieve the research aim and objectives. As shown in Figure 1.1, the adopted research methodology process encompasses five interrelated stages that were informed by the research objectives and culminated in associated resulting outcomes. The philosophical stance of this research is closely associated with the research objectives and conditioned by the research questions that emerged out of the interrogation of the literature (see Section 2.12). The relationship between research questions, objectives, philosophical stance and adopted research strategies and methods are discussed in Section 3.2 and summarised in Table 3.1.

The employed data collection methods in this research are summarised in the sections below.

### 1.4.1 Literature review

An extensive critical literature review was conducted to address the first three research objectives. The literature review, which addresses the first three research objectives is discussed in Chapter 2, covers key topics that are pertinent to the research scope. These are: waste concepts and definitions; pressures for change; construction waste quantification and composition; classification of construction waste causes; design waste generators; current and emerging construction waste management approaches and tools; construction waste minimisation through design; potential strategies to reduce design waste; and construction waste minimisation challenges. The literature searches were based on related terminology encountered while reviewing the literature (e.g. design waste). Additionally, respective email alerts (e.g. Mimas ZETOC Alert Service) were established to allow continuous literature updates. While reading relevant literature, associated citations were searched through Google Scholar Citations to access newly published material in the field. Literature available in English was included in the search. Both printed (e.g. books, journals, theses, reports and magazines) and electronic publications (e.g. the academic information system of Loughborough University) were used in the literature review. Other industry sources of information were accessed via the author's network. These include: BSI; BRE; WRAP; CIRIA; CPA; and RIBA. Collectively, the reviewed literature facilitated the understanding of the research gap, enabled the refinement of the research objectives and informed the structure of the questionnaire survey. Five key research questions, which stemmed from the literature review, directed the stages of data collection and the development of the resulting DoW Framework (see Section 2.12).

### 1.4.2 Questionnaire survey

Having identified construction waste minimisation industry and research trends, knowledge gaps from the literature that informed the research questions, a quantitative method was adopted to investigate salient issues related to current design waste and onsite waste management practices. Several key themes were identified from literature and subsequently developed into two questionnaire surveys, which were sent to the top 100 UK contractors and architects. Two data collection instruments, which address Objective 4 and 5, were devised to address the fourth and fifth research objectives respectively. The aim of the first questionnaire survey was to investigate current contractors' methods of onsite waste management and responsibilities and capture their views on onsite as well design-specific waste generation causes. The second questionnaire survey aimed at ascertaining architects' views on waste minimisation design practices within the profession and the associated design out waste barriers. The questionnaire design and development process is described in Section 3.5.1 and the associated data analysis is discussed in Chapter 4.

### 1.4.3 Semi-structured interviews

A qualitative study, which addresses Objectives 6, was subsequently conducted to address the sixth research objective and build upon the quantitative data resulting from the analysis of both questionnaire surveys by investigating design waste causes and sources. As such, the interview questions were designed to expand upon the questionnaire results to provide an in-depth qualitative examination of the underlying design waste generators across each RIBA Plan of Work stage. Qualitative information was gathered from a sample of the questionnaire respondents through 24 follow-up semi-structured interviews that engaged 12 sustainability and environment managers from contracting companies and 12 partners and associates from architectural practices. The interview design and development process is described in Section 3.5.2 and the associated data analysis is discussed in Chapter 5.

### 1.4.4 Designing out Waste (DoW) Framework development

The DoW Framework methodological process is discussed in Section 6.2.3. The sequential data analysis emanating from the findings of the literature review, questionnaire surveys and interviews culminated in the development of a Designing out Waste (DoW) Framework, which addresses Objective 7. The DoW Framework structure, design, content and resulting process diagrams are presented and discussed in Chapter 6.

### 1.4.5 Designing out Waste (DoW) Framework industry review

A combination of quantitative and qualitative methods was used to validate the Designing out Waste (DoW) Framework. The aim of the industry review process was to test and refine the Framework's structure, clarity, appropriateness and potential impact. The industry review data were gathered through 28 questionnaires and a follow-up industry review focus group involving eight members of the RIBA Practice and Profession Committee and the RIBA Sustainable Futures Group.

### 1.4.6 Data analysis

Quantitative data input and analysis of both the primary data collection and the Framework industry review questionnaire surveys used Statistical Package for Social Science (SPSS). Microsoft Excel and Microsoft Visio Professional were used for data manipulation and data presentation. As the interviews generated a large amount of rich textual information, NVivo (computer assisted qualitative data analysis software) was used for the analysis of the collected qualitative data. On the other hand, the focus group data analysis used manual content analysis as the amount of qualitative data was deemed manageable without the support of a software system.

## 1.5 Contribution to knowledge overview

This research has identified the underlying design waste origins, causes and sources across the RIBA Plan of Work stages that informed the development of a Designing out Waste (DoW) Framework. This was subsequently reviewed and refined by practising architects who are members of two leading RIBA working groups.

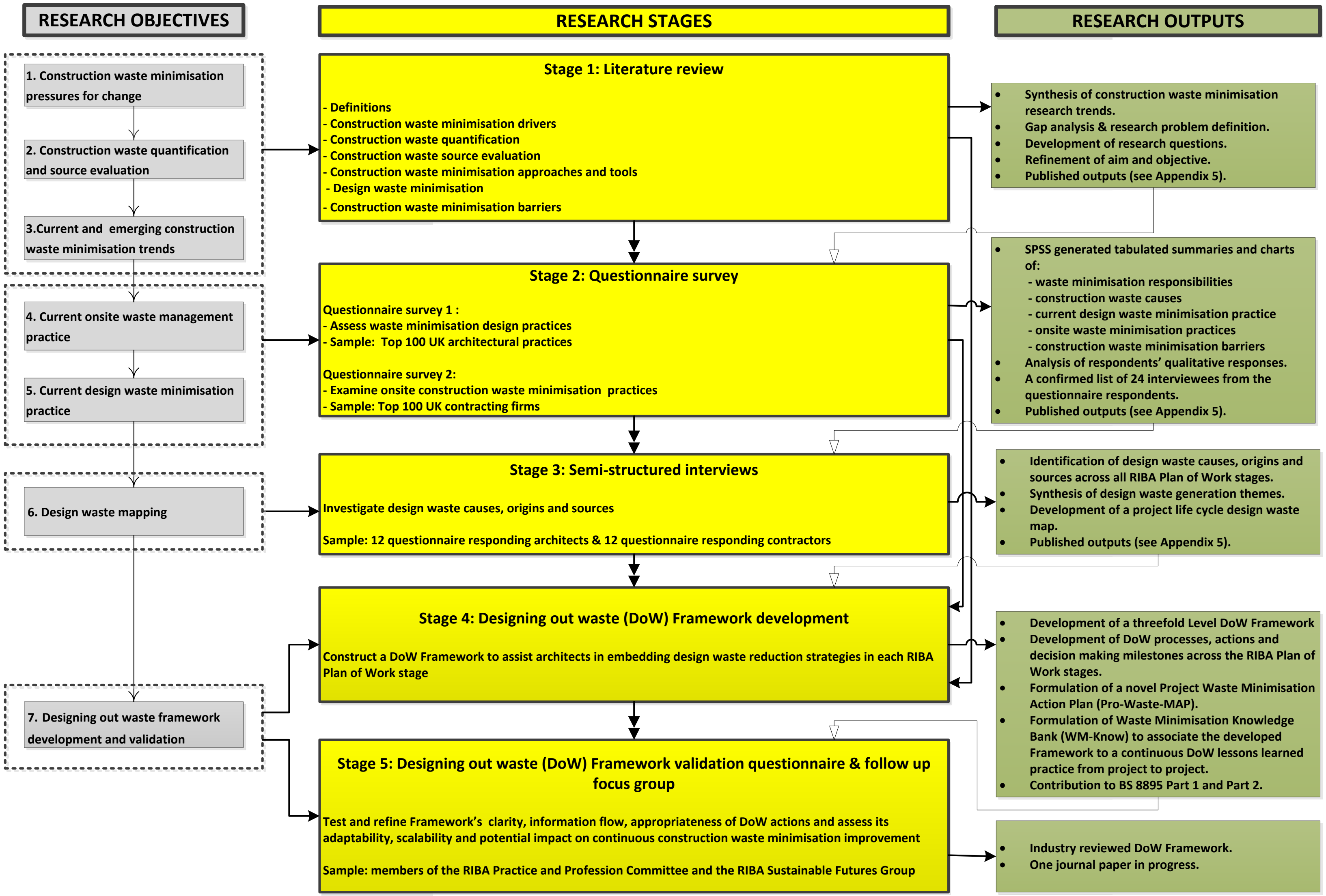



**Figure 1.1: Research process: objectives, stages and outputs**

The main research contributions to knowledge, which were reported in a number of publications (Appendix 5), are discussed in Section 8.3 and highlighted below.

- **Contribution to theory**

  - This research added value to the body of construction waste management research through the classification of existing and emerging research trends. Indeed, the current and developing thinking in the field was categorised into 16 related research clusters.
  - This research contributed to the theoretical understanding of design waste knowledge. As such, this research extends construction waste minimisation knowledge through an assessment of current design waste reduction practices of the UK top 100 architectural practices; and establishing a relationship between design waste causes, sources and their origins across a project life cycle.

- **Contribution to designing out waste practice**

  To date, no research endeavours have been conducted to develop structured methods that fully consider waste source evaluation, which in turn would inform the formulation of designing out waste strategies in a chronological and consequential order across all project stages. As such, the contributions to of this research to designing out waste practice are twofold:

  a. Exploration of design waste origins causes and sources that led to the development of a comprehensive design waste mapping across the RIBA Plan of work stages.
  b. Development of an informed multi-level Designing out Waste (DoW) Framework that was based on the findings of the design waste mapping and structured in accordance with the RIBA Plan of Work stages.

## 1.6 Thesis structure

The structure of the thesis is made up of eight chapters.

**Chapter 1** provides an overview to the thesis. The chapter begins with a description of the context of the research, highlighting the knowledge gaps and stating the research aim and objectives. Subsequently, an overview of research methodology is presented and insights into the research contribution to knowledge are presented. The final section encompasses a brief guide to the structure and organisation of the thesis.

**Chapter 2** presents a literature review, which sets out the context of the research. The chapter begins with a review of definitions; explores construction waste minimisation drivers; examines construction waste quantification and source evaluation; presents a critical debate of current and emerging construction waste management and minimisation approaches, practices and tools; evaluates design waste minimisation state of research and knowledge gaps; examines construction waste minimisation challenges; and concludes with a synthesis of the literature review that led to the research questions. The chapter also acknowledges the limitations of the reviewed literature.

**Chapter 3** describes the research methodology. The chapter starts with a discussion on the reasoning and sequence of the research questions and their relationship with the philosophical stance, research objectives and research strategies. Subsequently, the chapter presents the design of the research methods; followed by a description of the development and industry review methods of the Designing out Waste (DoW) Framework. Data analysis techniques used in this research are also presented in this chapter.

**Chapter 4** presents the results of the two questionnaire surveys. The chapter covers: respondents' background information; waste management and minimisation responsibilities at project level; construction waste causes; design waste minimisation practices (architects' responses); onsite waste management practices (contractors' responses); and waste minimisation challenges and enablers. The final section highlights the questionnaire limitations.

**Chapter 5** presents the results of the interviews. The chapter provides: insights into interviewees' background information; waste minimisation importance in current projects; and a detailed analysis of design waste mapping during briefing, design, tender and construction stages. The Chapter concludes with a reflection on interview limitations.

**Chapter 6** describes the design and industry review of the developed Designing out Waste (DoW) Framework. The first section describes the Framework's structure and key components. The second section presents the results of the Framework industry review process that emanated from the questionnaire survey and follow-up focus group activities. The chapter also underlines the limitations of the DoW Framework context and remit.

**Chapter 7** presents a discussion of the emerging research themes in line with the research questions within the context of literature and explores implications of the findings.

**Chapter 8** presents the research conclusions in accordance with objectives and research questions; specific contributions to the knowledge; and recommendations for industry, government and further research.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter, which addresses Objectives 1, 2 and 3, provides a critical evaluation of the published literature in relation to the salient issues of construction waste management and minimisation. It begins by an examination of the relationship between sustainable development, sustainable construction and construction waste management; followed by a review of definitions of the key waste terminologies and concepts. Subsequently, the principal construction waste management pressures of change are examined though a discussion of environmental, legislative, economic and business drivers (Objective 1). The subsequent two sections review research trends that are related to construction waste quantification and composition and source evaluation (objective 2). The remaining sections, which address Objective 3, identify and discuss current and emerging construction waste management approaches and tools; assess existing design waste minimisation methods and strategies; and examine the main construction waste minimisation challenges.

## 2.2 Background

Environmental problems such as global climate change, native deforestation, pollution and resource depletion and scarcity have been targeted by a plethora of global, national, regional and local sustainable development-related programmes. The interest in sustainable development (SD) arose out of a desire to increase the quality of life and opportunities that economic development can bring; yet, find ways to do it that preserve the environment for present and future generations.

The ambiguity of the concept of SD has led to a large political and academic interpretation debate, which has resulted in a wide variety of definitions. Although the term ‘sustainable development’ was used as early as 1972 at the United Nations Conference on the Human Environment in Stockholm, it was not until 1987, that the term was fully defined in a United Nation report entitled ‘Our Common Future’ and was subsequently translated into policy options. The report defined SD “as development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p.43). Since then, several hundreds of local, national and international initiatives were initiated to address different SD aspects, making it a key element in policy documents in many governments, international agencies and business organisations. However, their impact fails to shape a common global implementation strategy due to the individualist approach and focus of various strategies, which were characterised by various interpretation of SD and associated political and economic interests. This has led to a frustrating dismay, even among groups and organisations that advocate and promote SD concepts (Ciegis *et al.*, 2009). They maintained that SD should be considered as a global long-term integrated approach to developing and achieving a healthy community by jointly addressing economic, environmental and social issues.

Sustainable construction (SC) is the application of SD principles to the construction industry (Brennan, 2015; Passer *et al.* 2015; Parkin, 2000). The construction industry is defined as all those involved in the construction supply chain, including those who produce, develop, plan, design, build, alter or maintain the built environment, building materials, manufacturers and suppliers (CRISP, 2000). SC is, therefore, a subset of SD that involves issues like design, tenders, site planning and organisation, material selection, recycling and waste minimisation (Wilkinson, *et al.*, 2014; Raynsford, 2000; Langston and Ding, 2001). SC was originally defined as the creation and responsible maintenance of a healthy built environment based on resource efficient and ecological principles (Kibert, 1994). A recent study described SC as encompassing a 'cradle to grave' appraisal of a project which involves managing the serviceability of a project during its life-time and eventual deconstruction (Dadhich *et al.*, 2015). This was supported by Tan *et al.* (2015) who pointed out that SC involves creating constructed assets using: best practice; and clean and resource efficient techniques from extraction of the raw materials to the demolition and disposal of its components. However, Govindana *et al.* (2015) acknowledged that one of the major challenges to achieve SC goals is the generation of vast amounts of wastes. Therefore, SC is closely associated with an integration and holistic waste management approach across all stages of a project lifecycle. Hence, the opportunities and responsibilities to minimise construction waste lie with all project stakeholders; including clients, designers, contractors and suppliers.

## 2.3 Waste concepts and definitions

Emerging SC thinking is redefining the concept of waste from a by-product of processes to missed opportunities in order to cut costs and improve project performance (Brennan, 2015). As such, Koskela (1992) argued that waste adds costs but does not add value. Similarly, Formoso *et al.* (2002) classified waste as: ‘unavoidable’, for which the costs to reduce it are higher than the economy produced; and ‘avoidable’, when the necessary investment to manage the produced waste is higher than the costs to prevent or reduce it. Therefore, the concept of waste should be looked at in terms of activities that increase costs directly or indirectly but do not add value to the project. There is no generally accepted definition of waste. A common definition of waste was issued by the Waste Framework Directive (WFD): “any substance or object which the holder discards or intends or is required to discard” (European Commission, 2008). This definition has been in use in its current wording for over three decades; and applies to all waste irrespective of whether or not it is destined for disposal or recovery operations. The European Council made several revisions to the WFD, from its initial publication in 1975 to the latest amendments in October 2008 that came into force in March 2011. The revised WFD sets the basic concepts and definitions related to waste management, such as definitions of ‘waste’, ‘recycling’ and ‘recovery’. Significantly, the definition of ‘waste’ has been clarified in the revised WFD through specific articles that formally introduce the concepts of ‘by-products’ and ‘end-of-waste’. The introduction of a definition of by-products in WFD Article 5 (1) formally recognises the circumstances in which materials may fall outside the definition of waste. This change is intended to recognise that many ‘by-products’ are reused before entering the waste stream. It describes when ‘waste’ ceases to be ‘waste’ and becomes a secondary raw material (so called end-of-waste criteria) and how to distinguish between waste and by-products. The revised WFD places greater emphasis on waste prevention. As such, the waste hierarchy (prevention; preparing for re-use; recycling; recovery; and disposal) is placed at the heart of EU waste management policies (Figure 2.1).

The WFD enabled Member States in the European Union to adopt their own national definitions of waste. Revisions to the WFD have been implemented in England and Wales through the Waste (England and Wales) Regulations 2011 (HM Government, 2011).

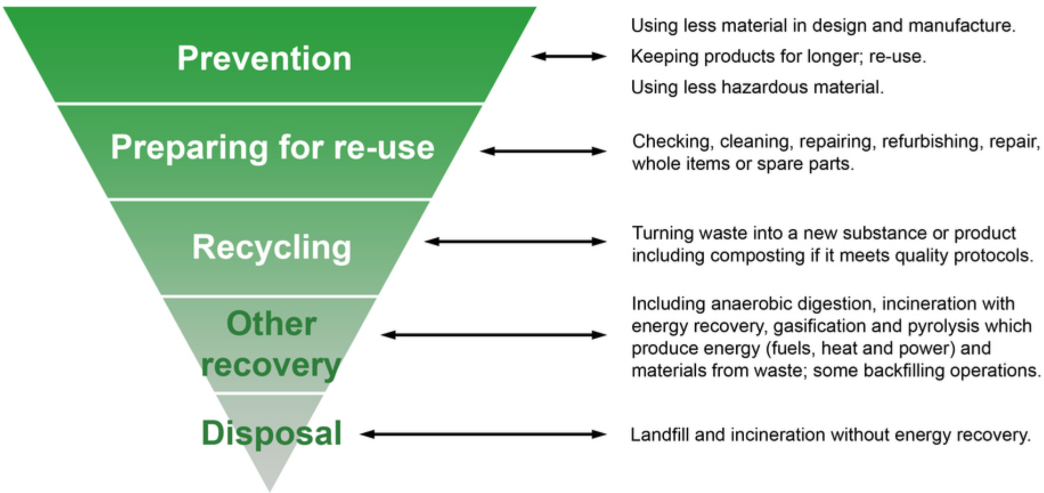



**Figure 2.1: EU Waste Hierarchy (after European Commission, 2008)**

Within a construction context, Greenwood (2003, p.2) referred to construction wastes as “materials which are considered not to be useful including, but not limited to conventional building materials such as steel, glass and architectural elements arising from the construction or demolition activities”. Similarly, Shen *et al*. (2004, p.473) defined construction waste as “debris; rubble; earth; concrete; steel; timber; and mixed site clearance materials, arising from various construction activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork and building renovation”. While the later covers construction, renovation and demolition phases for civil and building projects, this research focuses on waste minimisation during the construction of buildings through improved architectural design processes. Within the scope of this research, the following definitions have been adopted:

- ‘construction waste’ is a material or product which needs “to be transported elsewhere from the construction site or used on the site itself other than the intended specific purpose of the project due to damage, excess or non- use or which cannot be used due to non- compliance with the specifications, or which is a by-product of the construction process" (Skoyles and Skoyles, 1987);

- 'waste minimisation' is "*a systematic approach to the reduction of waste at source, by understanding and changing processes and activities to prevent and reduce waste*" (Environment Agency, 2011);
- 'waste management' is "*the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker*" (European Commission, 2008);
- 'design waste' is "*the waste arising from construction sites both by acts and/or omissions on the part of the designer, including opportunities to reduce waste lost by not using reclaimed materials*" (Coventry and Guthrie, 1998);
- construction waste 'origins' are associated with "*project stages (e.g. RIBA Plan of Work stage A: Appraisal) or processes (e.g. architectural detailing) during which waste occurs*" (Osmani, 2013b);
- construction waste 'causes' are waste creators, such as design changes, that lead to onsite waste generation (Poon, 2007);; and
- construction waste 'sources' are associated "*with waste generation provenance and project stakeholders' contributory responsibility (e.g. client, architect)*" (Osmani, 2013b).

## 2.4 Construction waste management pressures for change

The key waste reduction pressures for change in the UK construction industry could be broadly categorised into four main groups: environmental; legislative; economic; and business drivers.

### 2.4.1 Construction waste management environmental drivers

In the United Kingdom, the construction industry is by far the greatest consumer of material resources and waste producer among all UK industries. Indeed, 420 million tonnes of materials are used each year by the UK construction industry; however, only 360 million tonnes are incorporated into products (Smith *et al.*, 2003). Additionally, WRAP (2008a) reported that the UK construction, demolition and excavation (CD&E) activities produce around 120 million tonnes of waste each year; of which, 13 million tonnes of unused materials that are delivered to UK construction sites and end up in landfill due to damages or over-ordering regimes.

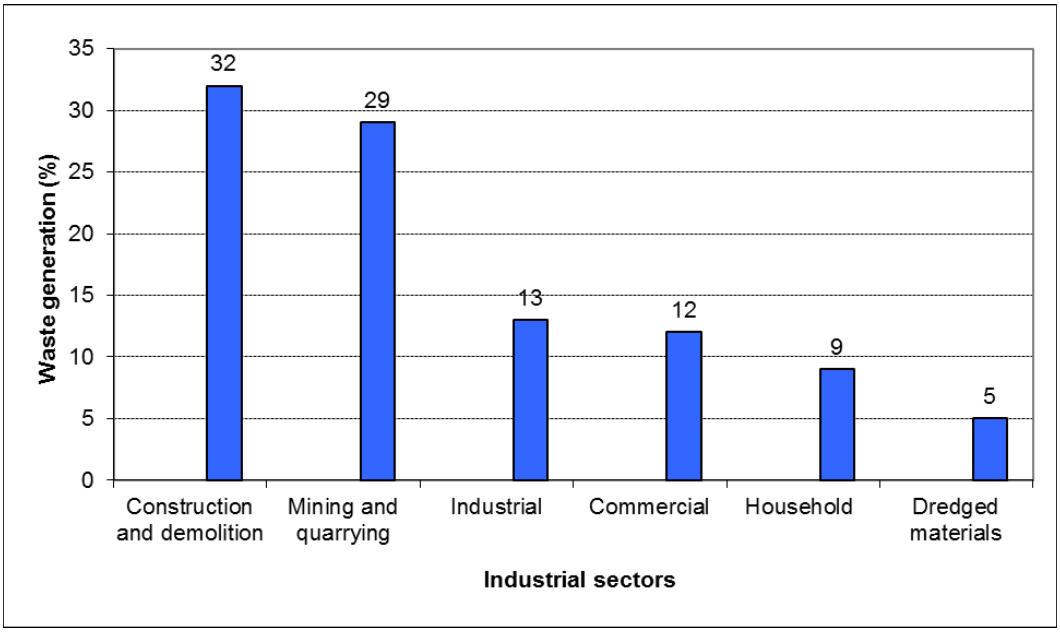



**Figure 2.2: Estimated waste arisings in England by industrial sector (produced by the author based on data from a number of UK government sources)**

As shown in Figure 2.2, CD&E activities account for 32% of all waste arisings in England, which equates to three times the combined waste produced by all households. This figure is substantially higher if additional construction-related wastes from other sectors are added, namely, through construction material product manufacturing processes in the industrial sector and during raw material excavation and production in the mining and quarrying sector. Moreover, an estimated 25 million tonnes of construction and demolition wastes end up in landfill sites every year, without any form of reuse or recovery (WRAP, 2008a). The recovery rate from non-hazardous C&D waste in the UK in 2012 was 86%. There is an EU target to recover at least 70% of non-hazardous C&D waste by 2020, which the UK is currently meeting (DEFRA, 2015). Detailed insights into C&D waste quantification and composition are discussed in Section 2.5.

### 2.4.2 Construction waste management policy and legislative drivers

The UK government has been using a combination of regulation, economic instruments and voluntary agreements to meet targets of ethical, social and environmental performance in driving the waste management agenda. The key UK policy and legislative drivers to control waste generation are summarised below.

The SSC calls for a step change in the sustainability of procurement, design and operation of all built assets to be driven by innovation (HM Government, 2008a). The aim of the SSC was to improve the built environment performance with a focus on reducing carbon emissions and resource consumption in new buildings. In encouraging the construction industry to drive its own resource efficiency programme, the SSC set a target to halve the amount of CD&E wastes going to landfill by 2012 against the 2008 baseline, as a result of waste reduction, re-use and recycling. A zero waste target by 2020 was debated, but concerns regarding industry fragmentation and poor engagement led to its omission. The monitoring of the 50% reduction in CD&E waste to landfill SSC target was entrusted to the Strategic Forum for Construction's Waste Subgroup. The Waste Subgroup, in which the author is a committee member, is one of several Subgroups created by the Strategic Forum's Sustainable Construction Task Group (SCTG) and is now part of the Greening the Industry Working Group of the Green Construction Board. The 2008 baseline was derived from national Environment Agency data, in the form of waste site returns, which contain information on the type and amount (in tonnes) of waste received at licensed waste facilities. As shown in Figure 2.3, the total CD&E waste received between 2008 and 2012 at waste transfer stations has increased considerably (11%) in relative terms. That said, the trend in amounts of CD&E waste to landfill has been downward, though in 2010 there was a rapid surge in the amounts of excavation material, essentially soil and stones, going to landfill (GCB, 2014).  . Indeed, the amount of CD&E waste sent to landfill has increased from 13.1 million tonnes in 2011 to 13.6 million tonnes in 2012, an increase of 4%. This was attributed entirely to an increase in the amount of excavation waste, mainly soils and stones, which has increased by 32% in absolute terms from the 2008 baseline year. The reasons for this are being explored with one avenue being the link to amendments in the Environmental Permitting (England and Wales) Regulations 2014 (HM Government, 2014). Amendments require a 'Permit' from the Environment Agency or Local Authority to carry out onsite waste 'treatment' activities. 'Treatment' is considered to be where waste either has a process applied to it, other than simple storage processes like compaction, or where waste from other sites is stored (HM Government, 2014). In its final report, the Waste Subgroup recommended that the future aspirations beyond 2012 should include: avoiding design changes; designing out waste; and optimising packaging (GCB, 2014).

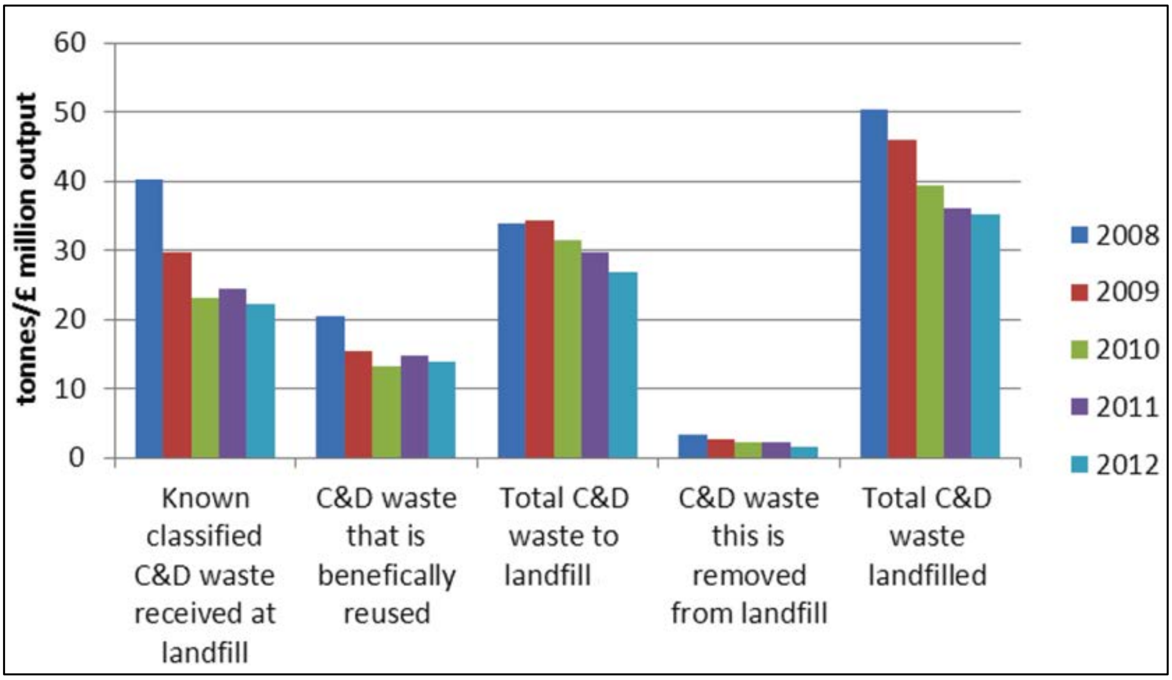



**Figure 2.3 Construction, demolition and excavation waste trends between 2008 and 2012 (GCB, 2014).**

Additionally, the UK government published Site Waste Management Plans (SWMPs) in 2004 as voluntary code of practice requirements, which subsequently were made mandatory in 2008 for construction projects costing more than £300,000 (HM Government, 2008b). The aim of SWMPs was to divert waste from landfill by increasing onsite reuse and recycling rates. The onus was on the client or principal contractor to take overall responsibility for the preparation and implementation of SWMPs. This entails the production of a site waste management plan (SWMP) that:

describes each waste type expected to be produced in the course of the project; estimates the quantity of each different waste type expected to be produced; and identifies waste management actions for each generated waste type, including re-use, recycling, recovery and disposal (HM Government, 2008b). Paradoxically, the legal requirement in England for construction projects to prepare and implement a Site Waste Management Plan (SWMP) ended with the revocation of the SWMPs Regulations (2008) in December 2013. DEFRA claimed that this was part of a 'red-tape cutting' exercise that should save UK businesses over £1 billion savings (DEFRA, 2013). However, it has been argued that the removal of SWMPs could act as a retrograde step to improve construction waste management practices (Constructing Excellence, 2013). That said; BUILDUK, which represents the major contractors and their supply chain partners operating in the UK, believe SWMPs provide a financial impetus for construction companies to manage waste more efficiently. As such, BUILDUK have committed to continuing use of SWMPs on its projects as industry best practice and a tool to aid waste reduction and acts as duty of care compliance (BUILDUK, 2014).

Legislation has been proven by far to be the strongest catalyst in implementing sustainable waste measures in many countries (McGrath and Anderson, 2000); Teo and Loosemore, 2001). Legislation at both European and UK level is driving change in relation to how waste is to be managed. Most legal frameworks on waste management in the UK derive from European Union Directives. The Waste Framework Directive (WFD) provides the overall structure for the waste management regime within the EU (European Commission, 2008). It sets the basic concepts related to waste management, such as definitions of waste, recycling, recovery. It placed a much greater emphasis on: waste reduction through the use of clean technologies; waste minimisation during project manufacture; recycling; reuse or reclamation; and the use of waste as an energy source. As such, Article 11.2.b of the WFD requires each Member State to achieve a 70% re-use, recycling and recovery rate of CD&E waste by 2020. In line with its obligations under the EU WFD, the UK enacted this in national laws through waste legislation, including the Landfill Tax (HM Government, 2015). The latter is charged according to the weight of materials deposited at landfill sites. From 1st April 2015, the standard rate of Landfill Tax rose from £80 to £82.60 per tonne.

Waste legislation should contribute to a transition away from landfilling towards waste reduction, reuse and recycling. As yet, current environmental statutory instruments do not appear to have noticeably reduced the amount of waste production, the UK government is likely to introduce additional legislative and fiscal measures in the future to push the construction industry towards a closed loop production system.

### 2.4.3 Construction waste management economic drivers

The construction industry spends over £1 billion per year in disposal costs (WRAP, 2008a). Additionally, waste typically costs companies 4% of turnover with potential savings of 1% of project cost through the implementation of a comprehensive waste minimisation programme (Envirowise, 1999). Furthermore, WRAP (2008a) estimates that £1.5 billion is wasted in materials that are delivered to the site but unused. Although direct costs of waste were associated with skip hire, disposal, material purchase and double handling (Coventry *et al.*, 2001), the true cost of waste is estimated to be around 20 times the disposal of waste (Innes, 2004). A pilot study by a major UK contracting company in a standard housing project revealed that that a typical construction skip cost breakdown is as follows:  6.4% for skip hire; 12.1% for labour; and 81.5 % for wasted, unused and discarded materials.

### 2.4.4 Construction waste management business drivers

More effective waste minimisation and management can also create business benefits through reducing potential health and safety and other liabilities arising from poor waste practices and enhancing companies' reputation for environmental management (Teo and Loosmore, 2010). Blok *et al.* (2015) correlated waste minimisation practices to gradual business ethical considerations by pointing out the increase customers' demands for more sustainable and eco-friendly products. Similarly, Zutshi and Creed (2015) argued that for the construction industry to improve its performance in this competitive age, it has become essential that sustainable practices, including waste minimisation, are adopted and implemented. Indeed, clients are increasingly demanding for enhanced sustainable project performance and are exerting more influence on the industry to reduce onsite waste and cut costs (Eriksson and Westerberg, 2011). Equally, WRAP (2008b) pointed out that the major business benefits relate to companies' environmental performance, which is playing an increasing role in successful tenders and is gradually becoming a necessary requirement for procurement across the entire supply chain. As such, Pekuri *et al.* (2015) reported that construction companies holding corporate waste management policies tend to have advantages in tendering for new projects. In response to such pressures, designers, contractors and product manufacturers are progressively abandoning their narrow theory of value in favour of a broader approach, which not only seeks increased economic value, but considers corporate social responsibilities and stakeholders' engagement and commitment.

## 2.5 Construction waste quantification and composition

Construction waste quantification and composition could potentially assist project managers and policy makers to make informed waste reduction decisions in future projects. The extant literature reveals several methods that have been used to quantify the construction waste generation at project level. Wu *et al.* (2014) identified five main waste quantification methodologies that include: site visits; waste generation rate; lifetime analysis; classification system accumulation; and variables modelling methods. That said; it is difficult to give exact figures of construction waste produced in a typical construction site. Poon *et al.* (2001) stated that waste generation represents 10 to 20% of the total weight of building materials in Hong Kong. Similarly, Guthrie *et al.* (1998) reported that at least 10% of all materials delivered to UK construction sites are wasted due damage, loss and over-ordering. However, Fishbein (1998) estimated this amount to be as much as 30% of the total weight of building materials delivered to a building site. In the United States, around 170 million tonnes of construction and demolition (C&D) waste is generated every year; of which, 48% was estimated to be recovered (EPA, 2009). Chun-Li *et al.* (1997) related the production of construction waste to the designed facilities' floor areas by stating that most buildings in the United States generate between 20 to 30 $kg/m^2$. Similarly, C&D waste represents over a third of combined landfilled materials and products in Canada (Begum *et al.* (2009); and 44% in Australia (McDonald and Smithers, 1998). Equally, 38% of solid waste in Hong Kong comes from the construction industry (Hong Kong Environmental Protection Department, 2013); and about 40% of the available landfill capacity is a resulting construction repository (Poon, 2007). Additionally, Bossink and Brouwers (1996) revealed that in the Netherlands, each building material generates between 1 to 10% waste of the amount purchased resulting in an overall average of 9% of purchased materials becoming waste. Pinto and Agopyan (1994) went further to report that, in Brazil, the construction project waste rate is 20 to 30% of the weight of the total site building materials. In the European Union, C&D activities produce the highest levels of waste, accounting for 821 million tonnes per year (33% of the total EU waste, almost four time the amount of household wastes, which account for 213 million tonnes (Eurostat, 2015). At present, 75% of C&D waste in the EU is being landfilled, although over 80% recycling rates have been exceptionally achieved in countries such as Germany and the Netherlands (Eurostat, 2015).

In terms of weight, brick masonry and concrete present by far the common onsite construction waste streams (Emmanuel, 2014). This has been supported by the findings of a comprehensive research conducted across the United States, the United Kingdom, China, Brazil, Korea and Hong Kong, which compared the types and volumes of construction waste in these countries (Chen *et al.*, 2002). Additionally, site observations showed that timber boards contributed to a significant onsite waste generation (Poon *et al.*, 2004b). Similarity, McGrath (2001) reported that a considerable amount of timber waste was mainly due to the number of timber pallets used onsite.

Poon *et al.* (2001) classified construction waste streams into two categories: waste from structural components, such as leftovers from concrete, timber and steel; and finishing waste, such as surplus cement mortar and plastering materials, broken ceramics and paints. Moreover, Guthrie and Mallett (1995) split C&D waste into three categories. These include materials which are:

- potentially valuable in construction and easily reused or recycled, that include concrete, stone masonry, bricks, tiles, pipes, asphalt and soil;
- not capable of being directly recycled but may be reused elsewhere, that include timber, glass, paper, plastic, oils and metal; and
- not easily recycled or present particular disposal issues, which include chemicals, asbestos, plaster, water and aqueous solutions.

Focussing on specific building materials, Ding and Xiao, (2015) reported that concrete, bricks and blocks represented more than 80% of the whole onsite waste production. Coventry *et al.* (2001) identified seven different types of waste: bricks; blocks and mortar make (33%); timber (27%); packaging (18%); dry lining (10%); metals (3%); special waste (1%); and other waste 10%. Similarly, Pinto and Agopyan (1994) listed a number of waste types that comprise: cement (33%); timber (32%); sand (28%); and bricks (12%). Furthermore, McGrath (2000) used a case study approach to audit types of building materials wasted on three different types of construction projects. The results from the three cases studies demonstrated that the most significant waste streams were: plastic and cardboard packaging; and inert material, comprising soil removed during the construction and the clean-up of the site. This was supported by Greenwood (2003) and WRAP (2007) who reported the main consistent waste stream produced during a construction project is rubble attaining 46% and 40% generation rate respectively.

Although existing data on C&DE waste quantification is a strong indicator of the detrimental impact of the activities of construction industry on the environment, a general consensus on representative amounts of waste in a typical construction site is absent from the literature. Therefore, comparison of results emanating from waste auditing literature is difficult to analyse due to: different project types (e.g. residential versus industrial buildings); clients' awareness and interest (e.g. aware versus unaware and/or public versus private); designers' engagement (e.g. pro-active versus reactive); contractors' practices (e.g. waste management plan in place versus no onsite waste management planning); use of different estimating methods and tools (e.g. rough estimation versus accurate waste auditing tools such as SMARTWaste); and differing use of construction technologies (e.g. traditional construction versus offsite construction). The latter is supported by Poon *et al.* (2001), who argued that the composition of onsite waste is inconsistent due to the technology used for the construction process. They cited an example of a project using prefabrication and noted that there was very little concrete and timber forms' waste for disposal when precast concrete elements were adopted

## 2.6 Classification of construction waste origins and causes

The extant literature reveals a number of construction waste generation causes and associated origins, which can be broadly categorised into 10 clusters. These are summarised in Table 2.1, which shows that construction waste is generated throughout the project from inception to completion and the pre-construction stage has its considerable share.

There are a variety of different approaches to the classification of the main origins and causes of construction waste. For example, Emuze *et al*. (2014) identified 15 construction waste causes, including: inadequate design information; late dissemination of information; poor planning of construction; poor team interaction; lack of leadership abilities; poor decision-making abilities; and unrealistic project execution plan. Ekanayake and Ofori (2000) grouped construction waste origins into: design; operational; material handling; and procurement origins. Likewise, Kern *et al*. (2015) classified origins of construction waste into: pre-construction; and construction phases. They reported that throughout the pre-construction phase, waste occurs during: planning and design stages (e.g. lack of coordination with standardisation of materials and extra materials ordering, estimating); purchasing (e.g. over allowance and materials' variable dimensions); and dealings with manufacturers and suppliers (e.g. goods damaged during delivery and loading). Equally, Treloar *et al*. (2003) cited a number of origins leading to generation of waste during the construction phase, which consist of:

- operational waste due to the nature of the construction process, including time pressure, poor craftsmanship, lack of supervision and poor work ethics);
- access to site for delivery vehicles, methods of loading and off-loading, which are origins of waste related to transportation and delivery; and

- storage where waste is generated by poor site management failing to provide adequate protection for materials.

**Table 2.1: Origins and causes of construction waste (compiled from the main sources within the literature)**

| Construction waste origin | Construction waste cause |
|---|---|
| Contract and tender documents | Tendering method (allowance being made for waste in the tender) |
| | Errors in contract documents |
| | Contract documents incomplete at commencement of construction |
| Design | See Table 2.2 |
| Onsite management and planning | Lack of onsite waste management plans |
| | Improper planning for required quantities |
| | Delays in passing information on types and sizes of materials and components to be used |
| | Lack of onsite material control |
| | Lack of supervision |
| Site operations | Accidents due to negligence |
| | Unused materials and products |
| | Equipment malfunction |
| | Poor craftsmanship |
| | Use of wrong materials resulting in their disposal. |
| | Time pressure |
| | Poor work ethics |
| Transportation | Damage during transportation |
| | Difficulties for delivery vehicles accessing construction sites |
| | Insufficient protection during unloading |
| | Methods of unloading |
| Material ordering | Ordering errors (i.e. ordering items not in compliance with specification) |
| | Over allowances (i.e. difficulties to order small quantities) |
| | Shipping and suppliers' errors |
| Material storage | Inappropriate site storage space leading to damage or deterioration |
| | Improper storing methods |
| | Materials stored far away from point of application |
| Material handling | Materials supplied in loose form |
| | Onsite transportation methods from storage to the point of application |
| | Inadequate material handling |
| Residual | Off-cuts from cutting materials to length |
| | Waste from application processes (i.e. over-preparation of mortar) |
| | Waste from cutting uneconomical shapes. |
| | Packaging. |
| Other | Weather |
| | Vandalism |
| | Theft |

Gavilan and Bernold (1994) went further by grouping construction waste origins into: design; materials procurement; materials handling; operations; and residual or leftover scraps. A similar approach was taken by Ekanayake and Ofori (2000) who categorised construction waste generation according to: 'design'; 'operational';

‘material handling’; and ‘procurement’ origins. They ranked the highest ‘operational’ waste contributors as damages to subsequent works and errors by tradesmen and improper planning. They also noted that inappropriate storage facilities at site and loose forms of material supply to the site were the major waste generation actors due to ‘material handling’. On the other hand, Bossink and Brouwers (1996) classified causes of construction waste according to the nature and technology of using materials in building products such as concrete, bricks and wood. They also attributed waste causes during the pre-construction stage to errors in contract clauses or incomplete contract documents. A recent research on construction procurement systems-related waste causes showed that these are related to: uncoordinated early involvement of project stakeholders; ineffective project communication and coordination; unclear allocation of responsibilities; and inconsistent procurement documentation (Gamage *et al.*, 2009).

## 2.7 Design waste causes

The main design waste causes that were identified from the literature are summarised in Table 2.2.

It has been estimated that 33% of wasted materials is due to architects failing to design out waste (Innes, 2004). Bossink and Brouwers (1996) attributed design waste causes to errors in contract clauses or incomplete contract documents. Ekanayake and Ofori (2000) reported that the key design-related waste causes are associated with: design changes, while construction works are in progress; lack of information on drawings; complexity of detailing; selection of low quality materials; and lack of familiarity of alternative products.

Similarly, Keys *et al.* (2000) reported that waste generated during the design process is chiefly due to: ‘poor communication’ leading to mistakes and errors; and ‘overlapping of design and construction’, which further complicate the management of the design process and moves waste prevention issues to the bottom of the priority list.

**Table 2.2: Design waste causes**

| Design waste cause | Employed method | Reference |
|---|---|---|
| Ineffective capture of client's requirements | Literature review; questionnaires; interviews; case studies. | Rounce, 1998; Lee *et al.,* 1999; Muhwezi *et al.*, 2012. |
| Inadequate stakeholders' coordination and communication | Literature review; system dynamics; questionnaires; interviews. | Serpell *et al.*, 1995; Rounce, 1998; Keys *et al.*, 2000, Alwi *et a*l., 2002; Poon *et al.*, 2007. |
| Design changes | Literature review; system dynamics; questionnaires; interviews; case studies. | Gavilan and Bernold, 1994; Bossink and Brouwers, 1996; Faniran and Caban, 1998; Ekanayake and Ofori, 2000; Alwi *et al.*, 2002; Polat and Ballard, 2004, Poon *et al*. 2004a and 2004b; Kulathunga *et al.*, 2005; Panos and Danai, 2012. |
| Lack of buildability considerations in design | Literature review; system dynamics; questionnaires; interviews. | Keys *et al.*, 2000; Innes, 2004; Wong *et al*., 2006. |
| Design and detailing complexity | Literature review; archival analysis; questionnaires; interviews. | Gavilan and Bernold (1994); Ekanayake and Ofori (2000); Innes, 2004; Poon *et al.* (2004a Kulathunga *et al.* (2005). |
| Limited use of design standardisation | *Literature review; questionnaires; interviews.* | *Santos et al., 2002; Polesie et al., 2009.* |
| Limited design for offsite construction | Literature review; questionnaires; interviews; case studies. | Keys *et al.,* 2000; Tam *et al.*, 2007; Jaillon *et al*., 2009. |
| Limited designers' experience in construction methods and sequencing | Literature review; questionnaires; interviews; focus groups. | Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000; Muhwezi *et al.*, 2012; Panos and Danai, 2012. |
| Designers unfamiliarity with alternative materials and products | Literature review; questionnaires; interviews. | Bossink and Brouwers, 1996; Ekanayake and Ofori, 2000; Innes, 2004; Muhwezi *et al.*, 2012. |
| Inadequate/incoherent/incorrect specification | Literature review; questionnaires; interviews. | Gavilan and Bernold, 1994; Bossink and Brouwers, 1996; Faniran and Caban, 1998; Ekanayake and Ofori, 2000; Keys *et al.,* 2000; Polat and Ballard, 2004; Innes, 2004; Panos and Danai, 2012. |
| Lack of attentions paid to material standard sizes and dimensional coordination | Literature review; questionnaires; interviews; case studies. | Ekanayake and Ofori, 2000); Kulathunga *et al.*, 2005; Chen *et al.*, 2002; Innes, 2004; Poon *et al*. 2004b; Bossink and Brouwers, 1996. |

Chandrakanthi *et al.* (2002) went further by stating that a lack of knowledge about construction techniques during design activities can also result in waste being produced. Equally, Baldwin *et al.* (2009) identified a number of design-related waste causes, including: building complexity, as a result of the emergence of a variety of design specialities and responsibilities within the same project; and coordination and communication flaws. These were attributed to the multi-disciplinary nature of design projects in which the information that passes to contractors is highly variable and open to misinterpretation; inevitably contributing to waste generation. However, Keys *et al.* (2000) described the process of construction waste production through design as complex because buildings embody a diverse range of materials and products. This is further complicated when more waste is created directly or indirectly by other projects' stakeholders, namely: clients, contractors; and suppliers. Nonetheless, there is general consensus in the literature that design variations leading to rework while construction works are in progress are significant waste causes (Cheng *et al*., 2011; Poon, 2007; Yuan and Shen, 2010; Panos and Danai, 2012).

A number of authors, namely Poon *et al.* (2004a) and Ekanayake and Ofori (2000), concurred that the main drivers for design variations during construction are:

- last minute client requirements (resulting in rework);
- designers' inadequate experience in evaluating construction methods and the sequence of construction operation (leading to detailing errors that require alteration or demolition of completed works);
- increasing design complexity (producing off-cuts);
- lack of design information (leading to assumption offers by contractors and sub-contractors, which result in over-ordering of materials);
- unforeseen ground conditions (the risk of the uncertain nature of ground conditions is often accepted that waste may occur on modifying the design as required rather than undertaking expensive preliminary investigations to confirm the conditions resulting in soil waste); and
- long project durations (allowing the design to be modified to suit changes in the market, research or legislation).

Poon *et al.* (2004a) investigated causes of design changes through a survey involving 250 building designers. They revealed that the potential to reduce waste ranked last among building designers in the selection of materials and construction methods. That said, research studies that specifically identify design causes and sources in relation to their origins across all project stages are absent from the literature. Hence, this research addressed this knowledge gap through Objective 6 to identify the underlying design waste causes, sources and their origins throughout project stages (from inception to completion) using a holistic and structured approach.

## 2.8 Current and emerging construction waste management approaches and tools

### 2.8.1 Construction waste management approaches

For the past two decades, an ever-increasing global research has been devoted to figure out how to curb construction waste generation. As shown in Table 2.3 research in the field of construction waste management research can be broadly categorised into 16 clusters, ranging from waste quantification and composition to the development of onsite waste auditing tools and recycling.

The bulk of construction waste research is largely guided by the ‘3 Rs’ principle of waste (reduction, re-use and recycling), otherwise known as the waste hierarchy (Figure 2.1). Earlier research reports, such as the studies of Envirowise (1999), Mills *et al.* (1999) and Coventry *et al.* (2001); and recent work by Hwang and Yeo (2011) and Yuan *et al.* (2011) aimed at promoting awareness in the building construction industry about the benefits of waste minimisation, including cost savings. The impact of legislation on onsite waste management practices resulted in a number of research studies (Eikelboom *et al.* 2001; Li and Zhang, 2012; Poon *et al.,* 2013; Ye and Yuan, 2014). Furthermore, research studies were conducted to investigate attitudinal, behavioural and incentivised approaches to improving onsite waste management (Lingard *et al.*, 2001; Teo and Loosemore, 2001; Kulatunga *et al.*, 2006; Begum *et al.*, 2009; Udawatta *et al.*, 2015; Lu *et al.*, 2015).

**Table 2.3: Construction waste management approaches**

| | Construction waste management approach | Employed method | Reference |
|---|---|---|---|
| 1 | Construction waste minimisation benefits | Literature review; system dynamics; questionnaires; interviews; case studies. | Envirowise, 1999; Mills *et al.*1999; Coventry *et al.* 2001; Hwang and Yeo, 2011; Yuan *et al*., 2011. |
| 2 | Construction waste quantification and composition | Literature review; observations; statistical models; questionnaires; interviews; case studies; archival analysis; mass balance principles. | Guthrie and Mallett, 1995; McGrath, 2001; Coventry *et al.*, 2001; Chen *et al.*, 2002; Emmanuel, 2014; Sáez *et al*., 2015; Bakshan *et al.*, 2015. Ding, T. and Xiao, J., 2015. |
| 3 | Construction waste source evaluation | Literature review; questionnaires; interviews. | Faniran and Caban, 1998; Ekanayake and Ofori, 2000; Poon *et al*., 2004a and 2004b. |
| 4 | Procurement waste minimisation | Literature review; questionnaires; interviews. | Gamage *et al.*, 2009; WRAP, 2013. |
| 5 | Design waste minimisation | Literature review; questionnaires; interviews; system dynamics. | Coventry and Guthrie (1998); Keys *et al.*, 2000; WRAP, 2009 2010a; BSI, 2013; Wang *et al*., 2015; BSI, 2015. |
| 6 | Waste reduction potential through Modern Methods of Construction (MMC) and off-site construction | Literature review; workshops; observations; questionnaires; interviews; case studies. | Baldwin *et al*, 2009 ; WRAP, 2007`; Jaillon *et al*, 2009; Li *et al.*, 2014 ; Wang *et al*., 2015. |
| 7 | BIM aided construction waste management | Questionnaires; interviews. | Porwal and Hewage, 2012; Cheng and Ma, 2013; Liu *et al,* 2015. |
| 8 | Onsite construction waste sorting methods and techniques | Literature review; observations; questionnaires; interviews; case studies. | Poon *et al.*, 2001; Wang *et al*. 2010. |
| 9 | Construction waste flow modelling | Literature review; Life Cycle Analysis (LCA); Material Flow Analysis (MFA); system dynamics; questionnaires; interviews; case studies. | Shen *et al.*, 2004; Yahya and Boussabaine (2006). |
| 10 | Onsite waste auditing and assessment tools | Literature review; software packages and online protocols. | BRE 2001, 2007, 2009; WRAP, 2010b; Li and Zhang, 2012; Li *et al*., 2014. |
| 11 | Impact of legislation on waste management practices | Literature review; content analysis; questionnaires; interviews; case studies. | Eikelboom *et al.* 2001; Li and Zhang, 2012; Poon *et al*., 2013; Lu and Tam, 2013; Ye and Yuan, 2014 |
| 12 | Onsite waste management practice improvements | Literature review; Life Cycle Analysis (LCA); system dynamics; questionnaires; interviews; case studies. | McDonald and Smithers, 1998; Formoso *et al*., 2002; Poon *et al*., 2001; Chadrankanthi *et. al*. (2002); Hao *et al.* (2008); Li and Yang, 2014. |
| 13 | Construction waste reuse, recycling and recovery | Literature review; observations; laboratory experiments. | Knoeria et al., 2011; Osmani, 2013a ; Emmanuel, 2014; Gastaldi *et al.*, 2015; Sangiorgi *et al.*, 2015. |
| 14 | Construction waste minimisation standards and guides | Literature review; focus groups; workshops. | Coventry and Guthrie *et al*., 1998; Greenwood *et al.,* 2003; WRAP, 2009 & 2010a; BSI, 2013; BSI, 2015. |
| 15 | Attitudes towards construction waste minimisation | Literature review; questionnaires; interviews. | Teo and Loosemore, 2001; Begum *et al.*, 2009; Lingard *et al.,* 2001; Sanders and Wynn, 2004; Kulatunga *et al.*, 2006; Udawatta *et al.*, 2015; Lu *et al.*, 2015. |
| 16 | Comparative waste management studies | Literature review; system dynamics; questionnaires; interviews; case studies; Big Data Analysis. | Chen *et al.* 2002; Ilozor (2009); Marzouk and Azab (2014); Wu *et al.* (2015). |

Tools, models and techniques have been developed to: handle and better manage onsite construction waste segregation (Poon *et al.*, 2001); quantify waste generation (Kern *et al.*, 2015); estimate waste generation rates (Bakshan *et al.,* 2015); waste data analysis (Treloar *et al.*, 2003; Tam *et al.*, 2014); audit waste (McGrath, 2001, BRE, 2007); reuse waste (Emmanuel, 2014); and collate and analyse onsite waste streams (BRE, 2009; WRAP, 2010b). Furthermore, different approaches to waste source evaluation were developed to identify construction waste causes (Table 2.1) and design waste causes (Table 2.2). Additionally, an increased number of studies were conducted to assess the potential impact of Modern Methods of Construction (MMC) and offsite construction techniques on waste reduction (Baldwin *et al.*, 2009, WRAP, 2007; Jaillon *et al.*, 2009; Li *et al.*, 2014; Wang *et al.*, 2015). Emerging information technologies, bar coding systems, GPS, GIS and wide area networks (WANs) are being progressively introduced into construction waste research (Cheng *et al.*, 2011). At the end of the waste management research spectrum, various waste recycling 'soft' decision making and marketing methodologies (Knoeria *et al.*, 2011) and 'hard' laboratory technologies and resulting improved waste materials (Osmani, 2013a; Gastaldi *et al.*, 2015) have been developed as a last attempt to divert construction waste from landfill. While these methods facilitate waste auditing, assessment, reuse and recycling; they were developed to manage waste that has already been produced. As such, there is insufficient effort and no structured approach to address waste at source and specifically design waste. That said, it is widely argued that future waste efforts should focus on designing out waste (Poon, 2007; WRAP, 2009 and 2010b; BSI, 2013 and 2015; Wang *et al.*, 2015). This is supported by Yuan and Shen (2010) who presented insights into construction waste research trends based on 87 published papers from eight journals. The latter showed that there was no clear research direction by reporting that the bulk stream of publications was devoted to broad-brush topics such as C&D waste recycling and reuse. Similarly, Lu and Yuan (2010) developed a framework for understanding global construction waste research based on 131 journal papers. They indicated that current research in the field was related to C&D stages, with very few attempts to investigate design waste.

The last few years witnessed an increasing, yet, limited design waste related research studies, including Building Information Modelling (BIM) aided waste minimisation. These are summarised and discussed in Sections 2.9 and 2.10.

### 2.8.2 Construction waste management tools

As shown in Table 2.4, several construction waste management tools are being used in the construction industry, ranging from waste planning, forecasting and tracking online portals to onsite waste sorting and auditing devices and techniques.

**Table 2.4: Construction waste management tools**

| Construction waste management tool | Reference |
|---|---|
| Net Waste Tool | WRAP 2008c. |
| Toolbox talks | Dainty and Brooke, 2004, WRAP, 2007a. |
| Building waste assessment score | Ekanayake and Ofori, 2004. |
| SMARTWaste suite | BRE, 2001, 2007 & 2009. |
| Site Waste Management Plans (SWMPs) | BUILDUK, 2014. |
| SWMP Tracker | WRAP 2010b. |
| ConstructCLEAR | TRL, 2010. |
| BreMap | BRE, 2009. |
| Material bar-code system | Chen *et al.*, 2002. |
| Webfill | Chen *et al.*, 2006. |
| | |

Most of existing construction waste management tools were developed by the Building Research Establishment (BRE) and the Waste and Resource Action Plan (WRAP). Although no longer a regulatory requirement in England, Site Waste Management Plans (SWMPs) 2008 Regulations are still considered to be good practice. As such, the majority of the larger UK contractors indicated they would still use the plans on their sites (BUILDUK, 2014). To assist the contractors in using SWMPs in their projects, WRAP (2010b) developed SWMP Tracker, which is an online tool to help collating and analysing data collected through Site Waste Management Plans. Similarly, an online tool entitled 'ConstructCLEAR' was designed by TRL (2010) to assist both construction and waste management sectors by streamlining and integrating the process of SWMPs, carbon reporting, waste management procurement and regulatory compliance. Additionally, WRAP (2008c) developed the 'Net Waste Tool', which helps generating waste forecasts during site operations and prioritising waste reduction and recovery actions to input into SWMPs. On the other hand, BRE launched a suite of 'SMARTWaste' tools, as a means of recording and generating data on the quantities and types of onsite waste streams (2001 and 2007). By auditing generated wastes, these can be used as a benchmark for waste control on future sites (Shen *et al.*, 2004). As such, the 'SMARTWaste' tools enable the creation of a separate waste plan for each individual site allowing its information be used to benchmark waste arisings on future sites, (BRE, 2009). BRE has also developed other construction waste management tools, including BreMap (BRE, 2009). The latter is a free web-based tool to assist waste producers and users to: locate the nearest landfill site; find the nearest waste recycling and reclamation sites; and source local reclaimed and recycled products. Chen *et al.* (2006) went further by developing an online construction waste exchange platform, called 'Webfill', between generators and potential users of construction wastes.

Existing construction management tools were developed to manage actual onsite waste that has already been produced in order maximise landfill diversion; however, none of these were intended to help architects understand and manage design waste.

## 2.9 Construction waste minimisation through design

An increasing body of literature, notably that produced by: Coventry and Guthrie (1998); Greenwood (2003); Poon *et al.* (2004a); Baldwin *et al.* (2009); WRAP (2009 and 2010a); Zhang *et al.* (2012); and BSI (2013 and 2015) has demonstrated that designers have an important part to play in construction waste minimisation and reduction. By and large, the literature indicated that architects should play three key roles within the context of waste minimisation at a project level: giving advice to clients; initiating waste reduction at a project level; and improving design waste practices generally. These are discussed below in accordance with the RIBA (Royal Institute of British Architects) Plan of Work 2007 Stages (Table 2.5). The latter is recognised throughout the UK construction industry as a design and management framework for running a project from appraising the client's requirements to project closeout.

**Table 2.5: RIBA Plan of Work 2007 (after RIBA, 2007)**

| Plan of Work Stage | Description |
|---|---|
| Stage A (Appraisal) | ▪ Identification of client's requirements and possible constraints on development.<br>▪ Studies to enable the client to decide whether or not to proceed and select a procurement route. |
| Stage B (Design Brief) | ▪ Preparation of strategic brief by or on behalf the client confirming key requirements and constraints.<br>▪ Identification of procedures, organisational structure and consultants. |
| Stage C (Concept Design) | ▪ Development of the strategic brief into a full project brief.<br>▪ Preparation of outline proposals and cost estimate.<br>▪ Review of procurement route. |
| Stage D (Design Development) | ▪ Development and completion of the project brief.<br>▪ Preparation of detailed proposals.<br>▪ Application for full development control approval. |
| Stage E (Technical Design) | ▪ Preparation of final proposals sufficient for coordination of all project components and elements. |
| Stage F (Production Information) | ▪ Preparation of production information in sufficient detail to enable tenders to be obtained.<br>▪ Application for statutory approvals. |
| Stage G (Tender Documentation) | ▪ Preparation and collation of tender documentation in sufficient detail to enable tenders to be obtained. |
| Stage H (Tender Action) | ▪ Identification and evaluation of potential contractors and/or specialists.<br>▪ Obtaining and appraising tenders.<br>▪ Submission of recommendations to the client. |
| Stage J (Mobilisation) | ▪ Letting the building contract.<br>▪ Appointing the contractor.<br>▪ Issuing production information to the appointed contractor.<br>▪ Arranging site handover to the contractor. |
| Stage K (Construction to Practical Completion) | ▪ Administration of the building contract up to and including practical completion. |
| L Stage (After Practical Completion) | ▪ Administration of the building contract after practical completion.<br>▪ Making final inspections for settling the final account. |

- Giving advice to clients by briefing them on the impact of waste production and highlighting benefits including cost savings. Indeed, many clients are under informed about the severity of construction waste (Dainty and Brooke, 2004). It has been argued that waste minimisation should be instigated, in partnership with clients and consultants, by analysing the benefits of waste reduction during the initial brief evaluation and value management or cost benefit studies (Yuan *et al.*, 2011). In line with this, Innes (2004) reported that waste minimisation case studies in construction have shown savings of 3% of build costs without significant investment outlay.

- Initiating waste reduction at a project level by addressing issues such as: design life (Wang *et al*., 2015); undertaking waste reviews at key design stages (BSI, 2015); waste reduction opportunities (WRAP, 2009); use of reclaimed materials (Gastaldi *et al*., 2015); use of prefabricated construction techniques (Li *et al*., 2014); and use of standardised components (Polesie *et al.*, 2009). These issues could potentially be embedded in Stage B (Design Brief) to: prepare feasibility studies; study site conditions; and develop the initial statement of waste minimisation requirements. These would be further investigated during the development of Stage C (Concept Design) during which waste minimisation may be assigned a weighting criterion to evaluate and select the preferred design option.
- Improving design practices by addressing the key causes of design waste. Several authors suggested that design waste should be tackled by addressing various issues during the design process that include: better coordination at project level to eliminate design and detailing amendments in order to avoid abortive work during site operations (Poon *et al.*, 2007); design for deconstruction (Dadhich *et al.*., 2015); planning to minimise wastage through off-cuts (BSI. 2015); the use of reclaimed building materials (Gastaldi *et al.*, 2015); and appropriate specification of design performance and products and improve design (Wang *et al.,* 2015). The RIBA Plan of Work Stage D (Design Development) and Stage E (Technical Design) provide an opportunity to implement waste reduction measures through low waste design, detailing and specification. Additionally, signing off the design at the end of Stage D would eliminate late changes during site operations. As a result, the preparation of production information during Stage F through accurate detailing and clear specification would avoid over-ordering (BRE, 2015).

## 2.10 Potential strategies to reduce design waste

The extant literature reveals various guidelines and strategies to reduce design waste. These broadly cover five major axes of the design process: contractual obligations; design waste minimisation guidelines; construction and buildability techniques; material specification; and education.

### 2.10.1 Contractual obligations

Contractual obligations could play a decisive role in reducing waste through incorporating waste minimisation activities by means of the use of specifically oriented contract tender clauses (Mendis *et al.*, 2015). For example, Dainty and Brooke (2004) suggested using contractual clauses to penalise poor waste performance. The same recommendation was put forward by Greenwood (2003, p. 4), who went further, calling for a fully integrated waste minimisation system at the contractual stage that ‘‘should identify and communicate the responsibilities for waste minimisation between all project stakeholders’’.

Since the completion of the research data collection and analysis, the RIBA published a new Plan of Work in 2013 (RIBA, 2013). As shown in Figure 2.4, the RIBA Plan of Work 2007 consists of eleven stages, defined by the letters ‘A’ to ‘L’, whilst the new RIBA Plan of Work 2013 comprises eight stages, defined by numbers ‘0’ to ‘7’.

The shift to numbers allows the stages to be aligned with a set of unified industry stages, namely the Construction Industry Council Scope of Services Stages (CIC, 2007).The use of stages and task descriptions between the two Plans of Work remains relatively the same. The RIBA Plan of Work 2013 includes two amalgamations of related stages from Plan of Work 2007 (Stage ‘E’ and ‘F’ and ‘J’ and ‘K’, which were merged onto the new Stages ‘4’ and ‘5’ respectively) and a breakdown of Stage ‘L’ into Stages ‘6’ and ‘7’. That said; the RIBA Plan of Work 2007 aligns its tender stages ‘G’ and ‘H’ to traditional procurement. Although traditional contractual arrangements remain the most prevalent form of procurement, which is used by 86% of architectural practices (RIBA, 2013), the RIBA Plan of Work 2013 takes into consideration other procurement systems, such as Design and Build

(D&B) and Private Finance Initiative (PFI). Hence, it does not contain a numbered stage that relates to the tendering activities, which can be customised by the user depending on the project procurement route. However, these are included in the RIBA Plan of Work 2013 Procurement task bar, which records specific tendering and procurement activities that occur at each stage in relation to the chosen procurement route.

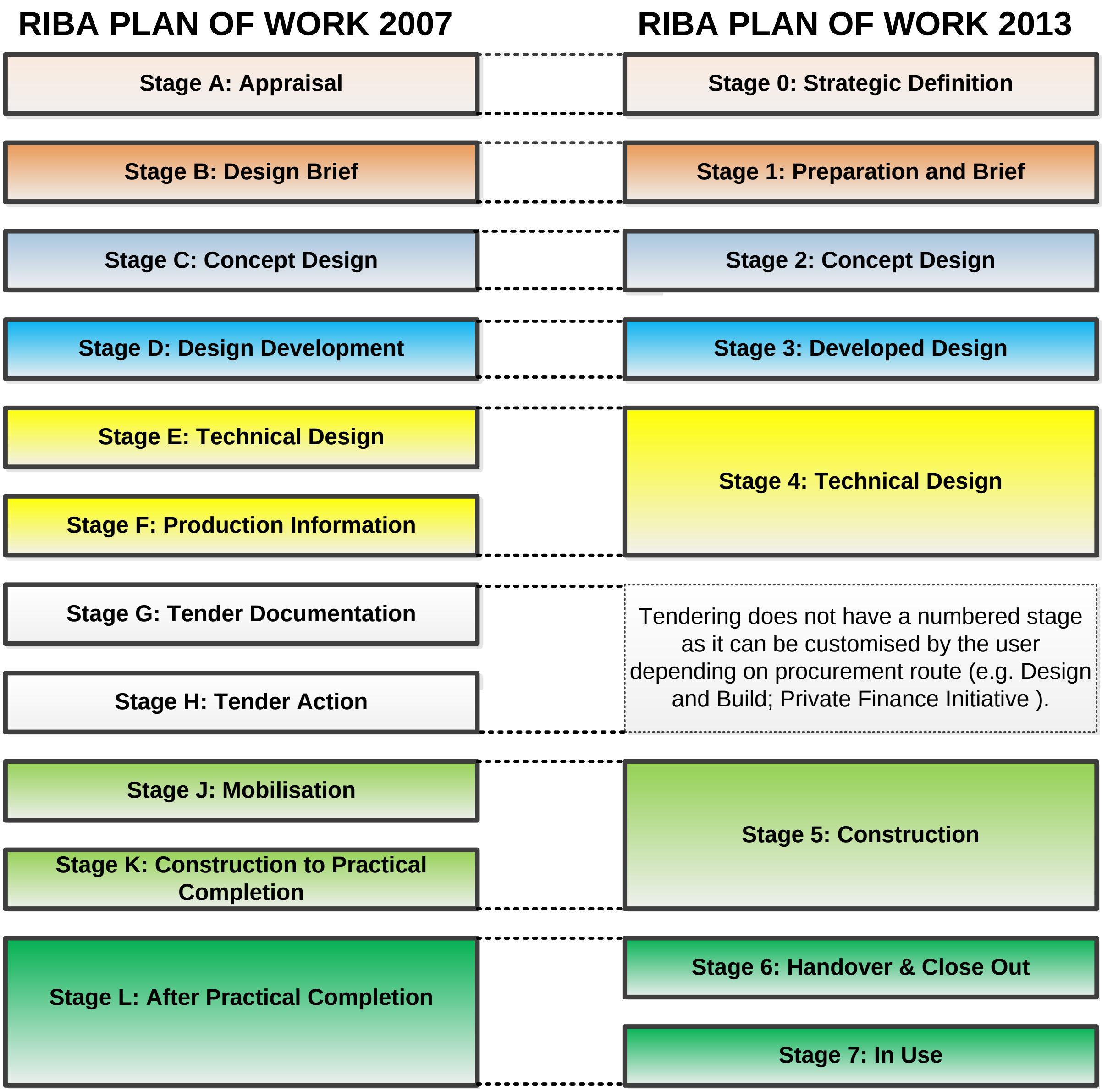



**Figure 2.4: Comparison between RIBA Plan of Work 2007 and 2013**

### 2.10.2 Design waste minimisation guidelines and methods

At present, there are insufficient design decision supporting tools to integrate designing out waste strategies in construction projects (Lu and Yuan, 2010). However, the last few years witnessed an increasing; yet, limited design waste related research. For example, WRAP (2009) introduced a guide containing broad guidance for architects to adopt a five-fold waste minimisation strategy in their projects. The guide comprises the following five principles:

- design for reuse and recovery;
- design for off-site construction;
- design for material optimisation;
- design for waste-efficient procurement; and
- design for deconstruction and flexibility.

Although the content of WRAP (2009) is a step forward to engage architects in designing out waste, the guide did not associate the proposed principles with all parameters of the design process environment, including stakeholders' coordination, communication and roles. More importantly, the guide failed to conduct a waste diagnosis across all design stages to map out the direct and indirect design waste origins, causes and sources that are critical in informing and implementing designing out waste principles and strategies. Similarly, a steering committee consortium, chaired by the author, developed Part 1 (BSI, 2013) and Part 2 (BSI, 2015) of a projected suite of a new multi-part British Standard (BS 8895) that focusses on designing for material efficiency in building projects. Although the standard is intended to be used by the design team, it gives broad recommendations for designing in material efficiency without correlating design strategies to design waste generators.

The Royal Institute of British Architects (RIBA) issued in 2011 a 'Green Overlay to the RIBA Plan of Work 2007' (RIBA, 2011). It provides supplementary sustainability information to the RIBA Plan of Work by highlighting ways to adopt sustainable building design into a project. This was done through embedding brief 'Sustainability Checkpoints' into each RIBA Plan of Work. However, designing out waste recommendations were restricted to 'Site Waste Management Plans (HM Government, 2008) and consisted of broad and sketchy designing out waste prompts without clear guidance for processes, actions and decisions. For example, the 'Green Overlay' suggested to "identify opportunities to reduce resource use and waste" in the RIBA Plan of Work Stage D (Design Development).

A recently published research, which used a multiple linear regression analysis, proposed a statistical model to determine the amount of waste generated in the construction of high-rise buildings by assessing the influence of design process and production system (Kern *et al.*, 2015). The study associated onsite waste generation to a set of design variables related to compactness of the building, the practice of waste recycling in the construction site, the floor plan area and the adopted construction system. That said; the latter was restricted to a very limited number of broad design variables that are specific to high-rise buildings. As such, it did not offer a comprehensive model to assess the impact of all design processes on onsite waste production for any type of building projects.

In the last few years, a limited literature suggests that Building Information Modelling (BIM) has the potential to drive out construction waste in building. As such, Liu *et al.* (2015) argued that BIM techniques can be used by designers as a platform for minimising construction waste in their projects. Equally, few studies explored the use of BIM as a platform to reduce construction generation for structural reinforcement (Hewage and Porwal, 2012) and during demolition and renovation activities (Cheng and Ma, 2013). However, methods and tools that integrate informed designing out waste strategies across all project stages are absent in the literature.

### 2.10.3 Construction and buildability techniques

The literature reveals that substantial amount of waste is directly related to late changes during site operations. Yuan *et al.* (2012) pointed out that these amendments change the type or quantity of building materials required at later stages. Furthermore, Hylands (2004) and Polesie *et al.* (2009) identified design standardisation as a construction method that improves buildability and contributes to a reduction of the quantity of onsite off-cuts. Gibb (2001) argued that standardisation and prefabrication of both building layouts and components result in less waste. Similarly, Baldwin *et al.* (2009) reported that pre-casting and prefabrication offer significant opportunities to reduce waste. Equally, Dainty and Brooke (2004) pointed out that the use of offsite prefabrication leads to better control of waste and damage. Various buildability techniques were deemed appropriate to reduce onsite waste. These include: substituting in situ concrete with precast slabs (Shen *el. al*., 2009); panel metal frameworks (Zhang *et al.*, 2012); and prefabricated components (Li *et al.*, 2014). A recently published research, which used simulation for a number of buildability scenarios, revealed that an increase in designing in prefabricated components resulted in less waste than a conventional construction technique (Wang *et al*., 2015).

### 2.10.4 Material specification

Construction waste can be reduced in a number of ways by specifying the use of efficient framing techniques, standard size supplies and prefabricated components into the design. Indeed, designs that require more material than necessary, as a result of over-specification, will generate waste (Shant *et al.*, 2014). Additionally, architects can influence reusability and recyclability of building materials through the choice of the structural system, component types and their connections and through the choice of materials (BSI, 2015). However, architects are often reluctant to specify recycled materials in their projects, mainly due to: concerns related to their properties (Oyedele *et al.,* 2014); guaranteed standards uncertainties (Wang *et al.*, 2015); and designers' unfamiliarity with alternative materials and products (Agyekum *et al.*, 2013). Research studies into alternative materials and products have been conducted more recently. Among these was the publication of the 'Green Guide' to specification by the BRE, which contains more than 1500 specifications of materials and components (BRE, 2015). The Green Guide information on the relative environmental performance of some materials and components undergoes regular updates to: reflect changes in manufacturing practices; the way materials are used in buildings; and evolving environmental knowledge. It contains a wide range of alternative specifications for: walls; floor systems; floor finishes; roofs; windows; doors; ceilings; paints; insulation; and landscaping. The performance of each specification is measured against a range of environmental impacts, including: toxicity; levels of emissions; water extraction; and waste production.

### 2.10.5 Education

It has been extensively reported in the literature that education programmes could potentially help the client and other stakeholders appreciate waste minimisation benefits and the strategies to be employed in the project to achieve set targets (Joachim *et al.*, 2015). This will ensure that the client understands the need for process and attitudinal change and that would encourage them to “influence waste conscious design and construction practices from the inception of projects’’ (Dainty and Brooke, 2004, p. 24). However, the flow of information and dissemination of best practice to reduce design waste requires commitment and effective consultation and communication involving all project stakeholders (BSI, 2013).

## 2.11 Construction waste minimisation challenges

Despite the evidence to support the economic and business benefits of waste reduction, the construction industry has been slow to reform its practices. The literature identified a variety of constraining factors that impede the construction industry to adopt a sustainable waste minimisation approach. These are largely due to the conservative aspect of the industry. Indeed, Kulatunga *et al.*, 2006 argued that a significant barrier to achieving effective waste management is the construction industry’s culture and its resistance to change. It is widely established in the literature that the major construction waste minimisation constraints are related to perceptions and attitudes toward waste management (Teo and Loosemore, 2001; Begum *et al.*, 2009; Lingard *et al.,* 2001; Sanders and Wynn, 2004; Kulatunga *et al.*, 2006; Udawatta *et al.*, 2015; Lu *et al*., 2015). These studies identified the main challenges facing clients, designers and contractors to adopt effective waste reduction strategies in their projects, which are listed below.

- Lack of managerial commitment.
- Lack of industry construction waste minimisation norms.
- Difficulties in changing existing practices.
- Lack of operatives experience in waste management.
- Perception that waste management systems are not cost-effective.
- Waste accepted as inevitable by-product of construction.
- Unwillingness to reuse or recycle materials with little economic value.
- Any savings made are unequally distributed, therefore giving little incentive for workers to participate in waste management.
- Poorly defined individual responsibilities for waste management.
- Limited waste minimisation guidance.

Udawatta *et al.*, (2015) also identified that managers' interest in waste minimisation and their level of commitment largely dictated the ability of operatives to undertake waste reduction activities in construction projects. The findings led to a number of recommendations to managers wanting to develop waste management policies. Among these was the need for managers to demonstrate commitment to reduce waste and provide necessary infrastructure to tackle it. The same deduction was made by Dainty and Brooke (2004, p.27), stressing that a good waste reduction strategy "requires adequate management resources to oversee and enforce its implementation". Equally, work carried out by BRE (2002) identified barriers associated with a lack of commitment from managers and the industry as a whole and suggested that a change of attitude is required across the construction supply chain.

Kulatunga *et al.* (2006) suggested that if waste levels are to be reduced, it is essential that waste performance needs to be made a priority in relation to other project goals. This is echoed by Lingard *et al.* (2000) whose findings suggested that managerial staff consider time, cost and quality to have a much greater importance than environmental issues. A subsequent research led by the same authors suggested that a possible encouragement to implementing waste minimisation practices would be the introduction of a rewards and reporting system for waste reduction and segregation carried out (Lingard *et al.* (2001). In a recent research, Liu (2014) explored challenges facing architects to design in waste reduction strategies in their projects. It was found that: architects' unawareness of design related waste causes; their inexperience in designing out waste; limited design waste information; and the involvement of structural and services engineers at different project stages with diverse time periods are key blockers to design out waste.

## 2.12 Literature review synthesis

Five key research questions emanating from the literature review are discussed below.

*1. What is the current status of construction waste minimisation practice?*

As discussed in Section 2.8, the current construction waste state-of-research is piecemeal and focusses on developing a wide range of support techniques and tools to help managing waste that has already been produced onsite. Although the 'Waste Hierarchy' (Figure 2.1) gives top priority to preventing waste in the first place, ongoing research predominantly relates to construction waste 'reuse, recycling' and 'recovery' (Section 2.8.1 and Table 2.3). Having identified the key themes from literature on construction waste minimisation drivers (Section 2.4 that addresses Objective 1); construction waste quantification and source evaluation (Section 2.5 that addresses Objective 2); and current and emerging construction waste research trends (Section 2.8 that addresses Objective 3), the next stage of this research, which addresses Objective 4 and 5, investigated current construction waste prevention and minimisation practices during the design and construction stages (see Sections 4.2.4 and 4.2.5).

*2. What are the key construction waste minimisation constraints and enablers?*

As discussed in Section 2.11, the literature identified a number of challenges that impede a coherent adoption of waste minimisation strategies in construction projects. However, these challenges were overarching and generic as they were mainly associated with the construction industry's resistance to change and were not specifically linked to the key project stages and stakeholders' direct or indirect impact on waste generation, namely designers. Therefore, this research explored the main construction waste minimisation blockers facing architects and incentives that would support them to adopt waste prevention measures in their projects (see Sections 4.2.6 and 4.2.7).

*3. What are the principal construction waste origins?*

As summarised in Table 2.1, the extant of the literature reveals a range of approaches to the classification of construction waste origins and causes. There is a consensus in the literature that construction waste is directly or indirectly generated throughout all project stages. However and as discussed in Section 2.7, no attempts were made in the literature to identify waste origins and causes in line with each project stage (see Section 2.3). Hence, this research examined construction waste origins and respective causes in each design stage in line with the RIBA Plan of Work (see Sections 4.2.3 and 5.2).

*4. What are the root causes and sources of design waste in each project stage?*

As discussed in Section 2.8.2, tools, models and techniques have been developed to help handle and better manage onsite waste generation. While these tools facilitate auditing, assessment and benchmarking, their waste source evaluation approach is curtailed and piecemeal, as it fails to effectively address the causative issues of waste production throughout all stages of a construction project. Furthermore, research studies that specifically identify design causes and sources in relation to their origins across all RIBA Plan of Work stages are absent from the literature. Hence, this research addressed this knowledge gap through the investigation of the underlying design waste causes, sources and their origins throughout project stages using a holistic and structured approach (see Chapter 5).

*5. How can architects adopt and sustain designing out waste as an integral part of the design process?*

Although it was extensively reported in the literature that design decisions have a significant impact on onsite waste generation, very little has been published on how architects could go about minimising waste through a change in design practices. Existing design waste guidance, such as WRAP (2010), ensures that architects recognise waste minimisation benefits and adopt waste reduction strategies in their projects. However, these are broad design guidelines without a comprehensible and focussed methodology to apply them in each design stage. As such, aim the final stage of this research was to use the outcomes of the preceding four research questions to develop an industry reviewed Designing out Framework to assist architects to embed waste reduction strategies across all project stages in line the RIBA Plan of Work stages (see Chapter 6).

The above questions were investigated in this research via a sequential mixed method, which is presented in Chapter 3. Answers to these questions are provided in Chapter 4, 5 and 6.

### 2.13 Literature review limitations

The literature review has provided strong insights into key issues related the research objectives. By and large, the literature review was confined to: books; journals; conference proceedings; research theses; government reports; industry publications; and standards. Additionally, there is a wide selection of literature available on construction waste management but the availability of material for design waste minimisation strategies was limited. As a rich and vast array of construction waste management literature was accessible, it was not possible to cite each publication in the field. However, the adopted systematic approach to examine relevant literature sources, as noted in Chapter 1, in addition to the author's active involvement in several related research projects and external committees ensured that the key academic, government and industry publications are included in the review. Although insights into global perspectives on construction and demolition waste were included in the literature review, the research was conducted within a UK context and focussed on construction waste minimisation through design. As such, the data collection and implications were associated with the UK construction industry.

### 2.14 Summary

This chapter has demonstrated that construction waste management is firmly on the UK government sustainable development agendas. As such, there have been a number of significant changes in legislation that are forcing construction companies to change their attitudes towards waste management. The new legislation is bringing about major changes within the field of waste management and minimisation with new policies aimed at making current waste disposal methods too costly. This has sparked a plethora of construction waste management research and industry attempts to develop waste control tools. Although there is a consensus in the literature that the design process is responsible for a significant amount of onsite waste generation, the current thinking of waste minimisation practices is heavily focussed on the physical minimisation of construction waste and identification of onsite waste streams. The challenge now is to offer a novel platform for the next generation of tools and techniques that would entrench and sustain designing out waste strategies in building projects. This is provided by this research and explained in the following chapters, starting with Chapter 3 which presents the adopted research methodology.

# CHAPTER 3

# RESEARCH METHODOLOGY

## 3.1 Introduction

This chapter presents a critical assessment and justification of the adopted research methodology. The first section discusses the reasoning and sequence of the research questions and their relationship with the philosophical stance and research objectives. The subsequent two sections comprise a detailed discussion that rationalises and explains the adopted research strategies and methods and their relationship with the philosophical position of the study. The final section describes the methodological process of the design, development and industry review of the resulting Designing out Waste (DoW) Framework.

## 3.2 Research philosophical position

Understanding research philosophy is the first step in designing a research methodology. The research philosophy is an over-arching term which is associated with the development of knowledge and the nature of that knowledge (Saunders *et al.*, 2012). It provides guidelines in the selection of a research approach containing a different subject or knowledge structure to support research design decisions (Easterby-Smith *et al.*, 2012).

The philosophical stance of this research was closely associated with the research objectives (see Section 1.3) and conditioned by the research questions that emerged out of the interrogation of the literature, which was synthesised in Section 2.12. As shown in Table 3.1, each question is closed linked to its corresponding objective(s) and was aligned with its underlying philosophical assumption, which in turn informed the selection of associated research strategies and methods that were used for data collection to answer each research question.

This research set out to investigate design waste generators and the most suitable approaches and methods to derive designing out waste knowledge. As reported and discussed in Sections 1.2, 2.6 and 2.7, it is widely argued in the literature that a significant amount of onsite construction waste is directly or indirectly impacted by design decisions. Hence, the focus on design as transferrable knowledge, which was identified in the literature as having a significant contribution on construction waste minimisation, is the theory that this research endeavoured to test in order to develop new understandings of design waste causes and consequential designing out knowledge.

**Table 3.1 Relationship between research questions, objectives, philosophical stance and adopted research strategies and methods**

| Research question | Research Objective | Philosophical stance | Research strategy | Research Method |
|---|---|---|---|---|
| 1. What is the current status of construction waste minimisation practice? | 4 & 5 | Positivism | Quantitative research | Questionnaire survey |
| 2. What are the key construction waste minimisation constraints and enablers? | 4 & 5 | Positivism | Quantitative research | Questionnaire survey |
| 3. What are the principal construction waste origins? | 4, 5 & 6 | Positivism (combined with constructivism) | Quantitative research (supported by qualitative research | Questionnaire survey and interviews |
| 4. What are the root causes and sources of design waste in each project stage? | 6 | Constructivism (combined with Interpretivism) | Qualitative research | Interviews |
| 5. How can architects adopt and sustain designing out waste as an integral part of the design process? | 7 | Pragmatism | Mixed research | - IDEF0 Modelling Method for the DoW Framework design.<br>- Questionnaire survey and a follow up focus group for the Framework industry review data collection |

As explained in the section below, the theory testing was based on pragmatism, combining ontological constructivism with interpretivism. Pragmatism provides different views to a research question (Creswell, 2013; Saunders *et al.,* 2012); and, therefore supports the requirement of multiple views of reality (Tashakkori and Teddlie, 2010), which guided this research to obtain a wide-ranging view of design waste paradigm.

*The first two research questions* are related to an examination of the current status of construction waste minimisation practice and associated barriers and enablers. As such, both questionnaire surveys were concerned with investigating 'what is' or 'what exists' and as such, deal with ontological perspectives that refer to assumptions about "*the nature of reality*" (Creswell, 2013) and "*study of being*" (Blaikie, 1993). Ontology is a system of belief that reflects an interpretation of an individual about what constitutes a fact (Tan, 2002). Ontology is associated with a central question of whether social entities need to be perceived as objective or subjective (Bryman, 2012). Objectivism (also known as positivism) relies on the existence of reliable knowledge about social events and their implications. The key philosophical position that objectivism makes is that the world is real, structured and its composition can be modelled for the researcher (Fitzgerald and Howcroft, 1998). On the other hand, subjectivism (also known as constructivism) claims that reality is more in the mind of the knower, that the knower constructs a reality, or at least interprets it, based upon his or her perceptions (Walliman, 2006). The first two research questions were concerned with an assessment of existing construction waste minimisation practices based purely on existing facts; and as such consider the world to be external and objective. Hence, a positivist approach was adopted to address the first two research questions.

*The third research question* is concerned with an exploration of construction waste origins, which were associated in Section 2.3 to project stages (e.g. Design Development; Construction) or processes (e.g. architectural detailing; material ordering) during which waste occurs. The underpinning philosophical stance for this question is twofold: (1) positivism (or objectivism) based on true experienced reality related to some aspects of the research question. For example, the identification of the construction stage as being a key construction waste origin based on contractors' actual observations and experiences. (2) Constructivism (or subjectivism), which incorporates assumptions in relation to the origins of construction waste, acknowledges that reality is made from the perceptions and consequent actions of social actors (Easterby-Smith et al. (2012). For example, there is no underlying reality to construction waste origins during pre-construction stages.

As such, each person experiences and perceives reality differently. Therefore, the philosophical approach to address the third research question combined positivism and constructivism.

*The fourth research question* is related to an investigation of the underlying causes and source of design waste. As defined in Section 2.3, 'design waste' is waste arising from building sites as a direct and/or indirect result of the design process; waste 'causes' refer to direct and/or indirect waste generators (e.g. design changes; unclear specification); and waste 'sources' are associated with project stakeholders' contributory responsibility (e.g. architect; contractor). As such, the fourth question intended to develop detailed understandings of design waste causes and sources based on two key project stakeholders' lived experiences and recollections and interpretations of those experiences. In this case, beliefs determine what should be counted as design waste source evaluation facts, which corresponds to interpretive paradigm. With its focus on complexity, richness, multiple interpretations and meaning-making, interpretivism is also subjectivist. Consequently, the fourth research question was underpinned by a combination of subjectivism (constructivism) and interpretivism.

*The fifth research question* explored ways to assist architects to understand design waste generators and integrate design out waste strategies across all project stages within conventional design processes. The answer to the fifth research question was informed by the acquired knowledge and outcomes of the preceding four research questions. The resulting knowledge aimed to provide a method to organise designing out waste actions and enable continuous waste minimisation performance. Hence, pragmatism, which is concerned with action, intervention, change and constructive knowledge (Goldkuhl (2012), was deemed the most appropriate philosophical grounding to address the fifth research question.

## 3.3 Research strategies

There are two distinct type of research strategy quantitative and qualitative.

The distinctions between the two research strategies triggered debate with regard to quantitative precision over qualitative richness.

**Table 3.2: Comparative insights into research strategies (compiled from literature)**

| Characteristic | Qualitative Strategy | Quantitative Strategy | Mixed Strategy |
|---|---|---|---|
| Purpose of Research | Exploratory plus confirmatory. | Confirmatory plus exploratory. | Confirmatory plus exploratory. |
| Research philosophy | Constructivism (combined with interpretivism). | Positivism. | Pragmatism; transformative Perspective. |
| Research Strategy | Inductive; grounded theory. | Deductive (hypothetical); Rooted in conceptual framework or theory. | Mixed inductive and deductive (inductive-deductive research cycle). |
| Research design | Ethnographic research designs and others (case study). | Correlational; survey; experimental; quasi-Experimental. | Mixed research designs, such as parallel and sequential. |
| Sampling | Mostly purposive. | Mostly probable. | Probable, purposive and mixed. |
| Data analysis | Thematic analysis: categorical and contextualising. | Statistical analysis: descriptive and Inferential. | Integration of thematic and statistical analysis; data conversion. |
| Type of data | Narrative. | Numeric. | Narrative and numeric. |
| Validity | Trustworthiness; credibility; and transferability. | Internal validity; external validity. | Inference quality; inference transferability. |
| Strengths | Natural data collection methods.<br>Being able to change process over time.<br>Being able to understand meanings from participants.<br>Contribute to theory generation. | Fast and economical<br>Covering a wide range of situations.<br>Capability to manage a large number of samples.<br>Statistics are aggregated from large samples. | Combined strength from both qualitative and quantitative research. |
| Limitations | Harder to control the pace, progress and end-points of the research process.<br>Limited generalisation capability.<br>Subjectivity.<br>Difficulty of replication.<br>Lack of transparency.<br>Data collection could be tedious and require more resources.<br>Analysis and interpretation of data may be more difficult.<br>Difficulties in controlling research process. | Tend to be inflexible and artificial.<br>Sampling limitation.<br>Non-response limitation.<br>Data input errors.<br>Data processing errors.<br>Failure to distinguish between people and social institutions.<br>Referring to artificial measurement process.<br>Relying on instruments and procedures. | Need for clear vision of research process. |

Crewsell (2009) argued that quantitative and qualitative research should not be viewed as polar opposites or dichotomies. Tashakkori and Teddlie (2010) went further to argue that the two methods should be viewed as complementary mediums. Subsequently a mixed method or triangulation may be used to overcome the limitations of a singular method by combining two or more methods.

The methodological key features of quantitative, qualitative and mixed methods are summarised in Table 3.2 and discussed in the sections below.

### 3.3.1 Quantitative research

Quantitative research strategies provide snapshots of a situation or a state of affairs. and thus are used to address questions such as 'what',' how much' and 'how many'? It is related to positivism with the aim of being 'objective' and 'empirical' in nature (Neuman, 2011). Quantitative perspectives assume that judgement in research is free from values and thus unbiased leading to the researcher being detached and objective (Hughes, 1990). As the positivist paradigm leads to a scientific, systematic approach to research; it lends itself to the use of a quantitative methodology. Hence, the latter has been adopted as the research strategy to address fully research questions 1 and 2 and partially research question 3 (see Section 3.2). Quantitative research seeks to examine correlation between facts and how their relationships align with existing theories and knowledge (Fellows and Liu, 2008). It is also used to investigate causal relationships between different variables (Leedy and Ormrod, 2012). This was applied in this research through two sets of questionnaire survey to assess the relationship between design practices and decisions on onsite waste generation (see Appendix 1 and Chapter 4). Quantitative research is commonly perceived as being more analytical in nature (Easterby-Smith *et al.,* 2012) and is opined as being unbiased and reliable, relying on hard facts and numbers (Fitzpatrick and Howcroft, 1998). In quantitative research, emphasis is placed on measurement (Punch, 2014) and statistical methods are deemed particularly useful when looking for relationships and patterns and expressing these patterns with numerical data (Neuman, 2011). As such, Tashakkori and Teddlie (2010) described quantitative research, which makes use of mathematical and statistical techniques, as a numerical description of trends, attitudes or opinions collated by studying a sample of the population. Computer software programmes, such as the Statistical Package for Social Science (SPSS), are commonly used to aid in the statistical analysis enabling a more efficient process. SPSS was used in this research to support the quantitative data of both questionnaires (see Section 3.5.1.6 and 3.6.2.3) Quantitative research is suitable when it is desired to find facts about a concept, a question or an attribute (Gill and Johnson, 2010). It is based on understanding, testing or verifying a theory, rather than developing one and seeking to identify causes and effects (Bryman, 2012).This is in line with the philosophical position of this research to test the theory that design is influential in reducing construction waste. As such, the first three research questions tested the theory through quantitative research using two sets of questionnaire survey to identify design waste causes and effects on onsite waste generation (see Appendix 1). Creswell and Clark (2011) argued that quantitative research is applied in a research to collect factual evidence and study the relationship between these facts in order to verify a theory or hypothesis. As such, the main emphasis of the quantitative approach of the research was on deductive reasoning, whereby the first three research questions were developed based on theory and then data were collected to test it.

### 3.3.2. Qualitative research

With its roots in anthropology, interpretive and psycho-analysis (Healy and Perry, 2000), qualitative research is 'subjective' in nature. It is a systematic, empirical strategy and is a means for describing and attempting to understand and observe regularities, patterns and themes (Fitzpatrick and Howcroft, 1998). A qualitative study aims to emphasise subjective methods commonly based on personal opinion, perception or feeling (Flick, 2007). As such, qualitative research is concurrent with the interpretivism paradigm, also known as phenomenological or social constructivism, which is based on the assumption that reality is consciousness, socially constructed and interpreted by humans, as social actors according to their beliefs and value systems (Healy and Perry, 2000; Silverman, 2010). Interpretivism is generally equated with qualitative research, which can be broadly categorised into two categories: exploratory research and attitudinal research. The former is used primarily to gain a greater understanding of a particular subject by diagnosing a situation, screening alternatives and discovering new ideas as a result of limited knowledge around the subject area (Tan, 2008). Exploratory research is particularly relevant to frame the nature of a research problem in an emerging field that has limited literature (Denzin and Lincoln, 2011). This is not the case in this study as the research problem was clearly defined based on a rich body of construction waste related literature. On the other hand, the purpose of attitudinal research is aimed at understanding, measuring or informing the change in individuals' stated beliefs (Gibson and Brown, 2009). It is used predominantly to assess the opinion or view of an individual towards a variable or question (Glesene, 1999).This qualitative research process was adopted to answer the fifth research question through an evaluation of designers and contractors' views on the root causes and sources of design waste in each project stage. Qualitative research seeks to pose 'questions', rather than test a theory a theory or hypothesis, allowing new theories to be formed (Creswell, 2009). Therefore, qualitative research usually adopts an inductive approach, which was adopted in the qualitative part of this research. Berg and Lune (2011) noted that the main advantage of qualitative research is its ability to capture meanings and interpretations. Fellows and Liu (2008) explained that the data gathered in qualitative research tends to be unstructured, or in its raw form; however, it is often detailed and thus rich in content and scope. Neuman (2011) went further by pointing out that any type of data can be quantified through coding. Additionally, Bryman (2012) stated that qualitative research generally places an emphasis on words rather than numeric information in the process of collecting and analysing data. The process of coding based on NVivo 'nodes' was used to support the analysis of the collected qualitative data of the interviews in order to identify patterns and trends related to design waste generators (see Section 5.3).

### 3.3.3 Mixed research

A quantitative study is ideally suited to test and verify a hypothesis because of its ability to measure numerical data using statistics (Gill and Johnson, 2010). It holds the ability to study a detailed relationship between dependant and independent variables. However, Bryman and Cramer (2005) argued that quantitative research limits the range of possible answers from respondents. Equally, Punch (2014) opined that that in quantitative studies often the underlying theory is not further explored, thus limiting the scope of the research to an extent. Hence, quantitative studies are only capable of providing a fixed framework on which the study can develop. Furthermore, Walliman (2006) indicated that it is difficult to quantify human feeling and emotion through quantitative research. Thus, such an approach leaves the scope to overlook potentially important additional factors due to the degree of distance observed between the researcher and respondent (Bryman, 2012). On the other hand, qualitative research enables an understanding of underlying reasons, opinions, and motivations (Denzin and Lincoln, 2011). It allows the researcher a greater amount of freedom, not required to follow a stringent design plan and allowing the research to unfold naturally (Blaikie, 2000). As such, more detailed and rich data can be attained. However, qualitative methods are often questioned due to a perceived lack of objectivity (Blaxter *et al*., 2010); often being criticised by individuals with a background in the 'scientific, quantitative positivist tradition' for being more susceptible to the influence of external environmental variables (Fellows and Liu, 2008). As a result, Amaratunga *et al*. (2002) stated that the use of two or more research techniques, known as 'mixed method' or triangulation', facilitates the reduction of the respective disadvantages of both qualitative and quantitative approaches; whilst benefitting the research through the exploitation of the advantages of each method. This was supported by Fellows and Liu (2008) by stating that mixed method can prove to be very powerful in gaining "*insights and results*" and to "*assist in making inferences and drawing conclusions*". Similarly, Tashakkori and Teddlie (2010) argued that that once a proposition has been confirmed by two or more independent measurement processes, the uncertainty of its interpretation is greatly reduced. Silverman (2010) further suggested that a sensible train of thought does not consider one methodology to be superior to another, but considers both as "*complimentary parts of the systematic, empirical search for knowledge*". In essence; triangulated methods seek to pinpoint the attributes of a phenomenon more precisely through examination from different viewpoints (Blaxter *et al.,* 2010); resulting in a stronger research design and more valid and reliable findings (Bryman, 2012); and adds rigour, breadth and depth to any research (Denzin and Lincoln, 2011). Therefore, triangulation was adopted as the research strategy to provide a multi-dimensional view of design waste origins, causes and sources using data collection techniques from both qualitative and quantitative perspectives in a compensatory and complementary manner. As shown in Table 2.2, the design strategy is in line with the wider context of research methods on construction waste minimisation that used mixed research, using predominantly questionnaire and interviews. Having identified construction waste minimisation industry and research trends, knowledge gaps and resulting research questions from the literature, a quantitative method was adopted that engaged a sample from architectural and contracting companies to investigate salient issues related to current design waste and onsite waste management approaches and practices. This was carried out through two cross sectional questionnaire surveys targeting the top 100 UK architectural practices and contracting firms (Appendix 2). A follow up qualitative method based on 24 semi-structured interviews was then adopted to expand upon the finding of the quantitative investigation and provide a detailed exploration of design waste origins, causes and sources (Appendix 2). The findings of the research quantitative and qualitative investigations informed the design of a novel industry reviewed Designing out Waste (DoW) Framework. A detailed description of the employed questionnaire surveys and follow-up interviews are discussed below in Section 3.4.

## 3.4 Research methods

The research process that includes relationships between the research objectives and research stages and methods as well as associated key outcomes are summarised in Figure 1.1. As shown in Table 3.1, the research methods were guided by the research questions and objectives; philosophical underpinnings; and research strategies. Having justified and described the research philosophical position and adopted strategies in Sections 3.2 and 3.3, the sections below present an account of the research methods that were used for the data collection and analysis.

### 3.4.1 Questionnaire survey

A questionnaire survey is a useful research tool when: large samples need to be surveyed; there is no essential need for face-to-face contact; and the funds for the research are limited (Buckingham and Saunders, 2004). Questionnaire surveys are the most common form of quantitative research methods (Blaxter *et al*., 2010). They take a snapshot of a section in society at a particular point in time with the intention that the results can be generalised for the whole population. The results obtained are perceived as being relatively valid due to the wide geographic area and large number of respondents that can be sampled (Creswell, 2014). It operates on the basis of statistical sampling and it is rarely possible to involve the full population. Statistical sampling is used to secure a representative sample as it saves money and time (Fellows and Liu, 2008). In a questionnaire survey, the researcher introduces the subject matter to the respondents and examines patterns of the relationship between variables (Brace, 2013).

Building on the literature review findings and as a primary survey, two sets of questionnaires were used in this research as a method of collecting data to: establish a general industry-wide perspective on causes and origins of construction waste; examine current waste minimisation practices and responsibilities; and identify barriers that hinder a more proactive approach to adopt and sustain waste reduction measures in construction. The first questionnaire, which addresses Objective 4, was sent to contactors to investigate current onsite waste management responsibilities, organisational and auditing methods and blockers. The second questionnaire, which addresses Objective 5, was administered to architects to ascertain their views on design waste minimisation practices within their profession and the associated barriers.

#### 3.4.1.1 Questionnaire design strategy

The most significant problem that many authors associate with the use of questionnaires is that the rate of response can be difficult to predict and control. As such, a focussed strategy was devised to ensure the largest possible return to enable meaningful data analysis. The design of the both questionnaires was done using procedures recommended by Frazer and Lawley (2000); Oppenheim (2000);

Fowler (2002); and Fellows and Liu (2003). These recommendations include the following:

- questions must be clear, unambiguous and easy to answer;
- the questionnaire should be designed attractively and should be uncluttered;
- questions should be in short sentences;
- use of simple language in writing questions;
- biased terms should be avoided; and
- the questionnaire must be designed to facilitate the analysis of its results.

Additionally, the following strategies were adopted to ensure high possible responses from respondents for both questionnaires.

- A personalised cover letter, addressed to a named person, was included with every questionnaire (Appendix 1.1 and Appendix 1.2). Some of the contact names were retrieved through companies' web sites, but a special attention was made to identify each respondent by name by phoning the targeted organisations.
- The cover letter contains: a brief introduction to the research under investigation; aim of the survey; incentives; and approximate time to complete the questionnaire (Appendix 1.1 and Appendix 1.2).
- A statement was added in both cover letters and questionnaires to assure the respondents that any data provided would be held in strict confidence and used for this research only (Appendix 1.1 and Appendix 1.2).
- The questionnaires were professionally printed, using 120mg A3 back-to-back paper.
- A self-addressed stamped envelope was provided.
- Three telephone and email follow-ups of all non-respondents.
- Further telephone calls were made to re-contact all the remaining non-respondents after two weeks from the telephone follow-ups.

#### 3.4.1.2 Questionnaire structure and content

The questionnaire, which was destined for architects (Appendix 1.3), included 18 questions, while the one sent to contractors (Appendix 1.4) contained 20 questions. Both questionnaires were divided into five sections, some of which were purposely duplicated to get comparative insights into common and inter-related issues. Both questionnaire surveys comprised the following seven sections.

- Section 1: Background information (same section in both questionnaires).
- Section 2:
  - Causes of waste (same section in both questionnaires).
  - Types of waste (contractors' questionnaire only)
- Section 3: Waste management responsibilities (same but customised questions were used).
- Section 4:
  - Waste minimisation design practices (architects' questionnaire only).
  - Onsite waste management practices (contractors' questionnaire only).
- Section 5: Barriers and incentives (same section in both questionnaires).
- Sections (6 and 7) were added at the end of both questionnaires:
  - Section 6 consisted of an open-ended question to capture respondents' views on other salient construction waste minimisation issues that were not covered in the survey.
  - Section 7 intends to: identify potential interviewees; and reiterates the researcher's commitment to send analysis of the results, if so required.

At the end of Section 2, 3, 4 and 5, a space was provided in both questionnaires as an option for respondents to add additional information with regard to the specific topic under investigation (e.g. waste management responsibilities).

The questionnaire included a combination of rating scales, multiple-choice questions and open-ended questions. Responses were requested based on current or recently completed building design projects. In the core questions, such as causes of waste, respondents were requested to assign an appropriate rating scale from '5' (the highest) to '1' (the lowest level). Some closed-ended questions are set out in both questionnaires calling for respondents to tick the issues and practices that best describe their answers. For the core and closed-ended questions, a category ‘other’ (please list/specify below) was provided to accommodate any responses not listed (Appendix 1.3 and Appendix 1.4).

### 3.41.3 Questionnaire pilot study

Pilot surveys are recommended in questionnaire design to: check the appropriateness and clarity of the questions; capture the recipients’ possible reactions to the questionnaire; and provide preliminary test of validity and reliability of the collected data (Fellows and Liu, 2008; Flick, 2007). Therefore, a pilot study tested its ease and comprehension. Ten copies of each questionnaire were distributed to academic staff and researchers within the School of Civil and Building Engineering at Loughborough University, before sending them to the targeted architects and contractors. The aim of the ‘trial-run’ exercise was to: get feedback on the survey’s structure; clarity of questions and instructions; flow of information; and length of questionnaire. Revisions were made to improve the clarity and quality of both questionnaires. Some of the actions taken based on the pilot survey were:

- the length of the questionnaires was shortened from five to four pages;
- the final format of questionnaires was changed from a stapled five A4 pages document to one A3 back-to-back page;
- confidentiality reassurance statement was added in both questionnaires; and
- some questions were reworded for clarity.

### 3.4.1.4 Questionnaire sampling size

A sample population of the survey needs to be considered prior to the data collection process as it is impractical that the data concerned could be collected from the entire population for the research (Frazer and Lawley, 2000). By and large, there are two sampling types commonly used in research: probability (random) sample; and non-probability sample. The probability sampling comprises four key techniques: simple random sampling (when the whole population is available); systematic sampling (when a stream of representative people is available); stratified sampling (when there are specific sub-groups to investigate); and cluster sampling (when population groups are separated and access to all is difficult).

The quantitative to qualitative process is a common sampling process, which has been used for data collection in mixed method research (Bryman, 2012), where the sequential data collected from a first sample is usually required to draw a second sample obtained from a purposive sampling procedure. As such, the adopted sampling technique for this research involves selecting a population for the questionnaires and interviews through chronological sampling methods (Tashakkori and Teddlie, 2010). The sample of the questionnaire survey in this research was divided into two homogeneous strata (architectural practices and contracting firms) and targeted a sample of individuals from each group (partners and associate from the architectural practices and sustainability and environmental managers from the contracting companies). Therefore, a stratified random sampling was used to select the research sample from the UK top 100 architectural practices and top 100 contracting firms.

The largest architectural and contracting companies in the UK were targeted for this survey because each has considerable and adequate resources in place, which should potentially facilitate the planning, enforcement and implementation of sustainable and holistic waste minimisation strategies in their projects, when compared with SMEs. Partners and associates were targeted within the architectural offices, as they oversee a significant number of projects and lead the decision making process over the wider context of strategic, design and communication matters within their practices. A similar targeting approach was adopted for contracting firms, where sustainability and environmental managers were selected due to their inter-disciplinary involvement with upstream corporate management and downstream project and site management, in addition to their insights into current and forthcoming waste regulatory and compliance issues. Additionally, all of the targeted architectural and contracting organisations have various offices and live projects across most regions of the United Kingdom.

A total of 200 questionnaires were sent to architects and contractors. One hundred questionnaires were sent to the top 100 UK architectural practices, selected from the AJ Plus (Architects' Journal). The AJ Plus raking of architectural practices is based on the number of qualified architects within the firms. Equally, one hundred questionnaires were sent to the top 100 UK contracting firms, selected from CN Plus (Construction News). The latter ranks contractors using an algorithm of turnover, profit, growth, staff employed and earnings per employee.

#### 3.4.1.5 Questionnaire response rate

All 200 questionnaires were posted on the same day and three telephone and email follow- ups were conducted for all non-respondents over a five weeks period. As shown in Table 3.4, 11 and 18 questionnaires were received after two weeks from the initial mailing from responding architects and contractors respectively. The first and second follow-up rounds increased architects' responses to 30 and 38 and contractors' to 39 and 46 completed questionnaires respectively. The final round of telephone calls to the remaining non-respondents resulted in a total of 40 architects' responses (response rate of 40%) and 49 contractors' responses (response rate of 49%).

**Table 3.3: Post-questionnaire dispatch follow-up process**

| Weeks | Completed questionnaires | | Follow-up telephone calls and emails |
|---|---|---|---|
| | Architects (out of 100) | Contractors (out of 100) | |
| 1 | 7 | 12 | - |
| 2 | 4 | 6 | - |
| 3 | 19 | 21 | First |
| 4 | 8 | 7 | Second |
| 5 | 2 | 3 | Final |
| **Total** | **40** | **49** | - |
| **Response rate (%)** | **40%** | **49%** | - |

The reasons for uncompleted questionnaires for both target groups can be summarised as follow:

- work pressure, where respondents' had deadlines to meet;

- high volumes of questionnaires that organisations receive; and
- policies of respondents' organisations to not reply to all surveys or take part in any research.

#### 3.4.1.6 Questionnaire data analysis

Computer aided software packages have been widely used to facilitate the handling of large volumes of quantitative data (Bryman and Cramer, 2005). They enable complex data to be easily manipulated and displayed in a number of ways (Robson, 2011). This makes the data analysis process more comprehensive, transparent and replicable; thus increasing the reliability and validity of the analysis. Hence, the Statistical Package for Social Science (SPSS) software was employed in this research to analyse the questionnaire data. Prior to data entry, codes were assigned to all completed questionnaires (e.g. A1 and A2 for architects; and C1 and C2 for contractors). Equally, questions and variables were coded (e.g. A4.1ISO for question 4.1 in the architects' questionnaire regarding ISO 14001 accreditation). Coding involved assigning a label to each question or variable and a number to each response category (e.g.1 for "yes" and 2 for "no"). Coding was followed by entering data into the SPSS data editor.

Once data input for both questionnaire responses was completed, a process of data 'cleansing' was undertaken to ensure that the data entry was correctly executed. As such, the following checks were carried out for both questionnaire surveys.

- *Double entry*: entering the data twice and verifying discrepancies against the original questionnaires data.
- *Frequency distribution*: running SPSS frequency distribution and scanning for errors in values based on the original questionnaires (for instance, if only five responses are possible, there should be no value "6").
- *Data listing*: printing out the values of all cases that have entered and verifying a random sample against the original questionnaires.

SPSS enabled the production of instantaneous probability checks that were used to identify whether any differences within results between any two categories were statistically significant. It also facilitated: the development of frequency distribution and statistic tables; and capturing the overall mean response levels. Cronbach's Alpha values were considered to investigate the relationship between the reliability coefficients of the respondents, whereby scale values between 0.5 and 1.0 were deemed reliable (Flick, 2007; Bryman, 2012).

The open-ended questions were tabulated manually and a frequency matrix was developed accordingly.

### 3.4.2 Semi-structured interviews

Both questionnaires' results gathered a considerable amount of information on: origins and causes of waste; waste management and minimisation responsibilities and practices; and barriers and incentives. However, questionnaire surveys are unlikely to gain a great depth of information due to lack of opportunities to clarify issues and probe respondents. Hence, questionnaires assist in generating overarching findings of the research issues rather than exploring issues in depth (Brace, 2013). Therefore, in-depth investigation was required to address Objective 6 (see Section 1.3 and the fourth research question (see Section 2.12) by investigating the root causes, origins and sources of design waste and establish relationships between onsite waste generation and the architectural design process. Therefore, a series of interviews were conducted with selected architects and contractors from the questionnaire respondents.

There are three fundamental types of research interviews: structured; semi-structured; and unstructured (Walliman, 2006; Stewart and Cash, 2006; Fellows and Liu, 2008; Fowler, 2014). Structured interviews are, essentially, verbally administered questionnaires, in which a list of predetermined questions is asked, with little or no variation and with no scope for follow-up questions to responses that warrant further elaboration. They only allow for limited participant responses and are, therefore, of little use if 'depth' is required. Conversely, unstructured interviews do not reflect any preconceived theories or ideas and are performed with little or no organisation. By and large, their use is generally only considered where virtually nothing is known about the subject area (or a different perspective of a known subject area is required), which is not the case for this research. Semi-structured interviews consist of several key questions that help to define the areas to be explored, but also allows the interviewer or interviewee to diverge in order to pursue an idea or response in more detail. The flexibility of this approach, particularly compared to structured interviews, was deemed suitable for this research as it allows for the elaboration of information or capture new insights into design waste aspects from the interviewees but may not have previously been thought of as pertinent by the researcher. Additionally, semi-structured interviews are commonly used in research to understand and interpret the relationships between variables (Berg and Lune, 2011), which is relevant to explore design waste variables. Therefore, follow up semi-structured interviews were selected to build upon the quantitative data from the questionnaire responses in order to identify the underlying causal relationships between the architectural design process and associated design waste generation.

#### 3.4.2.1 Interview design and development

The interview process used well-established semi-structured interview techniques to: minimise any interviewer bias; avoid prejudice stemming from either the interviewer or interviewee; and facilitate the interview through open and non-leading questions (Stewart and Cash, 2006; Kvale and Brinkmann, 2009). The follow up semi-structured interviews were designed to build upon the quantitative data from the questionnaire responses related to construction waste origins causes. The key ‘design waste’ related findings from the questionnaire results informed the design and content of the semi-structured interviews. Statistical questionnaire responses were interrogated at depth during the interviews to collect attitudinal and perceptual perspectives on design waste generators, supported by related probes from the from the questionnaire results. The interview questions supplemented and expanded on data gathered in Section 2 of the questionnaire (see Appendix 1). As such, detailed interview questions were developed to capture the underlying design related causes and sources and develop a complete design waste mapping process across each

RIBA Plan of work stages. As shown in Appendix 2.1, the interview template comprised 14 questions covering four sections:

- *Section 1: Background information* (four questions) summarised: the interviewee's work experience; current professional responsibilities; and gauged their views on waste minimisation importance in the construction industry.
- *Section 2: Waste minimisation* (four questions) aimed at: broadly identifying causes of building waste throughout projects' life cycle; and investigating architects' contribution to drive waste minimisation.
- *Section 3: Design waste mapping* (five questions) investigated design waste causes and sources across the RIBA Plan of Work stage (Table 2.1). For an effective capture of qualitative responses within the restricted timescale of interviews, the sequence of project stages of the RIBA Plan of Work 2007 Protocol combined interdepended stages. Therefore, the Protocol was streamlined in the interview schedule into five project stages:
    - Appraisal and Design Brief (Stages A and B);
    - Concept and Design Development (Stages C and D);
    - Technical Design and Production Information (Stages E and F);
    - Tender Documentation and Action (Stages G and H); and
    - Mobilisation and Construction (Stages J and K).
- *Section 4: Further comments* (1 question) consisted of an open-ended question to accommodate any additional information by the interviewees with regard to origins, causes and sources of construction waste generation in general and design waste generators in particular.

#### 3.4.2.2 Interview sampling frame

The interviewees were selected based on the questionnaire respondents' willingness to participate in a post-questionnaire qualitative data collection stage. Indeed, respondents were asked in section seven of both questionnaire surveys, whether they were interested in taking part in a follow-up interview (see Appendix 1.3 and Appendix 1.4). As such, 10 responding architects and 18 responding contractors showed an interest in participating in the interviews. In an attempt to increase the number of interviews, contacts were made with eight questionnaire responding architects who initially did not wish to partake in a post-questionnaire data collection stage to re-consider their potential participation. Of which, only two architects accepted to be part of the interview process. To have an equal number of interviewees from the two clusters, 24 interviews were conducted involving 12 partners and associates from architectural practices and 12 sustainability and environmental managers from contracting firms. The list pf participating interviewees is presented in Table 5.1.

#### 3.4.2.3 Interview pilot study

Prior to undertake the 24 interviews, a series of pilot interviews were carried out with four academic staff at the School of Civil and Building Engineering at Loughborough University. The piloting exercise helped to: refine the clarity of some questions; re-assess the allocated time for each interview section; practice different probing techniques; and test the digital voice recorder.

#### 3.4.2.4 Interview process

Contacts were made through telephone calls and emails with all 24 interviewees to arrange a date and time for the interviews. Subsequently, the interview schedule (Appendix 2.1) was sent to the targeted architects and contractors prior to the interview proceedings. Additionally, a copy of ethical checklist was also sent to each respondent.

Each interview was conducted on a one to one basis and lasted between 45 and 60 minutes. After granting the permission from the informants, the proceedings were recorded, using a high quality digital voice recorder, so that the interviewer could concentrate on interviewees' responses and associated probing techniques. The interviewer started each session by an introductory statement by asserting the aim of the interview, giving an overview of the structure and the content of the session and re-iterating that the information provided will be treated in confidence.

Semi-structured interviews allow the interviewer more freedom to probe a range of issues within the scope of the research and raise specific queries (Berg and Lune, 2011); yet, the interview process will remain focussed on a set of questions derived from the interview protocol (Creswell, 2014). The effectiveness of the interview technique is largely determined by the nature and quality of follow-up questions. Hence, an integrated prompt and probe approach was adopted in all interviews to get the interviewees to give more information or shade new light about particular topics and issues. As shown in Appendix 2.2, the discussion in all 24 interviews was stimulated by literature review and questionnaire data analysis probes. For example, the probe in question 2.4 was: “how far would you agree with some authors in the literature who argue that by and large clients are not informed about waste minimisation benefits at the start of the briefing stage?.

Additionally, probes help motivate informants, facilitate the flow of an interview and elicit information. As such, the interview proceedings included a range of probing techniques related to interviewees’ responses and statements. These included: detailed-oriented probes (e.g. who else was involved in the preparation of the waste minimisation strategy?); elaboration probes (e.g. could you please elaborate further on reasons for such practice?); and clarification probes (e.g. you said the design was complex, what did it entail?).

#### 3.4.2.5 Interview data analysis

All 24 digital recordings of interviews were saved in a laptop then transcribed to capture the full extent of the interviewees’ responses. Due to the open-ended nature of interview questions, the narrative quality of transcripts was of an unstructured nature consisting of long paragraphs, in different sections with abbreviations and colloquial commentary in places. Thus, each transcript was read twice to obtain a general sense of the qualitative information.

Computer Assisted Qualitative Data Analysis Software (CAQDAS) software packages, such as NVivo, were designed for qualitative researchers working with very rich text-based data. They assist researchers in the analysis of non-numerical or unstructured qualitative data. They are used for classifying, sorting and arranging information and identifying themes (Silverman, 2010). NVivo is widely used in the analysis of qualitative data, including interviews and focus group discussions, as they support data formats such as: audio files; videos; digital photos; Word, PDF; spreadsheets; rich text; plain text; and web and social media data (Bazeley and Jackson, 2013). Therefore, NVivo, which was used in this research for the analysis of the interviews, enabled the ingestion of interviewees' digital data with the textual transcripts and established coding of the textual data. It was instrumental in: classifying, sorting and arranging interviewees' responses; examining relationships in the gathered data across the RIBA Plan of Work stages; cross-examining information in a multitude of ways by using NVivo search engine and query functions; and combining analysis between architects and contractors' responses for each interview question.

The process of coding in NVivo helped with the identification of patterns in the transcripts. NVivo queries were used to automatically code the sources based on the words or phrases. As such, 'Word Frequency' query was run to code the words that occurred most often. For example, 'waste cause' and 'waste minimisation responsibility' appeared frequently and its occurrences were saved in respective 'nodes'. Relationship nodes to record the link between onsite waste generation and design waste were created. Furthermore, NVivo coding helped run a 'Text Search' query on a specific word or phrase and automatically code the text that was found. For example, all 'design change' occurrences were highlighted and coded. Subsequently, a 'Coding Comparison' query was run to determine the percentage of agreement and disagreement between coded responses of the interviewees. The process allowed the display of the interview results of design waste causes and sources across the RIBA Plan of Work stages into summary tables, as presented and discussed in Chapter 5.

## 3.5 Designing out Waste (DoW) Framework development and industry review

### 3.5.1 Designing out Waste (DoW) Framework development

This section presents an overview of the methodological approach used for the development of the Designing out Waste (DoW) Framework. Insights into the synergies between the research findings and the DoW Framework design and development are provided in Chapter 6.

Process modelling and mapping tools have been used as enabling improvement opportunities for economic benefits through resource minimisation (Rybicka *et al.*, 2015). Within the context of waste management, Burmeister (2010) used process modelling techniques to identify waste that has high potential for reuse and recycling. Furthermore, process modelling tools serve to generate information to better understand waste production and its recovery routes. As such, Smith and Ball (2012) reported that these provide two benefits: preventive activities through waste minimisation options; and informing activities through understanding the volumes and characteristics of waste in order to enable high reuse and recycling yields.

Among the widely used modelling tools is the IDEF0 functional modelling method, which was designed to map decisions, actions and activities of an organisation, system or process (Grover and Kettinger, 1998). It is a well-tested and used process mapping tool by government and industry worldwide to show data, functional flows and system control of lifecycle processes (Karhu *et al.,* 1997). IDEF0 may be used to define the requirements and specify the functions, and then to design an implementation strategy that meets the requirements and performs the functions. It is a technique for performing and managing requirements, functional analysis, system design, maintenance and baseline for continuous improvement (Smith and Ball (2012). IDEFO models provide a map of functions and their interfaces that require capturing in order to make decisions interpretable and achievable (Karhu *et al.*, 1997).The structural concept of DoW Framework and content and layout of its three Levels were based on the principles of IDEF0, which are based on top-down, hierarchical method of analysing activities. As such, applying the IDEF0 method in the Framework design resulted in an organised and hierarchical representation of

DoW activities and decision making actions across the RIBA Plan of Work stages, as explained and illustrated in Chapter 6.

A pivotal source of reference to IDEF0 method is the manual published by Ross *et al.* (1980), in which they provide detailed descriptions of its concepts, functional analysis and procedures and supported by examples. An IDEF0 model is composed of a hierarchy of interrelated diagrams, represented by basic boxes and arrow graphics. As shown in Figure 3.1, each box represents an 'activity' which is a single action, process or sub-process described by an active verb. Arrows represent the relationships between activities and are positioned by the side of the activity box which they touch. There are four types of arrows.

- *Input arrows* indicate required elements to be processed by the 'activity'.
- *Control arrows* regulate, constrain and direct the 'activity'.
- *Mechanism arrows* are physical (human or material) means to execute the 'activity'.
- *Output arrows* represent resulting elements produced or modified by the 'activity'.

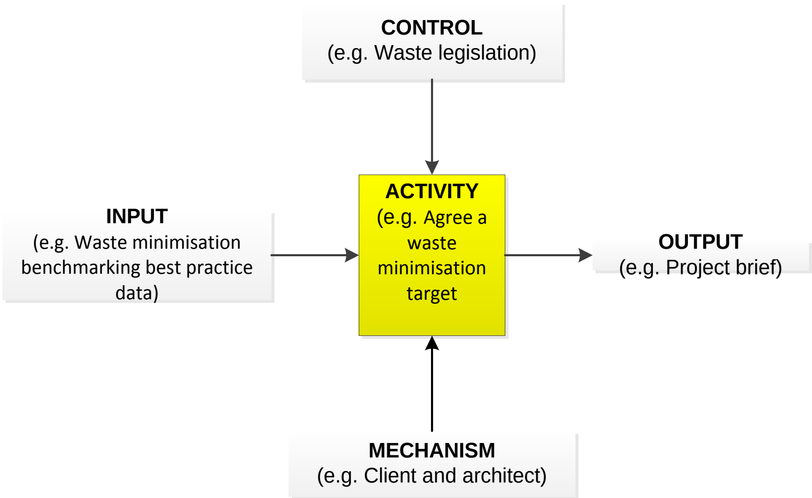



**Figure 3.1: Example IDEF0 Activity box from the developed DoW Framework**

The IDEF0 diagrams allow a hierarchical decomposition of modelled processes and activities into its component functions, as illustrated in Figure 3.2. The IDEF0 decomposition process was applied in the design of the three Levels of the DoW Framework as follows.

- Level 0: the top-level 'Context' diagram, showing high level waste minimisation strategic actions throughout the six key project life cycle stages (Stage 1: Briefing; Stage 2: Concept Design; Stage 3: Design Development; Stage 4: Technical Design; Stage 4: Tender and Stage 6: Onsite operations).
- Level 1: a decomposition 'Parent' diagram, consisting of a breakdown of each Level 0 waste minimisation strategic action into associated Level 1 DoW processes and actions. Level 1 includes a DoW decision making milestone at the end of each project life cycle stage.
- Level 2: Six decomposition 'Child' diagrams, comprising a breakdown of each Level 1 DoW 'activity' into respective Level 2 sub-processes, actions and decisions.

Level 0, 1 and 2 diagrams were produced using Microsoft Office Visio 2007, which is designed to aid visualisation, exploration and communication of complex information, systems and processes.

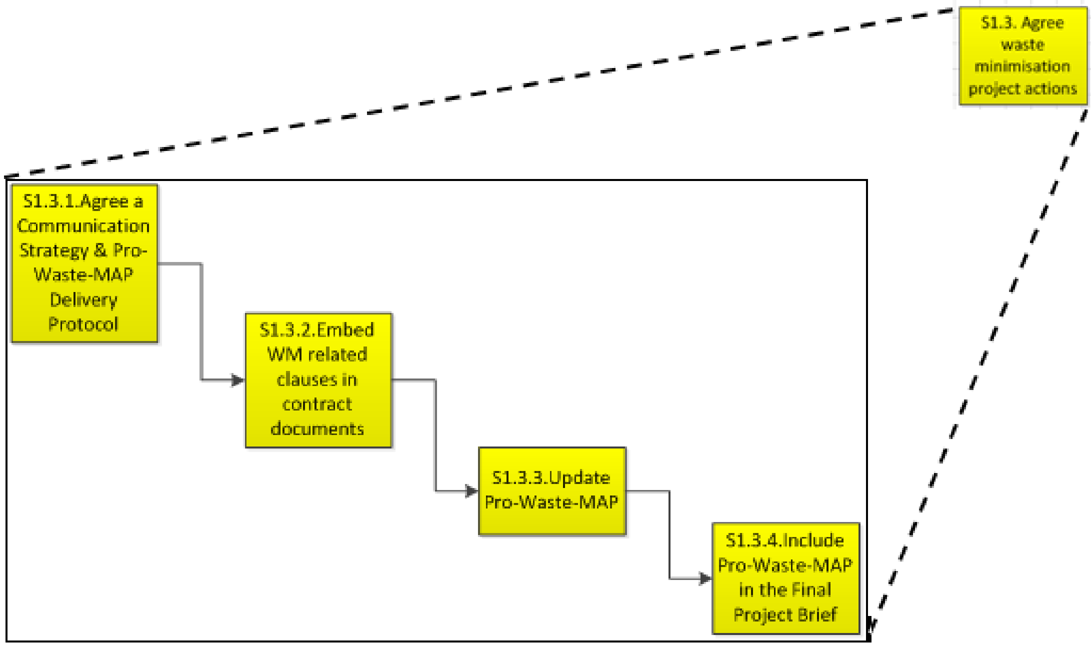



**Figure 3.2: Example of IDEF0 decomposition from the developed DoW Framework**

A detailed discussion and illustration of DoW Framework development, including: purpose; structure; 'Levels'; contents; and flow charts are provided in Chapter 6.

### 3.5.2 Designing out Waste (DoW) Framework industry review

#### 3.5.2.1 DoW Framework industry review method

The DoW Framework industry review method consisted of the following three stages.

- Stage 1: An industry review questionnaire (Appendix 3.1) was devised and sent to 15 members of RIBA Practice Committee and 13 members of the RIBA Sustainable Futures Group. The questionnaire was used to capture architects' views and feedback on the proposed DoW Framework in terms of the clarity of its overall structure, content and process information flow; as well as the appropriateness of the proposed DoW actions and decisions in each of the three Framework Levels. As shown in Appendix 3.1, the questionnaire comprised five sections: respondent's background information; three sections to assess the clarity of the structure, content and flow of the Framework's Levels 0, 1 and 2 respectively; and a final section on further comments.

- Stage 2: A follow-up focus group was carried out with eight industry review questionnaire respondents to: gather qualitative data on participants' suggestions on DoW Framework improvement; and discuss its potential practical implementation and impact. The industry review focus group started by a short presentation, which was delivered by the author on: the research context; key findings to date; and the focus group agenda. This was followed by three activities: Framework improvement suggestions; its appropriateness and adaptability; and its potential impact assessment on continuous construction waste minimisation improvement. An A1 flipchart (Appendix 3.2) was produced to guide and record participants' responses. For each activity, delegates were given 15 minutes to individually write down their comments on post-it notes (one comment per post-it note), followed by a 20 minutes group discussion to: collectively agree overlaps; discard duplicates; add further comments; and organise and cluster comments. Finally, a brief plenary session was led by the author to thank the delegates for their participation and give them a final opportunity as a group to reflect upon the issues raised.

- Stage 3: A pre-industry review pilot study was conducted with five construction management academics at the School of Civil Engineering at Loughborough University. The aim of the pilot study was to review and refine the structure, clarity and information of the industry review questionnaire and activities of the follow-up focus group. Minor revisions were made to improve the clarity and quality of both industry review instruments.

The DoW Framework was finalised based on the industry review participants' feedback and recommendations for improvement, which are presented in Chapter 6.

#### 3.5.2.2 DoW Framework industry review sample size

The sampling frame of the industry review questionnaire survey and the follow-up focus group was confined to members of the RIBA Practice Committee (15 architects) and the RIBA Sustainable Futures Group (13 architects). The role of the former committee is to develop and disseminate tools for an effective architectural design practice. The remit of the RIBA Sustainable Futures Group is to maximise the profession's contribution to more sustainable development and work with the Practice Committee on the development of professional standards to ensure issues of sustainability are appropriately integrated in the architectural design process. Since the Framework was developed to embed waste minimisation strategies during design stages (Objective 7), the sample frame of the industry review process was confined to architects. Additionally, the industry review was a testing exercise to assess the potential implementation of the DoW Framework during the architectural design process in line with the RIBA Plan of Work, which was developed specifically for architects as the targeted users. Therefore, contractors, who provided insightful information on construction waste during the data collection stages based on their onsite waste management experiences, were not engaged in the industry review process of the DoW Framework.

#### 3.5.2.3 Designing out Waste (DoW) Framework industry review data analysis

The DoW Framework industry review questionnaire employed the same data analysis method as the primary data collection survey, which is discussed above in Section 3.5.1.6. As such, the Statistical Package for Social Science (SPSS) software was employed in this research to analyse the industry review questionnaire data.

The qualitative data emanating from the industry review focus group was analysed using manual content analysis as the amount of textual data was deemed manageable without the support of a software application. The content analysis facilitates the translation of the collected qualitative data into forms of explanation, understanding or interpretation of the views of participants and situations under investigation (Bryne, 2001). The analysis process typically involves identifying, coding and categorising patterns found within the data (Lincoln and Guba, 1985). As such, the employed manual content analysis enabled the narrative focus group data to be divided into meaningful information units for each of the three focus group activities.

## 3.6 Summary

This chapter has described the methodological approach of the research. It gave a detailed account of the adopted research methodology that included: philosophical stance; research strategy; research design; data collection methods; and data analysis process and techniques. The research has adopted a combined qualitative and quantitative research strategy. A two stage, sequential mixed methods study has been identified as appropriate to address the key research objectives. Findings from the literature review, questionnaire and follow-up interviews, were used for the design and development of the DoW Framework. A questionnaire and a follow-up focus group were employed for the DoW Framework industry review. The results of the questionnaire surveys and follow up interviews are presented in Chapter 4 and 5 respectively; while Chapter 6 examines the DoW Framework design procedure and industry review process.

# CHAPTER 4

# QUESTIONNAIRE RESULTS

## 4.1 Introduction

This chapter addresses Objective 4 (identify and evaluate current onsite waste management responsibilities and practices); and Objective 5 (determine the extent of the integration of waste minimisation strategies into the current architectural design practice). Having identified the key themes from the literature on construction waste minimisation approaches and practices (see Chapter 2), two questionnaire surveys were employed to establish a general industry-wide perspective on construction waste causes; examine waste management responsibilities at project level; and capture respondents' views on design waste reduction and onsite waste management practices and associated challenges. The sampling frame was confined to the top 100 architectural practices and contracting firms in the UK. Both questionnaires were divided into seven sections (Appendix 1.3 and Appendix 1.4).

This chapter presents the results of both questionnaire surveys. It contains the following sections: background information; waste management and minimisation responsibilities at project level; construction waste causes; design waste minimisation practices (architects' perspectives); onsite waste management practices (contractors' perspectives); waste minimisation barriers; waste minimisation incentives; and further comments. The chapter concludes with a discussion on questionnaire limitations.

## 4.2 Questionnaire results and analysis

Of the 100 architectural practices and 100 contracting companies 40 and 49 completed questionnaires were received respectively. The overall cumulative response rate was therefore 44.5%. As noted in Chapter 3, this particularly high response rate may have been attributable in part to the researcher identifying specific individuals within each company to receive the questionnaire and then following up with regular telephone calls and email reminders in an effort to optimise the response rate. The respondents' responses are examined in the sections below.

### 4.2.1 Background Information

Table 4.1 shows the position held by respondents within the surveyed architectural practices and contracting companies. All responding architects hold senior management positions as ‘partners’ or ‘associates’ who are responsible for decision making process over the wider context of strategic, design and communication matters within their practices. Similarly, sustainability and environmental managers, within contracting companies, are involved with upstream corporate sustainable strategies and downstream onsite waste management practices, in addition they ensure that company projects comply with EU and UK waste legislation. Therefore, the questionnaire respondents were adequately suited to provide comprehensive insights into construction waste minimisation practices within their companies.

**Table 4.1: Positions of questionnaire respondents**

| Position | Frequency | Percentage (%) |
|---|---|---|
| **Responding architects** | | |
| Managing Director/Partner | 27 | 67.5 |
| Associate/Technical Director | 13 | 32.5 |
| **Total** | **40** | **100** |
| **Responding contractors** | | |
| Sustainability/Environmental Manager | 39 | 80 |
| Health and Safety Manager | 6 | 12 |
| Compliance Manager | 4 | 8 |
| **Total** | **49** | **100** |

Table 4.2 shows the size of both responding groups. In terms of the number of employees: 65% of the surveyed architectural firms employ more than 100 staff; while more than 65% of contracting companies have in excess of 500 employees.

**Table 4.2: Number of employees within responding companies**

| Number of employees | Responding architects | | Responding contractors | |
|---|---|---|---|---|
| | Frequency | Percentage (%) | Frequency | Percentage (%) |
| 10-49 | 1 | 2.5 | 0.0 | 0.0 |
| 50-99 | 9 | 22.5 | 0.0 | 0.0 |
| 100-499 | 19 | 47.5 | 14 | 28.6 |
| 500-999 | 5 | 12.5 | 13 | 26.5 |
| 1000-4999 | 2 | 5.0 | 14 | 28.6 |
| More than 5000 | 0 | 0.0 | 5 | 10.2 |
| No answer | 4 | 10.0 | 3 | 6.1 |
| **Total** | **40** | **100** | **49** | **100** |

Table 4.3, which summarises the annual turnover of the surveyed organisations, shows that: 65% of the architectural practices have an annual turnover of more than five million pounds; while more than 75% of contracting companies' turnover is in excess of £100 million, out of which, 33% is over £500 million. Hence, the responding architectural and contracting companies have adequate human and financial resources to potentially facilitate the planning, enforcement and implementation waste minimisation strategies in their projects. As such, questionnaire responses were based on informed construction waste related strategic and logistical realities.

**Table 4.3: Annual turnover of responding companies (£ million)**

| Annual Turnover (Million pounds) | Responding architects | | Responding contractors | |
|---|---|---|---|---|
| | Frequency | Percentage | Frequency | Percentage |
| Less than 1 | 1 | 2.5 | 0 | 0.0 |
| 1-4.99 | 7 | 17.5 | 0 | 0.0 |
| 5-9.99 | 14 | 35.0 | 0 | 0.0 |
| 10-19.99 | 7 | 17.5 | 0 | 0.0 |
| 20-49.99 | 1 | 2.5 | 5 | 10.2 |
| 50-99.99 | 1 | 2.5 | 6 | 12.2 |
| 100-499.99 | 3 | 7.5 | 21 | 42.9 |
| Over 500 | 0 | 0.0 | 16 | 32.7 |
| No answer | 6 | 15.0 | 1 | 2.0 |
| **Total** | **40** | **100** | **49** | **100** |

#### 4.2.1.1 Environmental policies and waste management tools

All respondents were asked about their companies' position as regards to sustainability policy and ISO 14001 accreditation status. Furthermore, contractors were asked about their companies' stance on waste management policy and onsite waste auditing tools. Results are shown in Table 4.4, which indicates that 82% and 91% of responding architects and contractors respectively have a sustainability policy in place. However, just 18% of architects held ISO 14001certification compared with 47% of contractors. That said; there is clear evidence that responding architects and contractors are in the process of seeking accreditation (25% and 20% respectively).

Of the 49 responding contractors: 82% have a waste management policy in place; over 67% developed an in-house waste management plan for each project they conducted; and 55% used SMARTWaste tool to audit and monitor onsite waste in their projects. Furthermore, 40% of SMARTWaste users, who added further comments, claimed they implement a consistent approach to their waste management through self-assessment methods by using weekly checklists and audits based on the SMARTWaste data. The impact of environmental policies and waste management tools on architects' waste minimisation practices is discussed in Section 4.2.4.1.

**Table 4.4: Environmental policies and waste management tools**

| Environmental Policy/tool | Architects' responses (%) | | | Contractors' responses (%) | | |
|---|---|---|---|---|---|---|
| | Yes | No | In the process | Yes | No | In the process |
| Sustainability policy | 82 | 13 | 5 | 91 | 3 | 6 |
| ISO14001 | 17.5 | 57.5 | 25 | 46.9 | 32.8 | 20.3 |
| Waste management Policy | N/A | N/A | N/A | 81.6 | 9.8 | 8.6 |
| In-house waste management plan | N/A | N/A | N/A | 67.3 | 12.5 | 20.2 |
| SMARTWaste | N/A | N/A | N/A | 54.8 | 40.1 | 5.1 |

#### 4.2.1.2 Sources of information on waste management

Respondents were asked about their sources of information on waste management. Results in Figure 4.1 suggest that the majority of respondents from both target groups seem to adopt a self-study approach to education. Indeed, around 60% of both respondents equally use published articles; and over 47% of architects and 69% of contractors revert to professional bodies to enhance their waste management knowledge. Results also suggest that contracting companies are being more proactive in organising waste management related training than architectural practices. The impact of sources of information on current design waste minimisation practices is discussed in Section 4.2.4.1.

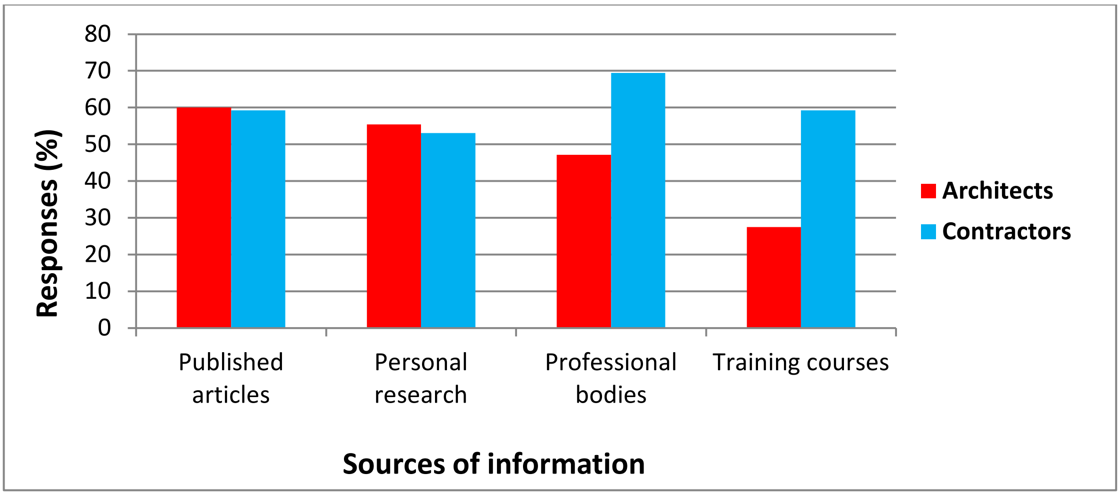



**Figure 4.1: Sources of information on waste management**

### 4.2.2 Waste management and minimisation responsibilities at project level

Respondents were asked about their companies' waste management responsibilities in construction projects. Responses have been presented in Figure 4.2, which shows that few architects' attempts were made in terms of waste minimisation planning, guidance and implementation. Indeed, 30% of responding architects acknowledged that they never assumed any waste minimisation responsibilities in their projects; 85% did not conduct waste forecasts in their designs; and only 2% stated that they organised waste management meetings.

Conversely, contractors seem to take a leading role on onsite waste management responsibilities, with over 73% adopting waste management goal setting and around 82% issuing guidelines for onsite waste segregation. Additionally, over 55% of contactors reported that they equally undertake waste forecasts and issue guidelines for onsite segregation. Responding architects' comments confirmed that they do not have direct involvement with onsite waste management, other than in health and safety plan statements.

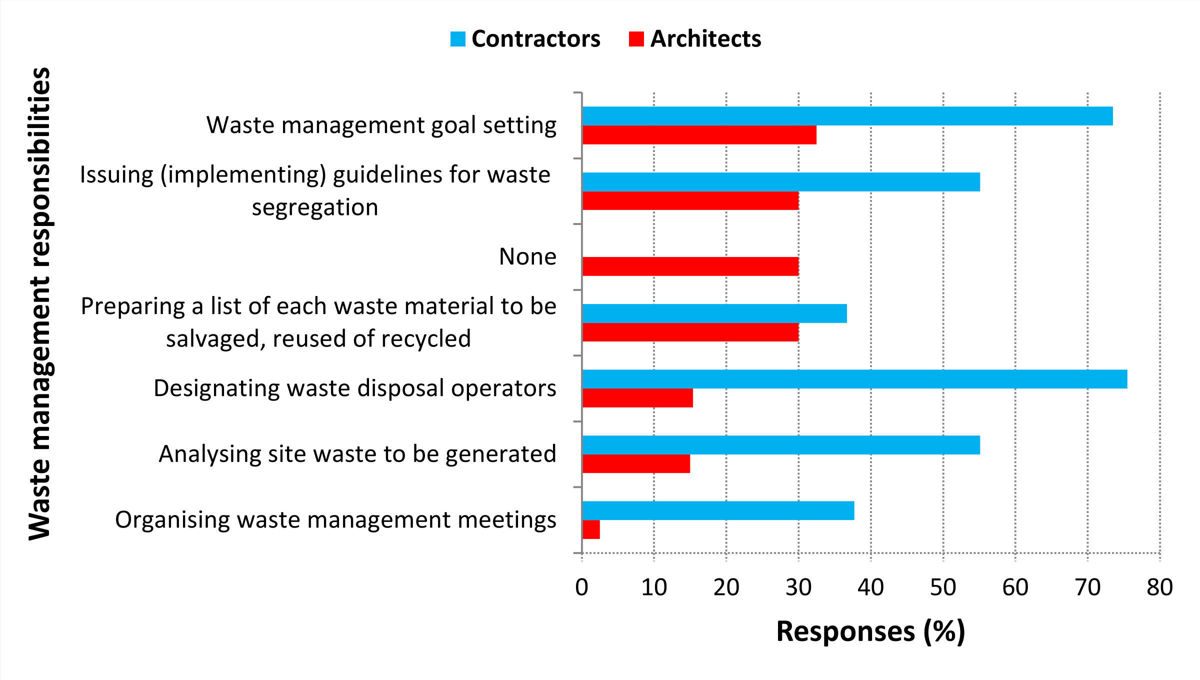



**Figure 4.2: Waste management responsibilities**

Respondents were subsequently asked to list additional waste management responsibilities, which are part of their current practice. Responding architects, who completed this section, concurred that waste management responsibility in their projects lies with the contactor and they often have little or no power over onsite activities. However, they acknowledged that waste minimisation responsibilities vary strongly with the type of procurement route and tend to depend on the client brief and the extent to which contracts are managed. Conversely, contractors' qualitative comments indicated that more efforts are being made to improve and enhance their existing waste management responsibilities. Some contractors went further by stating that training and completion of waste management plans for all sites are being implemented that comprise: a waste management steering committee in place; monitoring and auditing waste streams; implementation of a programme of training and awareness; and optimisation of waste reuse and recycling opportunities.

At the end of the questionnaire section on 'waste management responsibilities', respondents were invited to add any other comments they wish to make on the topic. Although architects' comments reiterated their perception that waste management is the sole responsibility of the main contractor, there was a consensus among them that waste is a significant problem in the construction industry. Contrary to expectations, a responding architect asserted that architects' responsibilities should be more pronounced since "*waste is ultimately a by-product of 'bad' design*". Another architect argued that "*amounts of wasted materials and components, site planning and responsibilities need to be reviewed and improved*". However, they all agreed that Design and Build contracts do not allow architects to play an independent role in this matter.

Most contractors' qualitative comments concurred that waste can only effectively be managed if it is addressed at design stages and a budget is provided. Additionally, they pointed out that contract clauses and a clear idea about responsibilities to control and monitor waste management will result in less onsite waste. Furthermore, some contractors raised concerns over onsite waste generated by subcontractors' own materials and products.

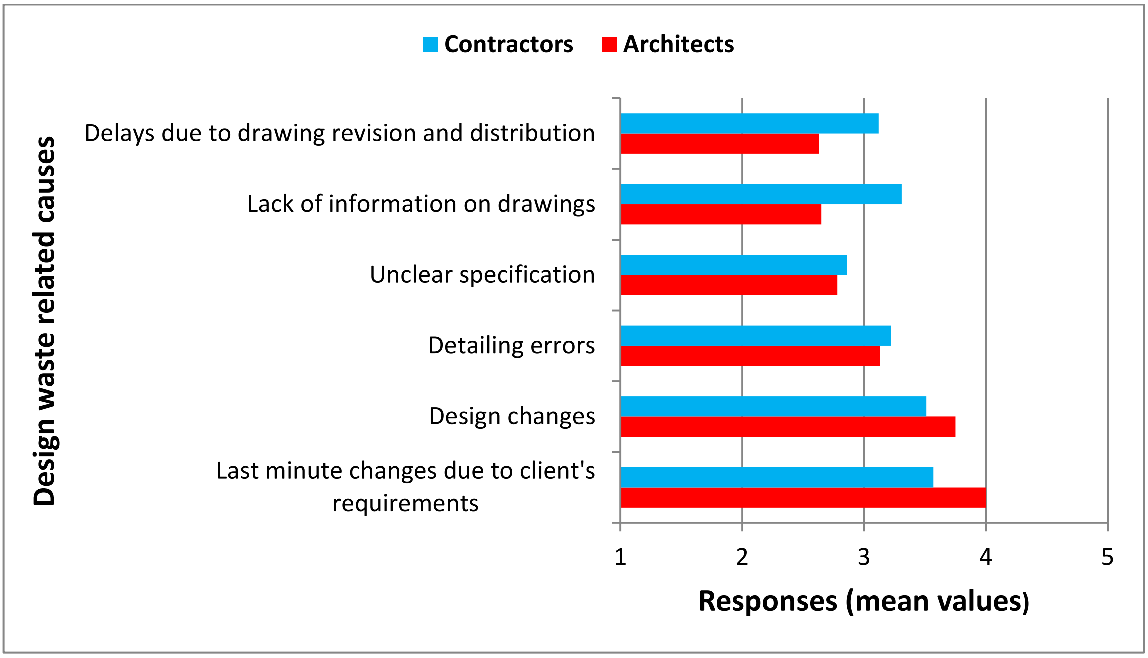
### 4.2.3 Construction waste causes

The questionnaire gave each respondent an opportunity to rate six design-related waste causes and six onsite-related waste causes, which are widely established in the literature, on a scale from 1 (not a waste cause) to 5 (major waste cause). The findings are shown in Figures 4.3 and 4.4.

#### 4.2.3.1 Design waste related causes

As shown in Figure 4.3, results indicate that 'last minute changes due to client's requirements' was ranked equally by responding architects (4.00) and contactors (3.57) as the most significant design waste related cause. Additionally, more than 70% of architects ranked 'design changes' as the second highest attribute that had most significant impact on construction waste generation; while it was considered to be a major waste cause by only 41% by contractors. Conversely, 47% of contractors and only 25% of architects were of the opinion that 'lack of information on drawings' is a major cause of design waste. While there was a consensus regarding the rating of 'detailing errors', 43% of contactors and only 18% of architects believed that 'delays due to drawing revision and distribution' is a key design waste cause. Finally, 'unclear specification' was deemed a minor design waste generator by both architects and contractors (23% and 21% respectively).

Based on their experience, respondents were asked to list other design waste related causes. There was a common agreement among architects that 'not designing to minimise waste in mind' and 'not designing for standardisation and to unit sizes' are major contributors to design waste. Additionally, they identified other design waste determinants, namely: no project stakeholders' consultation process; late input from consultants; no contractor on board during the initial design process; undefined waste management responsibilities; architects' limited involvement in Design and Build contracts; and time pressure. On the other hand, contractors concurred that 'poor design'; 'inadequate design brief'; and 'not working to standard dimensions' are the main underlying causes of design-related waste. They also identified other design waste generators such as: poor take offs; specification-drawings variances; and unsuitable specification.



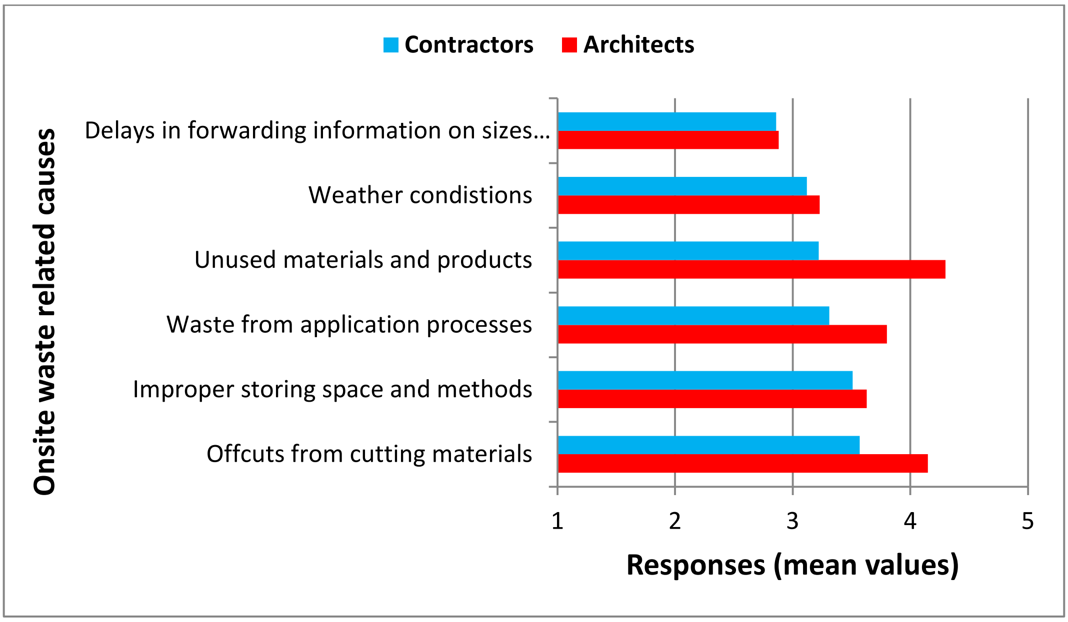

1. No waste generation; 2: insignificant; 3: minor; 4: significant; 5: major waste generation.

**Figure 4.3: Design-related waste causes**

### 4.2.3.2 Onsite waste related causes

Both architects and contractors agreed that: 'off-cuts from cutting materials'; 'unused materials and products'; 'improper storing space and methods'; and 'waste from application processes' were the major onsite waste sources. In terms of weighting, architects rated 'unused materials and products' as the most severe waste causes (4.30); whereas contractors reported that 'off-cuts from cutting materials' and 'unused materials and products' are equally the major onsite waste generators, with mean values of 3.57 and 3.51 respectively (Figure 4.4).

Based on their experience, respondents were asked to list other causes of waste during site operations. The manually tabulated results indicate that architects consider: 'lack of forward planning by the contractor'; 'design changes by the contractor'; and 'specification and details not being followed' as being major causes of waste during site operations. They also argued that: poor ordering regimes; errors during ordering; poor site coordination; inadequate reading of design information by the contractor; inferior workmanship leading to material damage; lack of onsite waste reuse/recycling; and poor site personnel training have significant impacts on construction waste generation.




1: No waste generation; 2: insignificant; 3: minor; 4: significant; 5: major waste generation.

**Figure 4.4: Onsite waste related causes**

Similarly, contractors recognised that: 'poor onsite waste management'; 'over-ordering'; 'untrained and unskilled labour'; and 'rejected work and unused materials' are major onsite waste causes. Additionally, they listed other significant waste causes during site operations, such as: inappropriate site location and logistics; poor work package programming; poor waste management by sub-contractors; client changes; material damage; and intricate buildability.

#### 4.2.3.3 Design waste generation across the RIBA Plan of Work stages

Architects were asked to rate potential design waste production in each RIBA Plan of Work (PoW) stage using a five-point Likert scale; where 1 indicates 'no waste' and 5 indicates 'major waste'.

As shown in Table 4.5, around 88% of responding architects opined that significant to major waste generation occurs during site operations (PoW 2007 Stage K; PoW 2013 Stage 5). They claimed that insignificant waste is generated during Concept Design (PoW 2007 Stage C; PoW 2013 Stage 2); and minor waste is produced during Design Development (PoW 2007 Stages; PoW 2013 Stage 3); and Technical Design (PoW 2007 Stages E; PoW 2013 Stage 4).). The mapping of RIBA PoW 2007 stages onto PoW 2013 is shown in Figure 2.4 and explained in Section 2.10.

**Table 4.5: Design waste generation during the RIBA Plan of Work stages**

| RIBA Plan of Work Stages | Architects' responses | | | | | |
|---|---|---|---|---|---|---|
| | Percentage | | | | | Mean Rating |
| | 1 | 2 | 3 | 4 | 5 | |
| Stage A (Appraisal) | 45.0 | 25.0 | 12.5 | 12.5 | 5.0 | **2.08** |
| Stage B (Design Brief) | 30.0 | 20.0 | 22.5 | 17.5 | 10.0 | **2.58** |
| Stage C (Concept Design) | 22.5 | 25.0 | 25.0 | 25.0 | 2.5 | **2.60** |
| Stage D (Design Development) | 15.0 | 12.5 | 37.5 | 30.0 | 5.0 | **2.98** |
| Stage E (Technical Design) | 15.0 | 7.5 | 47.5 | 22.5 | 7.5 | **3.00** |
| Stage F (Production Information) | 7.5 | 17.5 | 35.0 | 35.0 | 5.0 | **3.13** |
| Stage G (Tender Documentation) | 15.0 | 22.5 | 30.0 | 27.5 | 5.0 | **2.85** |
| Stage H (Tender Action) | 30.0 | 10.0 | 27.5 | 27.5 | 5.0 | **2.68** |
| Stage J (Mobilisation) | 22.5 | 17.5 | 32.5 | 17.5 | 10.0 | **2.75** |
| Stage K (Construction to Practical Completion) | 2.5 | 5.0 | 5.0 | 30.0 | 57.5 | **4.35** |

1: No waste generation; 2: insignificant; 3: minor; 4: significant; 5: major waste generation.

The manually tabulated architects' responses regarding causes of design waste revealed that the major concern of architects lies in the lack of understanding of what creates design waste. They, however, acknowledged that poor decision making during early design stages can have major implications on onsite waste production, as one respondent stated: ''poor design is a principal driver of waste''. Another architect went further by stating that ''fundamentally flawed designs at appraisal stage may generate more indirect waste than design stages''. Finally, responding architects were invited to add any other comments they wish to make regarding design waste causes across the RIBA Plan of Work stages. Architects' comments were as follows.

- "Waste minimisation should start at briefing stages".
- "Good design at the very earliest stage and efficient construction and operation at later stage".
- "Buildings are often not designed to suit size modules, despite recent publicity about this".

### 4.2.4 Design waste minimisation practices (architects' perspectives)

#### 4.2.4.1 Waste minimisation design strategies

Responding architects were asked to rate from 1 (never used) to 5 (used in all projects) the extent to which design waste strategies are being implemented in their projects. Table 4.6 shows that very few attempts were made to design in waste reduction strategies. Indeed, none of the respondents conducted 'waste estimation feasibility studies' as a matter of course in all their projects and only about 2% designed for deconstruction as a common practice. However, more than a third of the surveyed architects claimed that they used, whenever possible, standard dimensions and prefabricated units to avoid onsite materials cutting. Contrary to the other questionnaire sections, it is interesting to note that all surveyed architects did not add qualitative comments, when asked to list other used waste minimisation design strategies in their projects.

**Table 4.6: Extent of implementation of waste minimisation design strategies**

| Waste minimisation design strategies | Architects' responses | | | | | | |
|---|---|---|---|---|---|---|---|
| | Percentage (%) | | | | | Mean Rating | Ranking |
| | 1 | 2 | 3 | 4 | 5 | | |
| Use of standard dimensions and units | 5.0 | 20.0 | 27.5 | 32.5 | 15.0 | **3.33** | **1** |
| Use of standard materials to avoid cutting | 5.0 | 15.0 | 40.0 | 35.0 | 5.0 | **3.20** | **2** |
| Use of prefabricated units | 2.5 | 20.0 | 42.5 | 27.5 | 7.5 | **3.18** | **3** |
| Avoidance of late variations in design | 15.0 | 12.5 | 27.5 | 37.5 | 7.5 | **3.10** | **4** |
| Specifying reused and recycled materials | 5.0 | 32.5 | 35.0 | 27.5 | 0.0 | **2.85** | **5** |
| Guidance for hazardous waste management | 18.5 | 30.5 | 21.0 | 20.0 | 10.0 | **2.83** | **6** |
| Designing for deconstruction | 30.0 | 32.5 | 27.5 | 7.5 | 2.5 | **2.20** | **7** |
| Feasibility study of waste estimation | 45.0 | 25.0 | 22.5 | 7.5 | 0.0 | **1.93** | **8** |

1: never used; 2: rarely used; 3: used in some projects; 4: used in most projects; 5: used in all project

Figure 4.5 represents the results of SPSS correlation between architects' responses regarding design waste minimisation used in their projects (Table 4.6) and ISO 14001 certified architectural firms (Table 4.4). ISO 14001 certification acts as a process of achieving continuous environmental improvement, including waste reduction. Contrary to expectations, the results shown that there was no clear relationship between architectural practices having ISO 14001certification and implementing actual waste minimisation activities. For example, none of ISO 14001 accredited firms undertake waste generation forecasts and only 5% frequently implement designing for deconstruction.

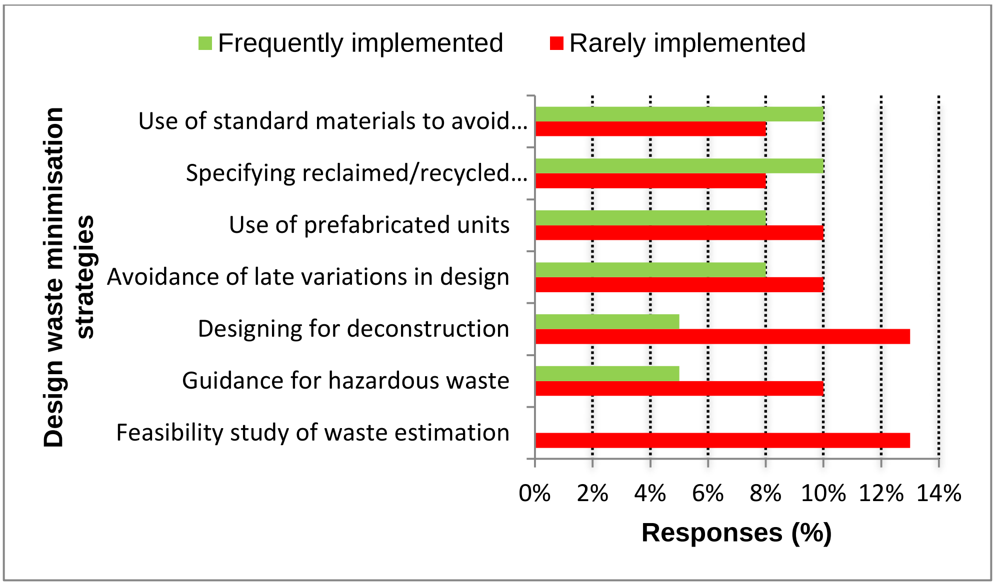



**Figure 4.5: ISO 14001 certification versus design waste minimisation practice**

Statistical test was also performed to identify the impact of architectural practices' waste related training on the implementation of waste estimation practice during design stages, the results are shown in Figure 4.6. By and large, responding architects who attended waste reduction training do slightly better as they tend to assess waste generation in their projects. That said, the extent of their endeavours seem limited and inconsistent as none of them and only 10% undertook waste estimation in some projects. Conversely, responding architects who were not provided with training, never or hardly conduct a feasibility study of waste estimation in their projects.

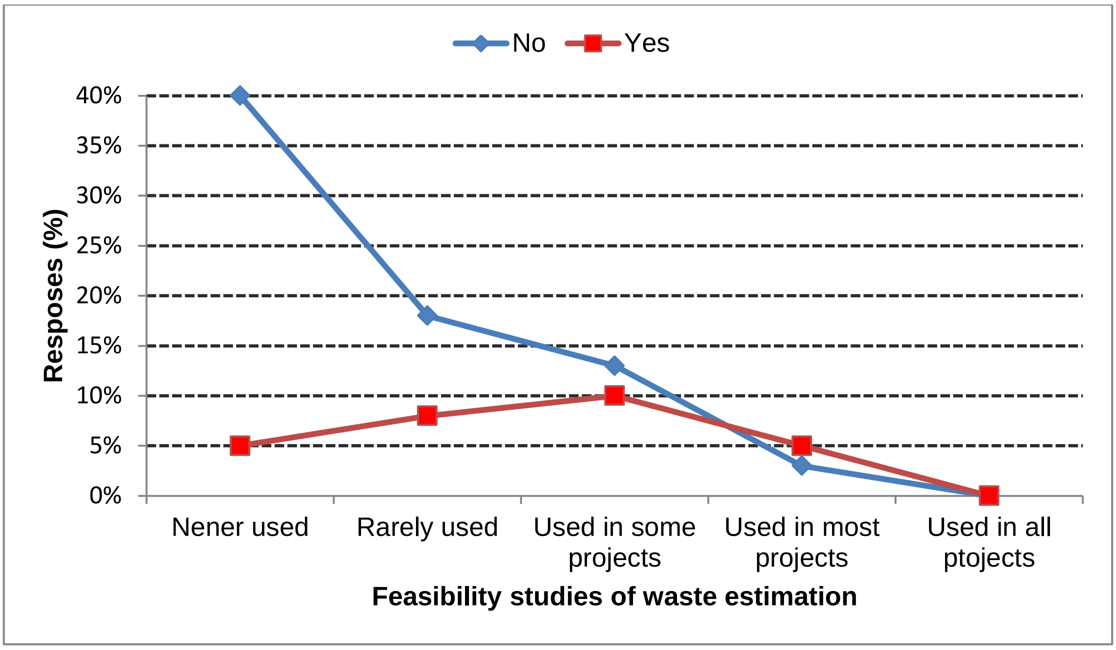



**Figure 4.6: Impact of waste related training on the implementation of waste estimation practice**

#### 4.2.4.2 Waste minimisation implementation across the RIBA Plan of Work stages

Architects were also asked to rate the extents to which design waste strategies are being implemented in each RIBA Plan of Work stage, using a five-point Likert scale: 1 (never used) and 5 (used in all projects). Results, which are summarised in Table 4.7, indicate that more than 82% of architects never, rarely or sometimes applied waste reduction strategies during Appraisal; Design Brief; and Concept Design stages. Additionally; only 8% reported that waste reduction measures were implemented in all projects during Technical Design and Production Information.

**Table 4.7: Extent of implementation of waste minimisation strategies across the RIBA Plan of Work stages**

| Waste minimisation design strategies | Architects' responses | | | | | |
|---|---|---|---|---|---|---|
| | Percentage | | | | | Mean Rating |
| | 1 | 2 | 3 | 4 | 5 | |
| Stage A (Appraisal) | 35.0 | 35.0 | 17.5 | 7.5 | 5.0 | **2.13** |
| Stage B (Design Brief) | 25.0 | 32.5 | 25.0 | 10.0 | 7.5 | **2.42** |
| Stage C (Concept Design) | 10.0 | 30.0 | 42.5 | 12.5 | 5.0 | **2.73** |
| Stage D (Design Development) | 5.0 | 25.0 | 30.0 | 32.5 | 7.5 | **3.13** |
| Stage E (Technical Design) | 2.5 | 15.0 | 35.0 | 40.0 | 7.5 | **3.35** |
| Stage F (Production Information) | 5.0 | 12.5 | 37.5 | 32.5 | 12.5 | **3.35** |
| Stage G (Tender Documentation) | 7.5 | 22.5 | 35.0 | 25.0 | 10.0 | **3.18** |
| Stage H (Tender Action) | 20.0 | 25.0 | 27.5 | 22.5 | 5.0 | **2.78** |
| Stage J (Mobilisation) | 27.5 | 32.5 | 22.5 | 12.5 | 5.0 | **2.48** |
| Stage K (Construction to Practical Completion) | 10.0 | 27.5 | 32.5 | 25.0 | 5.0 | **2.88** |

1: never used; 2: rarely used; 3: used in some projects; 4: used in most projects; 5: used in all project.

Respondents were invited to add any comments they wish to make regarding 'waste minimisation design practices'. There was a consensus among the 13 architects who completed this section that waste minimisation is often not taken on board during the design process. Most of them concurred that lack of time does not allow them to incorporate waste reduction in their projects; and argued, yet again, that designing out waste depends on procurement routes and types of clients.

### 4.2.4.3 Design waste causes versus waste minimisation design strategies

Figure 4.7 represents the results of SPSS correlations between architects' responses regarding design waste generation (Table 4.5) and implementation of design waste minimisation strategies across all RIBA Plan of Work stages (Table 4.6).

Respondents considered that waste arising during Appraisal (RIBA Plan of Work Stage A) was insignificant; therefore, no design waste reduction measures were initiated. It is interesting to note fairly consistent overlaps of 'insignificant waste production' and 'relatively low implementation of design waste reduction' during Design Brief; Concept Design, Design Development, Technical Design, Production Information; Tender Documentation and Action; and Mobilisation (Stages B–J). However, a diverging trend becomes apparent during Construction to Completion

(Stage K). This would suggest that architects considered that most construction waste occurs during site operations and is rarely generated during design stages, directly or indirectly.

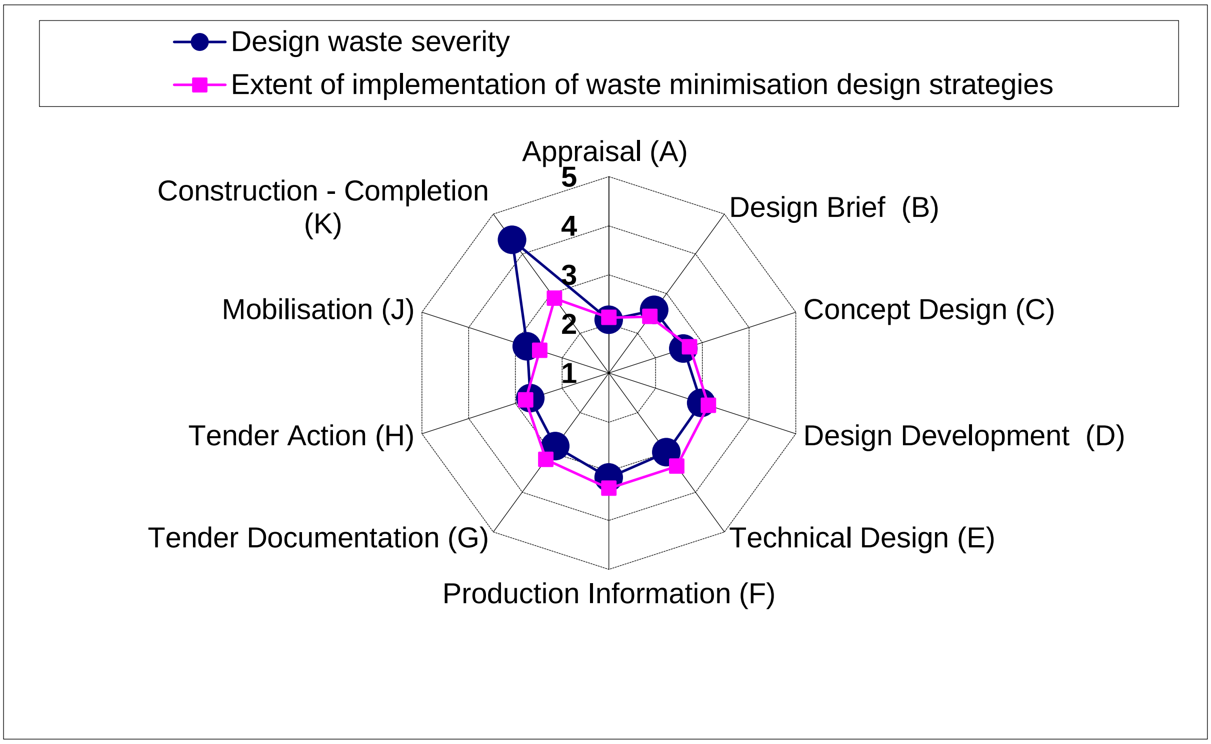



**Figure 4.7: Design waste severity versus extent of implementation of waste minimisation design strategies across the RIBA Plan of Work stages**

### 4.2.5 Onsite waste management practices (contractors' perspectives)

#### 4.2.5.1 Onsite waste production and segregation practices

Responding contractors were asked to: rate the waste production level (by volume) of onsite construction material streams from 1 (no waste generation) to 5 (major waste generation); and indicate whether onsite waste segregation for each waste stream is being implemented. Over 81 % of contractors concurred that: packaging is a significant to major onsite waste stream; followed by plasterboard and timber wastes, 63% and 61% respectively (Table 4.8).

**Table 4.8: Onsite waste segregation and segregation**

| Waste stream | Waste production level (%) | | | | | | Waste segregation (%) | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | Mean value | Yes | No |
| Packaging | 2.0 | 2.0 | 14.4 | 40.8 | 40.8 | **4.16** | 53.1 | 46.9 |
| Plasterboard | 6.1 | 6.1 | 24.5 | 36.8 | 26.5 | **3.71** | 61.2 | 38. 8 |
| Timber | 2.0 | 12.2 | 24.5 | 53.1 | 8.2 | **3.53** | 75.5 | 24.5 |
| Concrete | 4.1 | 16.3 | 61.2 | 16.4 | 2.0 | **2.96** | 42.9 | 57.1 |

1. No waste generation; 2: insignificant; 3: minor; 4: significant; 5: major waste generation.

When invited to list other noteworthy onsite waste streams; most contractors found that excavation materials, including: soil and stones; bricks and block; metals; and unused materials are major waste streams in building projects. They also listed other significant onsite waste streams, such as: roofing materials; insulation, electrical cables; and aggregates.

In terms of waste segregation, Table 4.8 shows that over 75% and 61% of respondents respectively segregate timber and plasterboard; while a segregation of packaging and concrete is adopted by 53% and 50% respectively.

#### 4.2.5.2 Onsite waste management strategies

Responding contractors were asked to rate onsite waste management strategies from 1 (never used) to 5 (used in all projects); their answers are shown in Table 4.9.

**Table 4.9: Onsite waste management strategies**

| Onsite waste management strategies | Contractors' responses | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Percentages | | | | | | Mean Rating | Ranking |
| | 1 | 2 | 3 | 4 | 5 | Total | | |
| Appropriate storage of materials | 0.0 | 6.1 | 6.2 | 46.9 | 40.8 | 100 | **4.22** | **1** |
| Provide easy access for delivery vehicles | 3.1 | 2.0 | 17.9 | 39.8 | 37.2 | 100 | **4.06** | **2** |
| Waste segregation | 2.1 | 6.1 | 20.4 | 44.9 | 26.5 | 100 | **3.88** | **3** |
| Set waste reduction targets | 12.3 | 18.4 | 19.4 | 33.6 | 16.3 | 100 | **3.23** | **4** |
| Onsite reuse of waste materials | 8.2 | 16.4 | 40.8 | 22.4 | 12.2 | 100 | **3.14** | **5** |
| Offsite reuse of waste materials | 14.3 | 22.4 | 38.8 | 18.4 | 6.1 | 100 | **2.80** | **6** |

1: never used; 2: rarely used; 3: used in some projects; 4: used in most projects; 5: used in all project.

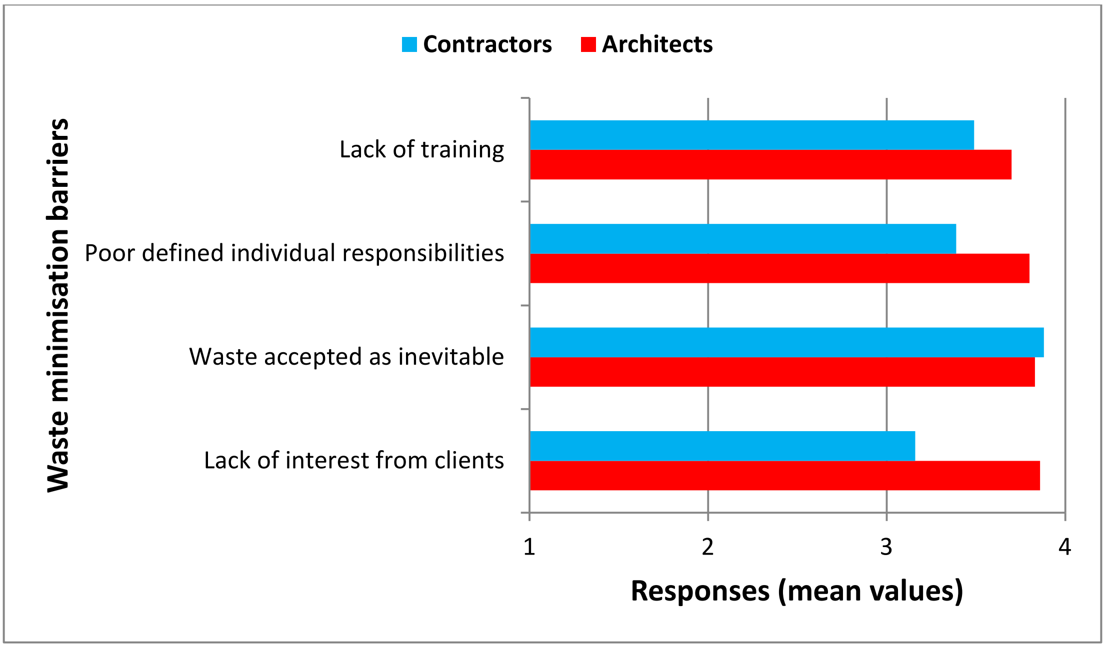
The majority of contractors reported that they used ‘appropriate storage of materials’ (88%) and ‘provided easy access for delivery vehicles’ (77%) in most or all their projects. Additionally, over 27% implemented onsite waste segregation and about 12% and 6% respectively claimed to reuse onsite and off-site waste materials in all their projects. Half of the responding contractors, however, maintained that they did set waste reduction targets in most or all their projects, which appears somewhat contradictory.

Respondents were invited to add any comments they wish to make regarding ‘onsite waste management practices’. All 11 respondents who completed this section stated that waste segregation is dependent on the nature of work and size and constraints of the site. This was illustrated by one respondent who stated that “it is quite difficult to maintain a fast running site”. He went further to state that “presentation is always more important, as such areas are cleaned up and material skipped just to improve the site appearance”. In reiterating their previous comments, most of the respondents agreed that a greater awareness is required at all levels namely: design; procurement and site operations; and commissioning in regards to recycling costs; penalties; and savings that can be made.

### 4.2.6 Waste minimisation barriers

Responding architects and contractors were asked to rate barriers that impede an integrated waste minimisation implementation in their projects, using a Likert scale from 1 (not a barrier) to 5 (major barrier). Their responses are shown in Figure 4.8.

Results show that: ‘waste accepted as inevitable’ (3.90) was rated the highest mean importance rating by contractors; followed by ‘lack of onsite personnel training’ (3.49); and poor defined individual responsibilities’ (3.39). Equally responding architects considered: ‘lack of interest from clients’ (3.86); ‘waste accepted as inevitable’ (3.83); and ‘poor defined individual responsibilities’ (3.80) as the most significant challenges.




1. Not a barrier; 2: insignificant; 3: minor; 4: significant; 5: major barrier.

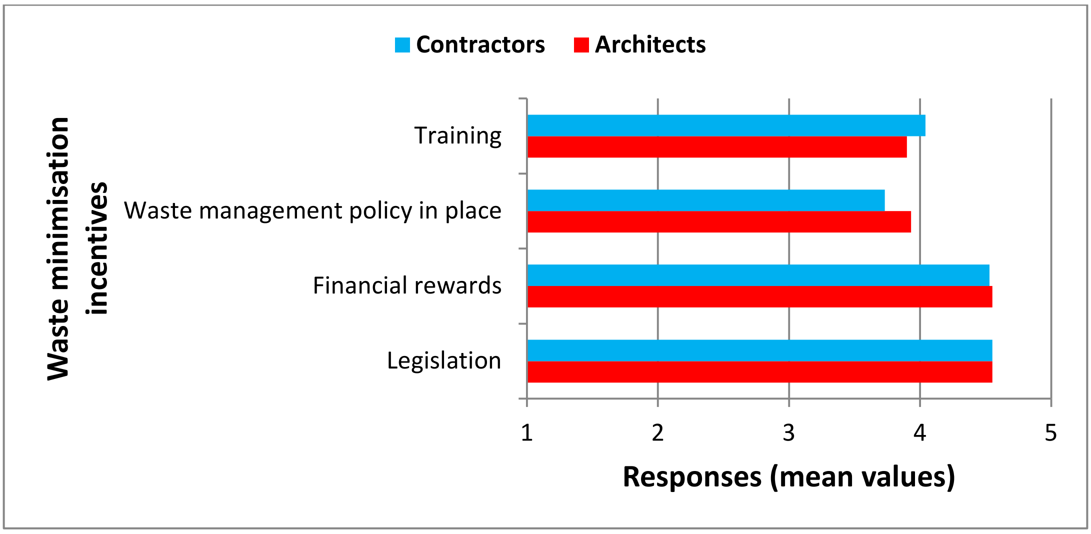
**Figure 4.8: Construction waste minimisation barriers**

Respondents were invited to add any comments they wish on 'waste minimisation barriers'. Architects' qualitative comments were mainly related to: restricted timescale for design; waste reduction seen as not a design priority; limitations of architects' input in Design and Build projects; and lack of cost and performance data on reused and recycled construction materials. As such, one responding architect opined that "reclaiming onsite materials costs more than skipping it". On the other hand, contractors identified: perception of waste; lack of associated budget in the cost plan; waste not addressed at briefing and design stages; and lack of interest from project management and sub-contractors as being the principal barriers to a successful waste reduction outcome in construction projects. Other contractors' comments on waste minimisation barriers included:

- difficult for staff to accept responsibility;
- poor supervision of sub-contractors;
- immature recycling industry;
- lack of onsite space for recycling, particularly in urban sites; and
- speed of construction.

### 4.2.7 Waste minimisation incentives

Responding architects and contractors were asked to rate incentives that would drive waste minimisation implementation in their projects, using a Likert scale from 1 (not an incentive) to 5 (major incentive). Their responses are shown in Figure 4.9. There was a greater degree of consistency in both respondents' views on the major incentives to waste minimisation practices. Indeed, responding architects and contractors rated equally 'financial rewards' and 'legislation' as the main waste minimisation incentives. While there was a consensus that legislation can be effective in maintaining the pressure to improve waste minimisation, it was suggested that: financial drivers at project level, such as allocated fees for architects and reward performance against agreed targets for contractors; and through government economic initiatives, such as tax rebates, will have a far-reaching impact on waste reduction practices. The latter was further emphasised by one respondent who argued that 'the government uses a penal system when a reward system would help clients address the issue with more enthusiasm'.




1. Not an incentive; 2: insignificant; 3: minor; 4: significant; 5: major incentive.

**Figure 4.9: Construction waste minimisation incentives**

### 4.2.8 Further comments

A space was provided at the end of both questionnaires to accommodate any other comments and views on the topic of construction waste minimisation and management. Most architects who completed this section acknowledged that waste minimisation design approach is not adopted in most of their projects, as one respondent put it: “waste reduction is rarely considered during the daily life in architects’ offices”.

Nonetheless, architects conveyed their willingness to work with consultants and contactors to design out waste if requested by their clients, particularly if they gained an enhanced fee for reducing waste. That said, responding architects believed that training and easily accessible sources of information are critical, as one respondent commented: “I have seen very little effective information on training offered in this field. We would probably make use of it far more if readily available, accessible and inexpensive courses were on offer to companies”. Additionally, architects argued that well-defined organisational and individual responsibilities and better coordination would help implementing waste reduction measures.

Similarly, responding contactors who added comments acknowledged that although they should and could do more to minimise and better manage onsite waste, they strongly believed, however, that waste could be substantially reduced through two focussed activities: the design process, as architects are the upstream participants of building projects; and efforts to drive a change in culture. They concurred that waste reduction must be addressed at source via a consideration at the briefing and design stages. Most of them argued that it would be beneficial if legislation to be instigated will look at reducing waste at the design stages. Others pointed out that: it is still rare to have recycled or reclaimed materials specified by designers; and stressed the importance of local recycling infrastructure, which is essential for the ability to segregate onsite waste. As such, there was a common view among contractors that sustainability, CSR and waste management policies are major drivers to recycling and reuse of materials. Contractors who have such policies in place have developed a waste reporting database for their generated waste streams that allow project managers in their various offices as well as site managers of all their projects to feed information into it. Similarly, others have now started to see the benefits of reduced costs from correct waste management practice; as such they are slowly convincing the rest of their supply chain to follow on with waste management plans on their own work packages.

The final section of both questionnaires comprised two questions: respondents were asked if they would like to receive a copy of the questionnaire's results; and to confirm whether they would like to take part in follow up interviews. Results show that all contractors expressed their desire to receive questionnaire's results compared to 23 architects; and 18 contractors and 10 architects agreed to be interviewed.

## 4.3 Questionnaire limitations

Data collection was limited to architects and contractors' perspectives and did not involve other designers such structural and building service engineers. The research produced findings that were centred on opinions from architects and contractors through two questionnaire surveys and follow-up interviews. The collected data could have resulted in different findings if another research design was adopted.

The sample population for both the primary questionnaire surveys was drawn from the top 100 UK architectural practices and top 100 UK contracting companies. Although the research identified the most appropriate sampling frame, as justified and explained in Section 3.5.1.4, the selection of a larger or different sample could have generated different results.

One major disadvantage of questionnaire surveys is the possibility of a low response rate (Creswell, 2014). The response rates of the primary questionnaire surveys that were sent to architects and contractors were 40% and 49% respectively. Notwithstanding a response rate between 25 and 35% could be expected (Fellows and Liu, 2008), the response rates could have been different if another type of sample population was selected. Interestingly, the DoW Framework industry review questionnaire generated a 57% response rate. Saunders et al. (2012) argued that a response level is usually correlated to the questionnaire subject interest in the topic. This would suggest that sustainability and environmental managers during the primary data collection and members of the two RIBA panels during the Framework industry review were interested in the subject of waste management and minimisation practice, which influenced their relatively high response rate. Moreover, some questionnaire respondents might have been unwilling to disclose waste management and minimisation practices at company and project levels, despite the researcher's assurance that organisational and individual names would not be mentioned in all outputs of this research

## 4.5 Summary

The findings of the questionnaire results reveal that most responding architects were aware of the importance of waste minimisation and agreed that waste is a significant concern in construction; however, they seemed reluctant to adopt waste design minimisation strategies in their projects. They acknowledged that waste is not a priority in the design process. Indeed, responding architects confirmed that waste minimisation strategies are hardly ever implemented. Additionally, they do not consider that waste is generated during the design process. Additionally, by acknowledging their lack of understanding of waste causes during the design process, architects recognised the need for a comprehensive design waste source evaluation, which should set out to influence a change to a waste reduction design paradigm.

Results also uncover that holding sustainability policies and environmental accreditation appeared to have no serious impact on design waste minimisation performance. That said, architects conveyed their willingness to work with consultants and contractors to design out waste if incentivised by clients, particularly if they gained an enhanced fee for waste minimisation feasibility and implementation studies. It is interesting to note that designing out waste is considered as an ad hoc process, not part of the core activities of the building design process. Contractors strongly believed, however, that waste could be substantially reduced through three focused activities: designing out waste; better waste management practices by sub-contractors; and change of culture to improve company and individual attitudes.

A recurring concern, which was raised by the responding architects, lies in the lack of understanding of what creates design waste. They, however, acknowledged that poor decision making during early design stages can have major implications on onsite waste production. Consequently, follow up interviews were conducted with a selected sample from responding architects and contractors to undertake in-depth qualitative investigation to capture the underlying design related causes and sources and develop a complete design waste mapping process across all the RIBA Plan of work stages. Results of the follow-up interviews are presented and discussed in the next chapter.

# CHAPTER 5

# INTERVIEW RESULTS

## 5.1 Introduction

This chapter, which addresses Objective 6, presents the results of the interviews. The chapter provides a detailed examination of the underlying causal relationships between the architectural design process and associated design waste generation, which is guided by a thematic discussion of the key design waste origins, sources and causes in each RIBA Plan of Work stage. .The first section of the chapter explains the connection between the questionnaire findings and the interview questions. The subsequent sections present the results of the interviews. The reporting sequence of the data analysis in this chapter follows the same chronological sections as the interview schedule (Appendix 2.1). This was followed by a discussion on the limitations of the interviews.

## 5.2 Relationship between the questionnaire results and the interview design

The aim of both questionnaire surveys was to ascertain architects and contractors' views on waste minimisation practices, responsibilities; challenges and overarching construction waste causes that emanated from the literature review (see Appendix 1.3 and 1.4). Questionnaires' results, which were examined in Chapter 4, gathered a considerable amount of statistical data based on the respondents' ranking of waste causes (Section 2 of the questionnaire); waste minimisation responsibilities (Section 3 of the questionnaire); and the extent to which waste minimisation is currently being implemented in construction projects (Section 4 of the questionnaire). SPSS statistical tests of the questionnaires' results established a correlation between design waste causes and waste minimisation design strategies, which was illustrated in Figure 4.7 and discussed in Section 4.2.4.3. However; questionnaires' results did not offer opportunities to interrogate respondents' ranking of waste causes and assess the impact of design activities and decisions on waste generation across all project stages. Therefore, in-depth investigation was needed to examine the underlying design waste causes and sources and their respective origins across all RIBA Plan Work stages. Hence, semi-structured interviews were adopted to explore waste causes related responses obtained from the questionnaire findings in more detail. As such, the four interview questions in Section 2 (Appendix 2.1) were designed to expand upon the questionnaire results of question 2.1 in relation to waste causes during design stages and onsite operations. Similarly, the five interview questions in Section 3 (design waste mapping) were developed to elaborate on the questionnaire results of question 2.2 in order the identify waste causes and sources in each RIBA Plan of Work stage. As shown in Appendix 2.2, the interview questions included a range of probes related to questionnaire results and were stimulated by follow up questions on interviewees' responses and statements.

## 5.3 Interview results and analysis

The analysis of the interview results was supported by the process of NVivo coding that helped with the identification of patterns across the interview transcripts regarding design waste causes. As discussed in Chapter 3, NVivo themes, known as 'nodes', were used to automatically code waste causes and sources based on the words or phrases from the interviewees' responses. The NVivo coding process of the interview results started with a 'broad-brush' coding to organise the data into a single overarching 'node' labelled as 'waste causes'.  Subsequently, NVivo 'node hierarchies' and 'aggregating nodes' were used to progressively create 'parent nodes' (main themes) and associated 'child nodes' (sub-themes). For example and as illustrated in Figure 5.1, 'limited design waste minimisation knowledge and guidance' was created as one of the 'parent nodes' in the analysis of design waste causes during RIBA Plan of Work Stages C and D (Concept and Design Development). Then, the gradual analysis of transcripts resulted in highlighting and coding 'architects lack of understanding of design waste causes and sources'; 'insufficient designing out waste know-how' ; and 'limited design designing out literature and best practice sharing' as 'child nodes' that were subsequently aggregated onto their related 'parent node' ('limited design waste minimisation knowledge and guidance'). Finally, NVivo 'coding comparison' query was run to determine the level of agreement between coded responses of the interviewees, which allowed  the display of the interview results of design waste causes across the RIBA Plan of Work stages into summary tables, which are presented and discussed below in Sections 5.3.3 to 5.37.

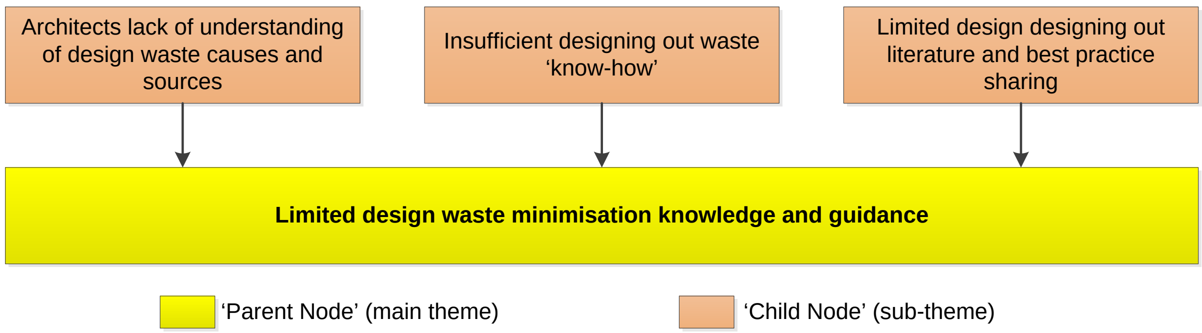



**Figure 5.1: Example of NVivo coding hierarchy of waste causes during Concept and Design Development stages**

The findings of the interviews are reported and discussed in the sections below.

### 5.3.1 Background information

As shown in Table 5.1, the sampling population comprised 24 questionnaire respondents (12 architects and 12 contractors) who expressed their willingness to participate in follow-up interviews.

All participating architects are partners and associates in their respective practices. Similarly, all participating contractors occupy senior environmental management positions and are heavily involved in material resource efficiency in their companies' construction projects. Additionally, 11 out 12 interviewees from contracting companies were responsible for the development and implementation of in-house sustainability and waste management policies.

Participating architectural practices and contracting firms are involved in a wide range of projects with a mix portfolio of new build and refurbishment projects. In terms of sector intervention, all participating contractors and seven out of 12 architects work on projects commissioned by both private and public clients; while the remaining five architectural practices operate solely within the private sector.

**Table 5.1: List of participating interviewees**

| Participating architects | | | Participating contractors | | |
|---|---|---|---|---|---|
| **Code** | **Position** | **Location** | **Code** | **Position** | **Location** |
| A1 | Partner | London | C1 | Environmental Manager | London |
| A2 | Associate | London | C2 | Group Compliance Manager | London |
| A3 | Partner | Leicester | C3 | Environment Manager | Lincoln, Lincolnshire |
| A4 | Director | Leicester | C4 | Sustainability Director | Ibstock, Leicestershire |
| A5 | Associate | London | C5 | Sustainability and Environmental Manager | Sandy, Bedfordshire |
| A6 | Managing Director | London | C6 | Group Environmental Manager | Birmingham |
| A7 | Associate | London | C7 | Sustainability Manager | Salford |
| A8 | Associate | London | C8 | Director for Engineering and the Environment | Wolverhampton |
| A9 | Senior Associate | Manchester | C9 | Waste Management Senior Consultant | London |
| A10 | Partner | Hartley Witney, Hampshire | C10 | Quality and Environmental manager | Downfield, Derbyshire |
| A11 | Managing Director | Wolverhampton | C11 | Environmental & Health and Safety Manager | Manchester |
| A12 | Senior Partner | London | C12 | Sustainability Manager | Derby |

### 5.3.2 Waste minimisation importance in current projects

Interviewees were asked about the importance of waste minimisation in their current projects. All contractors considered waste minimisation as important; mostly due to legislative, financial and business drivers. Furthermore, 11 out 12 contractors have: a waste management policy in place; and conduct regularly onsite waste management awareness and training programmes. However, C12 opined that the waste issue among designers and supply chain partners "*is gaining importance, however, it is not* *one of the contributing factors such as on time, to budget and quality*". The majority of responding architects (10 out 12) considered waste minimisation is not a design priority in their current projects; and as such "*it is rarely discussed during design development"*, as architect A4 put it. Notwithstanding current architects' emphasis on waste minimisation is low, all architects acknowledged that it is growing in importance driven by cost, rising general awareness and ever-changing environmental legislation. A fundamental issue raised by all architects was the lack of awareness and useable information to make the right design decisions to reduce waste in their projects. This was exemplified by interviewee A3 who pointed out that "*if required by the client, architects are willing to integrate waste minimisation strategies in their design; however, they do not know how to do it*". This was reiterated further by interviewee A10 who reported that "*there is little or highly incoherent information specifically for architects to assist them with a detailed waste minimisation methodology*".

There was a consensus among all interviewees that: client interest and commitment; project type; procurement route; and level of architects' involvement in construction delivery determine the extent to which waste minimisation is considered in a construction project. However, both participating stakeholders stressed that the level of importance attached to waste minimisation during a construction project is set by the client. They, however, noted public clients tend to give waste minimisation more forward thinking that private developers. Architect A8 made a further distinction between clients by stating that "*there is not much difference between types of projects but the difference relates to user/occupiers versus developers*". He went on to elucidate that "*where there is no hand on ownership, there is less interest in waste minimisation*". That said, all participants concurred that an increasing number of clients are requesting environmental considerations, including waste minimisation, during the design and construction of buildings via environmental assessment accreditation schemes, particularly BREEAM and propelled by Corporate Social Responsibility.

### 5.3.3 Design waste causes and sources during briefing stages

Table 5.2 encapsulates interviewees' insights into the most significant design waste causes and sources during briefing stages (RIBA Plan of Work Stages A and B: 'Appraisal' and 'Design Brief'). These are synthesised and discussed below.

#### 5.3.3.1 Waste minimisation is not a brief requirement

There was a consensus among all 24 interviewees that waste minimisation is generally not a brief requirement in projects. There was a shared view that the quality of instructions that architects get from clients is not always clearly stated and structured. Additionally, all architects agreed that the timescale of preliminary investigation prior to design at present is not sufficient for waste minimisation considerations. Architects agreed that reducing design waste should, therefore, start with the client specifying waste performance as a major requirement both for design and during construction, "*as a result, waste minimisation will spread down the chain*" (A7). That said, C9 pointed out that the architect is expected to communicate the importance of reducing design waste to the client. The client being unaware of the benefits, especially associated costs with waste reduction measures, was raised by all participating contractors and only five architects. Most contractors suggested that the briefing stage provides an opportunity for quantity surveyor and the architect to identify potential benefits and communicate this to the client, who in turn should be taking the lead in issuing recommendations to inform stakeholders about the importance and impact of waste minimisation throughout the project life cycle. Conversely, most architects argued that waste consideration during the brief stage minimising waste depends on the type of client. This was exemplified by respondent A9 by stating that "*for our commercial clients, finishing the project as soon as possible overrides everything else, including environmental considerations*". When probed on reasons for the lack of architects and consultants' engagement in advising the client regarding waste control and management; all responding contractors were of the opinion that this is mainly due to time constraints imposed by clients. Equally, all architects reported that they work in accordance with a tight time schedule from start to end. This was consolidated by responding 9A pointed out that allocating sufficient time to consider the potential for waste and plan on how to reduce it during design should be provided by the client in every project.

Poorly identified waste minimisation responsibilities, which have been identified by all participating architects and contractors, is leading to confusion on who should take the lead in driving the waste minimisation agenda and define how this will be implemented and monitored. All interviewees concurred that contracts should be clear on organisational responsibility and include contractual agreements with measurement benchmarks. However, all contractors reiterated the fact that this has to be client-led. Correspondingly, architects agreed that this should be a contractual requirement and contract documents should set out waste minimisation goals and what is expected from each stakeholder.

**Table 5.2: Design waste causes and sources during RIBA Plan of Work Stages A and B (Appraisal and Design Brief)**

| Waste cause | Interviewees' responses | | Waste source |
|---|---|---|---|
| | Architects (Out of 12) | Contractors (Out of 12) | |
| **Not a brief requirement*** | | | |
| Not client-driven | 12 | 12 | Client. |
| No specific WM-related briefing requirements | 12 | 12 | Client. |
| Client unaware of WM benefits | 5 | 12 | Architect; Consultants. |
| Time constraints | 12 | 12 | Client. |
| Poorly defined WM responsibilities | 12 | 12 | Client. |
| WM not embedded in contact documents | 12 | 12 | Client. |
| **Insufficient incentives and enablers*** | | | |
| WM not a legislative requirement for designers | 12 | 12 | Government. |
| No designing out waste financial incentives | 11 | 8 | Client. |
| No WM feasibility studies | 12 | 12 | |
| Lack of recognised WM benchmarking and baselines | 12 | 12 | Government; Professional bodies (e.g. RIBA); Architect; Consultants. |
| No WM target setting | 9 | 12 | Client; Architect; Consultants. |
| **Lack of early collaborative engagement*** | | | |
| Limited early interaction and coordination among project team | 12 | 12 | Client; Architect; Consultants. |
| WM not embedded in appraisal studies | 10 | 12 | Architect; Consultants. |

* Main design waste cause theme (NVivo Parent Node, as explained in section 5.3)

There was a clear consensus among all interviewees that waste minimisation should be driven from the project outset and written into contract documents; as such responsibilities would inevitably be established through all project stages.

### 5.3.3.2 Insufficient incentives and enablers

There was an agreement among contractors that informing clients about waste minimisation actions should be initiated by the architect. This was disputed by 11 architects who argued that proactive actions in this matter will need architects to go "*above and beyond their legal requirements*" (A9); whilst financial incentives could objectively drive forward the waste agenda during the design process. This was further explained by A2 who pointed out that "*the client should perhaps set aside an additional fee, for the architect to consider waste minimisation in the design process*". On the other hand, two-third of contractors disagreed by stating that design waste considerations should be part of architects' standard activities without additional financial incentives. Equally, C6 indicated that reducing waste could potentially give the architects a marketing advantage, showing that they are taking waste seriously in gaining new commissions. This could be a significant driver for architects to consider waste reduction in their designs. This was echoed by A12 who compared the waste issue to health and safety considerations by recognising that 20 years ago, architects did not think about health and safety too much because it was assumed to be the contractor's responsibility; yet, it is now routinely considered part of CDM Regulations (HM Government, 2015). He went on to argue that architects eventually will get at that stage with waste minimisation. He acknowledged, however, for the moment and by and large "*the idea has not permeated the architectural offices*".

All contractors were of the view that the briefing stage should comprise detailed research into how waste can be minimised through design. This was seen as an opportunity for architects and quantity surveyors to conduct a waste minimisation feasibility study, whereby information is assembled, waste reduction target is set and a mechanism is put in place to monitor the process throughout the project life cycle. They added that this should include: working out rough ideas on materials; assess their resource efficiency suitability; and develop an initial cost plan. On the other hand, architects argued that currently waste minimisation is not a design priority and "*feasibility studies at the 'Appraisal' and 'Briefing' stages will be looking at fundamental design parameters*" (A5). This was echoed by A1 who went further by stating that "*the extent at which waste minimisation will be considered at these stages will depend on how it fits into the most critical design issues*". However, all architects concurred that if waste reduction is not addressed at 'Appraisal' and certainly in the ‘Design Brief’, then there is a potential to “*create a framework which will go on being wasteful all the way through the project life cycle*” (A8).

All participating architects admitted that at present, waste minimisation endeavours are not considered during feasibility studies and the lack of waste related information; especially benchmarking data makes it even more difficult to pragmatically assess the potential for waste reduction during the design process. Similarly, all contractors agreed that current waste minimisation baselines are piecemeal and not universally applied and maintained that the client and the design team should be in a position to identify a waste minimisation target during ‘Appraisal’ and ‘Design Brief’ stages. This was disputed by three architects who stated that they do not even know at that point what the building is going to be made of, since ‘Appraisal’ and ‘Design Brief’ are broad brush stages. On the other hand, two-third of responding architects agreed that a baseline must be set but they stressed that enabling knowledge based implementation mechanisms should be put in place to make such waste reduction targets feasible. Finally, the role of government was deemed critical to encourage waste minimisation. For example, C8 suggested that the government should associate financial incentives, such as such as tax rebates, with waste minimisation good practice that could help push waste reduction plans forward.

#### 5.3.3.3 Lack of early collaborative engagement

Little interaction among the client, architects and consultants was a factor identified by all interviewees as an indirect cause of design waste. The need for a whole strategic team approach and decision making was considered critical if waste minimisation was to filter through the entire process, which should be driven by a collaborative engagement of the client and the design team to embed it in feasibility studies and set up the foundation for a subsequent designing out waste implementation strategy.

### 5.3.4 Design waste causes and sources during design stages

Table 5.3 summarises the interviewees' insights into the salient design waste causes and sources during the RIBA Plan of Work Stages C and D (Concept and Design Development), which are discussed below.

### 5.3.4.1 Insufficient design timescale

Due to time constraints, all responding architects argued that they cannot adequately explore individual solutions. As such, they often make use of design and specification data from past projects. This was reinforced by one participating architect who emphasised that "*if there is no time to research systems, architects will keep defaulting and probably pull off what they have used or heard of before*" (A7). Ten out 12 architects suggested that if there was no sufficient time, design issues are considered in order of importance. A contractor also commented that clients want "*buildings designed, built and occupied as quickly as possible*" (C11). Equally, C2 argued that if longer periods were allowed for pulling project details together, then issues such as waste and alternative methods of construction can be realistically considered. This was echoed by C6 who acknowledged that if designers are up against very tight deadlines "*they will go with what they know*".

### 5.3.4.2 Lack of architect's engagement

All architects affirmed that a number of considerations have to be taken into consideration during the design process, which include spatial as well as statutory requirements and waste is not usually part of this agenda. They alluded that during 'Concept' and 'Design Development' stages, architects start to crystallise physical shapes and dimensions, materials and specification. They opined that even though design waste will be an initial consideration, other issues soon distract architects from implementing it, such as "*getting through planning and other regulatory approvals*" (A6) that require more urgent and thoughtful attention. However, most architects acknowledged that this process "*generates a certain amount of waste, even if it is not currently recognised and well defined as such*" (A11). As such, C2 stipulated that architects should produce better design quality and well-though specifications.

**Table 5.3: Design waste causes and sources during RIBA Plan of Work Stages C and D (Concept and Design Development)**

| Waste cause | Interviewees' responses | | Waste source |
|---|---|---|---|
| | Architects (Out of 12) | Contractors (Out of 12) | |
| **Insufficient design timescale*** | | | |
| Restricted design stage timescale leading to off the shelf design solutions | 12 | 12 | Client. |
| Limited research and best practice review | 12 | 12 | Architect; Consultants. |
| **Lack of architect's engagement*** | | | |
| Not a design priority | 12 | 12 | Architect; Consultants. |
| No waste management plan | 10 | 12 | Client; Architect; Consultants. |
| Design complexity | 10 | 12 | Architect; Consultants. |
| Not designing to standard material sizes | 6 | 12 | Architect; Consultants. |
| No evaluation of impact of design solutions on waste generation | 10 | 12 | Architect; Consultants. |
| Limited involvement of architects' in design development | 12 | 12 | Architect; Consultants; Specialist Contractors. |
| **Limited knowledge and guidance*** | | | |
| Lack of understanding of design waste causes and sources | 12 | 12 | Architect; Consultants. |
| Insufficient designing out waste 'know-how' | 12 | 9 | Architect; Consultants. |
| Limited design designing out literature and best practice sharing | 12 | 12 | Professional bodies (e.g. RIBA). |
| **Lack of partnering commitment and coordination*** | | | |
| Inadequate client-architect coordination | 10 | 12 | Client; Architect |
| Poor coordination and communication between designers | 9 | 12 | Architect; Consultants. |
| Lack of contractor's early involvement | 7 | 12 | Client. |
| Design not frozen at the end of RIBA Plan of Work Stage D (Design development) | 12 | 12 | Client; Architect; Consultants. |

* Main design waste cause theme (NVivo Parent Node, as explained in section 5.3)

There was a consensus among contractors that design waste is the consequence of: not initiating a waste management plan during design development; design complexity; not designing to standard material sizes; and lack of impact assessment of design solutions on waste generation. Architects attributed their lack of engagement in designing out waste to their limited involvement in design development. This is due to an increasing amount of specialist design, particularly in Design and Build (D&B) procurement. The restricted architects' contribution to the whole process, particularly their confined onsite supervisory roles, was also raised by all architects as a factor that could lead to indirect design waste. They concluded that up-coming architects will have little or no practical knowledge of site activities and will be unable to relate the impact of their design on onsite activities, including waste generation. The prevalent practice that architects are not responsible for the entire design was raised by all contractors. This was typified by C9 pointed out that "*architects rarely produce a design for 100% of the building*", as most the specialised design work packages in D&B procurement, such as curtain walling, are done by specialist contactors, which leads to lack of design coordination and ultimately design waste.

**5.3.4.3 Limited knowledge and guidance**

The lack of knowledge related to: design waste origins, causes and sources on the one hand; and waste reduction 'know-how' during the design stage were raised by both architects and contractors as indirect design waste causes. There was a consensus among all interviewees that this knowledge will assist the architect to make informed decisions regarding design waste minimisation. This was affirmed by one contractor who enunciated that "*there is a need to conduct waste reduction assessments; know industry best practice, targets and expected improvement outcome*" (C6). Similarly, most responding architects confirmed that waste related guidance is essential at the start of a project and argued that measuring, acquiring and communicating such information is a key challenge that needs to be addressed. All responding contractors acknowledged that it is the designer's responsibility to acquire knowledge, which can contribute towards achieving and disseminating best practice. However; over half of architects reported that insufficient waste reduction knowledge during design is closely related to the lack of guidance and information from organisations such as the RIBA. When probed on the extent to which WRAP's Designing Out Waste document (WRAP, 2009) is implemented in their projects, most architects reported that the document is helpful in terms of awareness but not as an implementation methodology, as it is too basic and some of its recommendations are not perfectly obvious to apply in a typical building project. As such, A6 added that "*a process chart that aids the architect in terms of defining potential areas of design waste causes and sources would be helpful and insightful*". To support such a process A12 suggested that design waste minimisation knowledge could be resolved by training and making relevant information available and accessible; while A4 acknowledged that best practice guides and case studies will help architects understand the impact of their design actions on waste production, which will then enable them to specify easier and more confidently.

#### 5.3.4.4 Lack of partnering commitment and coordination

As shown in Table 5.3, all contractors and 10 out 12 architects agreed that design waste can indirectly occur because of a lack of coordination between the architect and the client leading to incoherent capture of brief requirements and subsequent client-led changes during the construction stage. Responding contractors went further by associating waste generation with poor coordination and communication among designers. Architects opined, however, that this "*depends on the kind of contractor and the type of procurement route*" (A11). On the other hand, contractors maintained that team collaboration should be firmly set during the early design stages and argued that "*if waste is not considered or known about at the briefing stages, it will be extremely difficult to carry it further in the design stages*" (C1). All contactors and over half of architects considered that early contractor involvement in the design process can lead to an informed designing out waste strategy and yields efficiencies in both time and resources. Finally, there was a common agreement among all interviewees that not 'freezing' the design at the end of 'Design Development' (Stage D), as it is the case for most projects, will inevitably lead to late changes during site operations; and hence, waste production. The importance of partnering commitment and coordination was summarised by C11 by stating that if design waste is to be reduced substantially, every stakeholder has to recognise the importance of dealing with waste. He went on to argue that by working together, the team can look carefully at the effects of design decisions on onsite waste generation.

### 5.3.5 Design waste causes and sources during specification and detailing stages

Table 5.4 summarises the respondents' views on the prevailing causes and sources of design waste during specification and detailing stages (RIBA Plan of Work Stages E and F**:** Technical Design and Production Information). These are reported and discussed below.

**Table 5.4: Design waste causes and sources RIBA Plan of Work Stages E and F: (Technical Design and Production Information)**

| Waste cause | Interviewees' responses | | Waste source |
|---|---|---|---|
| | Architects (Out of 12) | Contractors (Out of 12) | |
| **Inadequate coordination and communication*** | | | |
| Lack of full design team coordination | 10 | 12 | Architect; Consultants; Client; Material Manufacturers. |
| Incoherent 'joined-up' detailing between designers | 8 | 11 | Architect; Consultants; Client; Material Manufacturers. |
| Lack of material size coordination between designers | 5 | 12 | Architect; Consultants; Material Manufacturers. |
| Weak linkages between architects and material manufacturers | 7 | 10 | Architect; Material Manufacturers. |
| Lack of industry modular coordination | 12 | 10 | Material Manufacturers. |
| **Incoherent specification*** | | | |
| No impact assessment of material specification on onsite waste generation | 9 | 11 | Architect; Consultants. |
| Unclear/incomplete/incorrect/unsuitable specification | 2 | 12 | Architect; Consultants. |
| Over-specification | 12 | 12 | Architect. |
| Time constraints leading to off shelf specification | 12 | 12 | Architect; Consultants. |
| **Detailing inconsistencies*** | | | |
| Complex detailing | 12 | 12 | Architect; Consultants. |
| Detailing errors | 3 | 12 | Architect; Consultants. |
| No impact assessment of detailing on material wastage | 10 | 12 | Architect; Consultants. |
| Designers' restricted detailing responsibility | 12 | 7 | Client. |
| Time constraints leading to off shelf details | 12 | 10 | Architect; Consultants. |
| **Limited use of modern methods of construction*** | | | |
| Limited use of off-site construction techniques | 10 | 11 | Architect; Consultants. |
| Architects' reluctance to design in prefabricated packages | 9 | 10 | Architect. |

* Main design waste cause theme (NVivo Parent Node, as explained in section 5.3)

#### 5.3.5.1 Inadequate coordination and communication

All contactors and most architects agreed that onsite wastage can indirectly occur because of a lack of an effective design team collaboration and communication, which is primarily due to time constraints and uncoordinated and 'parallel' design packages.

Contractors indicated that design waste is the consequence of designers' coordination flaws that lead to onsite cutting and alterations to accommodate services due to incoherent detailing and production information coordination. Furthermore, they concurred that poor material size coordination and lack of joined-up detailing are major causes of design waste. This was exemplified in a practical example by C4; whereby not gauging the steelwork with block work resulted in a significant amount of block wastages. That said, architects argued that there are conflicts and ambiguities between standard sizes of different product manufacturers. For example, brick dimensions may work well on the outside but would not match plasterboard standard sizes on the inside, which result in off-cuts (A3, A7, A8; A11). As such responding architects called for a whole-industry modular coordination. Most contractors identified weak linkages between designers and manufacturers as a significant indirect waste cause. This was illustrated by one contractor who suggested architects should utilise manufacturers and suppliers visits to architectural offices "*to closely work with them to identify optimum ways to minimise waste through suitable material sizes*" (C10).

#### 5.3.5.2 Incoherent material specification

The general comment from contractors is that design waste is inevitable if no impact assessment of material specification on onsite waste generation is conducted and unsuitable materials are specified. Conversely, the majority of architects claimed that design information documents that specify materials and products that turn out to be unsuitable are not very common. Yet, all architects concurred that owing to time pressure they frequently revert to off-shelf material specification, which seems rather contradictory. The responsibility for specification related waste production was ascribed by responding contractors to: architects who allow "*aesthetics sometimes overrun the practicalities*" (C10); manufacturers and suppliers for their poor quality of information provided to designers; and the lack of flexibility in material sizes. Contractors also identified other design waste causes, such as over-specification and unclear or incorrect specification. Most responding contractors considered these are major waste causes, particularly during 'Mobilisation' (stage J). They argued that if contractors get the right and full set of specification, they can accordingly cost and accurately source materials. They concluded that amendments to incorrect or incomplete specification require changes, which in turn lead to waste generation.

#### 5.3.5.3 Detailing inconsistencies

All architects and contractors agreed that complex detailing is another cause of design waste, as one contractor explained: "*endless cutting processes are often required to get materials to the right detail specified by the architect*" (C3). This in line with architects views who acknowledged that "*if a building component is intrinsically difficult to build, then the site worker will not get it right the first time*" (A6). Although, most contractors and architects concurred that there are usually checks to ensure that errors are minimised, they agreed that detailing errors occur as a result of time constraints and poor communication among project stakeholders. To address detailing errors participating contractors recommended that architects should not detail or specify in isolation without assessing the impact on the whole project performance, including waste generation. One contractor referred to a wholesome approach to design when he said "*it is not just dimensions of the unit but it should be the dimensions of the whole; in other words it is an understanding on how tolerances go together*" (C8). Architects explained that designers' detailing responsibility is restricted in D&B projects since specialist contractors produce most of detail drawings of their respective work packages; hence not fully coordinated specialist contractors- architect design information that eventually generates design waste. Furthermore, all architects acknowledged that in some cases off shelf detailing is practiced due to timescale restrictions.

#### 5.3.5.4 Limited use of modern methods of construction

More than 83% of architects and 93% of contractors suggested that design waste could be minimised by implementing offsite manufacturing and prefabrication methods during construction. One contractor recognised that standardised design seems to "*happen a* *lot more on the continent than it does in the UK; it might be worth promoting this practice*" (C9). Architects agreed but cautioned that with prefabrication there will be a lot more coordination especially at 'Mobilisation' (stage J) and 'Construction' (stage K), as noted by A5. This was echoed by one contractor who argued that "*prefabrication requires higher accuracy with the final product, as well as the setting out*" (C2).

### 5.3.6 Design waste causes and sources during tender stages

Respondents identified a number of key design waste causes and sources during tender stages (RIBA Plan of Work Stages G and H: 'Tender Documentation' and 'Tender Action'). Findings are summarised in Table 5.5 and discussed below.

**Table 5.5: Design waste causes and sources during RIBA Plan of Work Stages G and H (Tender Documentation and Tender Action)**

| Waste cause | Interviewees' responses | | Waste source |
|---|---|---|---|
| | Architects (Out of 12) | Contractors (Out of 12) | |
| **Waste minimisation not entrenched in tender documentation*** | | | |
| Waste minimisation not issued and enforced in document control procedures for tender and contact | 12 | 12 | Client. |
| Poorly defined waste minimisation responsibilities | 12 | 12 | Client. |
| Lack of waste minimisation tender's agreements | 12 | 12 | Client. |
| No waste reduction target setting and implementation guidance | 12 | 12 | Client; Architect; Consultants. |
| No financial costing of waste in bill of quantities | 11 | 12 | Quantity Surveyor. |
| **Incomplete tender documentation*** | | | |
| Detailing and specification under development during tender stage | 12 | 12 | Client; Architect; Consultants. |
| Not fully coordinated design and detailing information | 7 | 12 | Architect; Consultants; Specialist Contractors. |
| Incomplete information from design team | 5 | 10 | Architect; Consultants; Specialist Contractors. |
| Incoherent information release schedule | 8 | 11 | Client; Architect; Consultants; Specialist Contractors. |
| **Limited architect's input*** | | | |
| Lack of waste minimisation design intent | 2 | 9 | Architect; Consultants; Specialist Contractors. |
| Lack of architect's waste minimisation recommendations in tender documentation and action | 4 | 11 | Architect. |

* Main design waste cause theme (NVivo Parent Node, as explained in section 5.3)

#### 5.3.6.1 Waste minimisation not entrenched in tender documents

All respondents suggested that: lack of waste minimisation enforcement; allocation of responsibilities; and issuing guidance for its implementation in tender documents are significant waste causes during tender stages. Equally, there was a common agreement among architects and contractors that a failure to include a full account of financial costing of waste in bill of quantities in a major waste cause. As such, all participating contractors opined that if waste minimisation is not an integral part within tender documentation, it will not be considered a high priority. Similarly, all architects implied that if the waste issue was picked up at the tender stage, contractors have enough time during ‘Tender Production’ stage to assess suitable options and forward recommendations to sub-contractors for potential areas and work packages where waste could be minimised. However, a number of architects were concerned that contractors might cost in extra expenses for waste management, as part of their offer.

#### 5.3.6.2 Incomplete tender documents

The majority of contractors considered late, incomplete or lack of design information clarity in tender documents as causes of design waste. Contractors cited: incomplete and poorly coordinated design and detailing information; incoherent release schedule; and detail and specification under development in tender stages as determinants that frequently lead to waste. Most architects related design information shortcomings to time constraints; and argued that the client should allow the design team a reasonable timescale to produce full design information sets.

#### 5.3.6.3 Limited architectural input

Two-third of contractors and less than a quarter of architects opined that there is no waste minimisation design intent in tendering stages. Additionally, 11 out of 12 contractors explained that architects could stress particular waste minimisation related recommendations in their design, which would guide contractors and sub-contractors to better manage onsite waste. On the other hand, architects argued that this should fall within the client’s remit, since it is a common practice that the architect’s role is to brief and advise the client; and claimed that "*if the client does not want this service, the architect cannot take it further*" (A12). This is a reiteration of earlier architects' comments for financial rewards from the client as an incentive to design out waste.

#### 5.3.7 Design waste causes and sources during construction stages

The main design waste causes and sources during construction stages (RIBA Plan of Work Stages J and K: 'Mobilisation' and 'Construction to Practical Completion'), pinpointed by interviewees, are summarised in Table 5.6 and discussed in the sections below.

##### 5.3.7.1 Limited 'Mobilisation' timescale and material over-ordering

Most responding architects and all contractors emphasised that the lead-in period for planning and mobilisation, which is required to avoid high incidences of waste, is usually extremely limited in construction projects. All contractors argued that it is not often possible to further explore how to deliver the design, while minimising factors that could lead to waste. Over two third of architects agreed that indirect waste production during 'Mobilisation' is closely associated with planning and coordination processes and a tight mobilisation programme leads ultimately to onsite waste generation.

All contractors indicated that the quality and timely provision of design information received has a significant impact on effective material ordering; and hence consequential waste generation. They concluded that if information is not released on time, the construction programme is affected and building work becomes out of sequence. This in turn affects material supply and storage, which eventually leads to waste. Responding architects generally agreed that this is a problematic issue and admitted that if architects spend longer designing and detailing, then less time is invested in detailing related changes and associated rework during site operations.

##### 5.3.7.2 Design changes and rework

Client-led changes during site operations were identified by all interviewees as having far reaching implication on waste generation. Responding architects indicated that in most projects clients make changes even after design has been signed off. This practice was considered by all interviewees to be prevalent in most building projects.

**Table 5.6: Design waste causes and sources during RIBA Plan of Work Stages J and K (Mobilisation and Construction)**

| Waste cause | Interviewees' responses | | Waste source |
|---|---|---|---|
| | Architects (Out of 12) | Contractors (Out of 12) | |
| **Limited 'Mobilisation' timescale and material over-ordering*** | | | |
| Insufficient mobilisation time | 10 | 12 | Client. |
| Missing/incomplete design information leading to material ordering assumptions and over-ordering | 9 | 12 | Architect; Consultants; Specialist Contractors. |
| No thorough check of design information prior to construction | 11 | 6 | Contractor. |
| **Design changes and rework*** | | | |
| Client-led | 12 | 12 | Client; Architect; Consultants. |
| Architect-led | 2 | 12 | Architect. |
| Contractor-led | 12 | 5 | Contractor. |
| Sub-contractors-led | 10 | 12 | Sub-contractors. |
| **Incoherent design information*** | | | |
| Incomplete design information | 10 | 12 | Architect; Consultants. |
| Inconsistencies between specification and drawings | 9 | 12 | Architect; Consultants. |
| Slow drawing revision and distribution | 4 | 12 | Architect; Consultants. |
| Design errors | 2 | 9 | Architect; Consultants. |
| Detailing flaws | 8 | 12 | Architect; Consultants. |

* Main design waste cause theme (NVivo Parent Node, as explained in section 5.3)

All contractors reported that architect-led design changes result in major rework during site operations. However, architects argued that if they make design changes, "*it is usually the consequence of last minute onsite client-led modifications*" (A3); and they "*sometimes redraw and change detail drawings due to contractor's concerns over buildability*" (A11). However, contactors related design changes by architects to their failure to correctly capture client's requirement during the briefing and design stages, considering the vagueness of the clients' initial project brief. All contractors and the majority of architects commented that sub-contractors' activities, such as material over-ordering and wrong fitting, generate a considerable amount of onsite waste. They, however, admitted that sub-contactors' over-ordering practice is usually the consequence of incomplete or unclear design information.

#### 5.3.7.3 Incoherent design information

All contractors stated that: inconsistencies between specification and drawings; and slow drawing revision and distribution lead to onsite waste generation and increase costs associated with rework. Most contractors reported that design and detailing flaws are major waste causes; whilst nearly two third of architects suggested that this is more an issue of poor interpretation of drawings by contractors. They went further by claiming that design errors once construction starts are rare; yet, they acknowledged that some details do not always work onsite, which result in abortive work. Few architects, on the other hand, admitted that a lack of clear information at times, which can be ambiguous, could have a great impact on onsite waste production.

## 5.4 Interview limitations

Interviewees' answers could have been influenced by their earlier input in the questionnaire responses. Although the researcher used the same probes that emanated from the questionnaire results and the literature review findings in all interviews (Appendix 2.2), it has not been possible to assess the extent to which their questionnaire responses had impacted on the data. That said; some of the probes which were specifically based on each interviewee's responses could not have been used in all 24 interviews.

## 5.5. Summary

The interview findings suggest that there is a strong connection between misinformed clients and lack of waste minimisation intent during Appraisal and Design Brief stages. This impacted indirectly on a wide practice of not having waste minimisation as a brief requirement, including failure to set project waste minimisation baselines and targets and conduct waste evaluation feasibility studies  This in turn has led to confusion over stakeholders' waste minimisation roles and responsibilities throughout all project stages.

The interview results reveal that design waste is affected by: a wide practice of not having waste minimisation as a brief requirement; no baseline setting; and lack of designers' understanding of design waste causes, origins and sources. This was compounded by; limited 'know-how'; incoherent coordination and communication between project members; and impeded by time constraints and disjointed design information. Therefore, the identified design waste causes cumulatively disallow due waste minimisation consideration, implementation and monitoring during the design stages.

Furthermore, the RIBA Plan of Work suggests that briefing should be signed off at the end of 'Design Development' (stage D). This is hardly the case in practice; hence, design changes during the construction stage, which is also attributed to ineffective client-designers communication and incoherent stakeholders' coordination. The fact that generally design is not completed before site operations start is a reality with non-traditional procurement routes. Indeed and owing to contemporary procurement trends, such as D&B projects, architects are less involved in the design of the entire building and production information, which in turn have restricted their responsibilities in detailing, specification and onsite supervision duties.

The design waste mapping findings that stemmed from the interviews informed the design and development of a Designing out Waste (DoW) Framework, which is presented in the next chapter.

# CHAPTER 6

# DESIGNING OUT WASTE FRAMEWORK DESIGN AND INDUSTRY REVIEW

## 6.1 Introduction

This chapter, which contains two main sections, addresses Objective 7: Construct and validate a Designing out Waste (DoW) Framework to assist architects in embedding design waste reduction strategies in each RIBA Plan of Work stage. The first section describes the DoW Framework development process. It starts with an introduction to the DoW Framework aim and objectives. This is followed by a detailed description of the Framework's structure and the content of its three levels, supported by eight associated process mapping diagrams. The second section presents the results of the DoW Framework industry review results that were gleaned from a questionnaire survey and a follow up focus group. This was followed by a discussion on the limitations of DoW Framework context and remit. As outlined in Section 3.6.2.2, the Framework industry review sampling frame consisted of leading architects who are active members of the RIBA Practice Committee and Sustainable Futures Group. The industry review participants offered a number of useful comments and suggestions for improvement that led to a refined industry-reviewed DoW Framework.

## 6.2 Designing out Waste (DoW) Framework design and development

### 6.2.1 DoW Framework aim and objectives

The aim of the DoW Framework is to provide a holistic and sequential design decisions to embed waste reduction strategies across the RIBA Plan of Work stages. The DoW Framework objectives are as follows.

- Act as a designing out waste decision making benchmarking process providing a project waste performance reference.
- Provide a method to organise designing out waste actions and define associated decision making flows throughout the RIBA Plan of Work stages.
- Review, refine and adopt informed designing out waste actions and decisions in each design stage.
- Provide a platform to capture designing out waste lessons learned at project closeout.

- Enable designing out waste continuous improvement via a congregating 'Waste Minimisation Knowledge Bank'.

### 6.2.2 DoW Framework structure and levels

The DoW Framework structure, which was developed in accordance with the RIBA Plan of Work stages, consists of four key functional facets:

- *DoW Framework levels*. As shown in Table 6.1, the proposed DoW Framework consists of three cascading, interrelated and complementary levels: Level O; Level 1; and six fold Level 2.
- *DoW Framework process flow*. Each Framework level contains designing out waste processes, sub-processes, decision making milestones and actions.
- *DoW Framework coding.* The Framework contents are guided by a coding system, which is organised and numbered in accordance with the RIBA Plan of Work stages. For example:
- S1 in Level 0 refers to Stage 1: Briefing;
- S.1.1 in Level 1 is the first decomposition process of Level 0 Stage 1 (S1); and finally
- S.1.1.1 in Level 2 is the first decomposition process of Level 1 Stage 1.1 (S.1.1).
- *DoW colour coded representation.* A colour coded system was adopted to facilitate process flow relationships and referencing between Framework Level 0, 1 and 2. For example, Stage 1 (Briefing) was assigned a yellow colour in all three Framework levels.

**Table 6.1: DoW Framework Levels**

| Level | Description |
|---|---|
| **0** | This Level presents a high level view of DoW across six key project stages (S1-Briefing; S2-Concept Design; S3- Design Development; S4-Technical Design; S5-Tender; and S6-Onsite operations). |
| **1** | This Level presents a breakdown of the six key project stages into associated DoW processes and project stage-specific decision making milestones. |
| **2** | This Level presents a breakdown of each project stage's DoW processes into associated DoW sub-processes and actions, resulting in six Level 2 DoW Frameworks (from Level 2-Stage 1 to Level 2-Stage 6) |

### 6.2.3 DoW Framework methodological process

As shown in Figure 6.1, the resulting design waste causes from Chapter 5, which are summarised in Tables 5.2 to 5.6, informed the design of the DoW Framework.

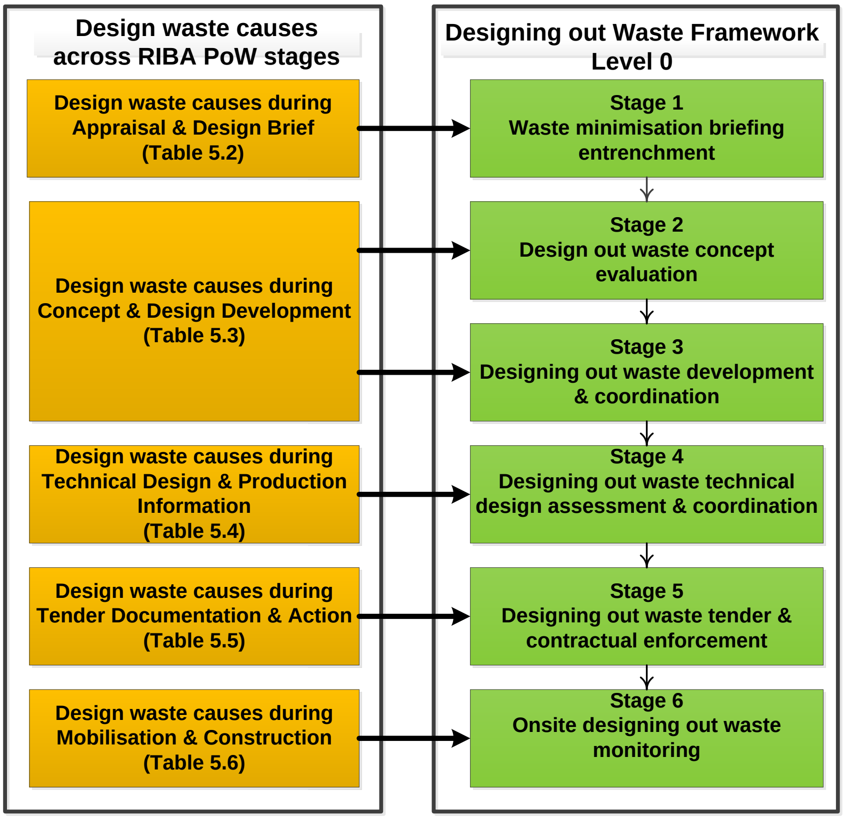



**Figure 6.1: Relationship between design waste causes across the RIBA Plan of Work stages and the content of DoW Framework Level 0**

The findings of design waste causes findings in each RIBA Plan of Work stage corresponds to a related stage of the Framework. For example, the research findings of design waste causes during the Appraisal and Design Brief (RIBA Plan of Work stages A and B), which are summarised Table 5.2 in Chapter 5, was associated with Stage 1 of the Framework (waste minimisation briefing entrenchment).

As explained in Section 5.3, NVivo 'node hierarchies' and 'aggregating nodes' were used in the interview data analysis to progressively create and structure design waste causes into 'parent nodes' (themes) and associated 'child nodes' (sub-themes). As illustrated in Figure 6.2, design waste 'themes' in each RIBA Plan of Work stage were mapped onto Level 1 of the Framework. Similarly, corresponding sub-themes were mapped onto Level 2 of the Framework.

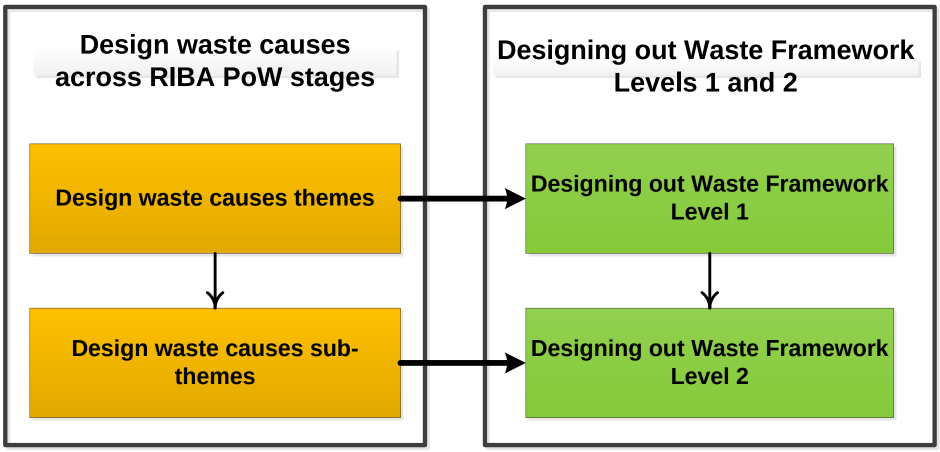



**Figure 6.2: Relationship between design waste causes across the RIBA Plan of Work stages and DoW Framework Levels 1 and 2**

To exemplify the connection between design waste causes and the content of DoW Framework Levels 1 and 2, Figure 6.3 shows the mapping of a design waste 'theme' and respective 'sub-themes' during RIBA PoW Appraisal and Design Brief stages onto DoW Framework Levels 1 and 2. 'Waste minimisation is not brief requirement', which was identified in Table 2.1 in Chapter 5 as a waste design waste 'theme', was mapped onto a corresponding designing out waste process in Framework Level 1 to 'assess client's waste minimisation'. This in turn was decomposed into four cascading and sequential designing out waste sub-processes associated with waste cause sub-themes in Framework Level 2. For example, 'client being unware of waste minimisation benefits' as a design waste sub-theme was associated to a consequential designing out waste sub-process to 'evaluate waste minimisation importance within client's sustainability aspirations.

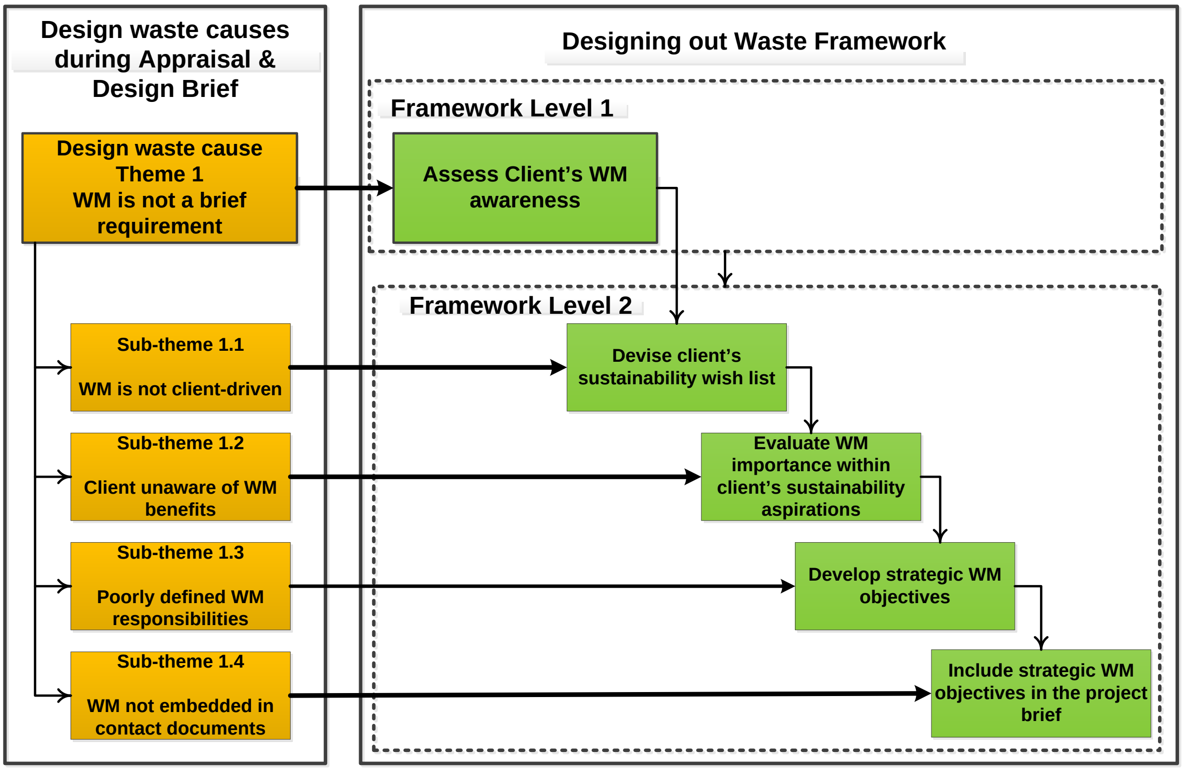



**Figure 6.3: Example of mapping a design waste 'theme' and respective 'sub-themes' during RIBA PoW Appraisal and Design Brief stages onto DoW Framework Levels 1 and 2**

### 6.2.4 DoW Framework Level 0

As shown in Figure 6.4, DoW Framework Level 0 provides a high level overview of designing out waste. It consists of three procedures and elements, which are described below.

0.1. *Six strategic DoW project stage specific prompts* across the RIBA Plan of Work stages. These are:

- <u>Stage 1 (S1): WM Briefing Entrenchment.</u> This stage provides the foundation project stage to: capture client's sustainability 'wish list'; and develop strategic waste minimisation objectives within the client' wider sustainability aspirations. Finally, convert the strategic waste minimisation objectives into project waste minimisation objectives via an agreed *DoW Strategy* and include them in the project brief.

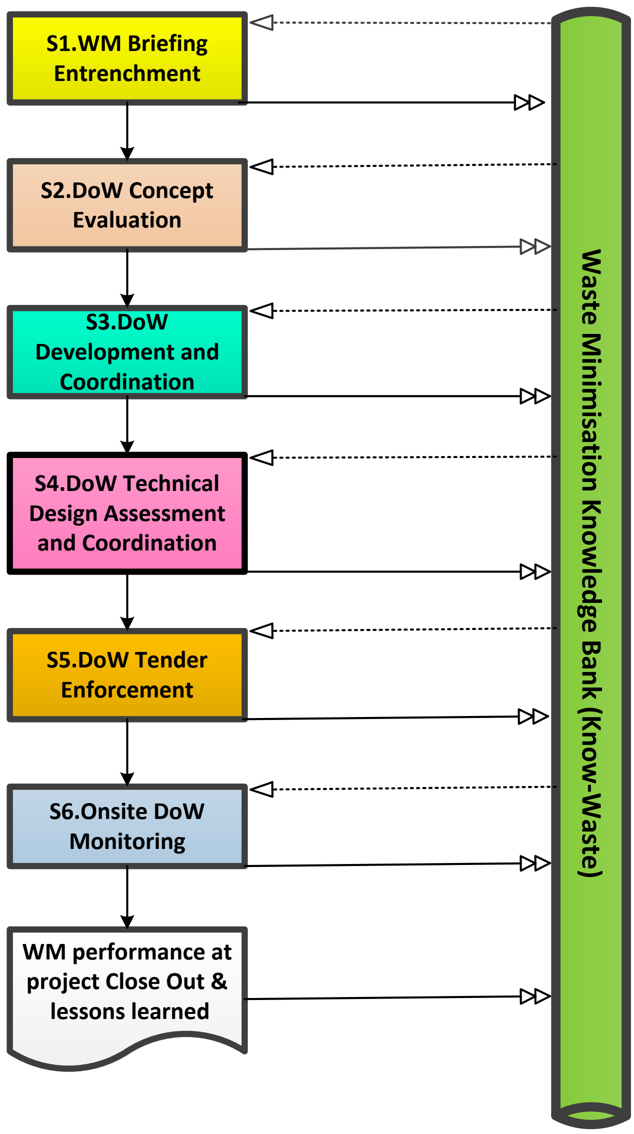



**Figure 6.4: Level 0 DoW Framework**

- Stage 2 (S2): DoW Concept Evaluation. This stage provides a platform to agree (as a design team) to consider, test and assess concept designing out waste strategies by organising review workshops and undertaking forecast, modelling and simulation studies. This stage culminates in the selection of a *Low Waste Concept Design* and respective outline material specification to be collaboratively developed, appraised and agreed by the design team.

- Stage 3 (S3): DoW Development and Coordination. In this stage, further analysis is carried out on the impact of the selected *Low Waste Concept*

*Design* and outline specification from Stage 2 on waste production, supported by collaborative design waste forecast techniques. This is followed by a continuous clash detection checks between architectural, structural and service developed designs to identify, eliminate and report design coordination flaws. If not detected at this stage, these lead eventually to design changes during the construction stage, as identified in the findings of this research. At the end of this stage, a *Developed DoW Design* is produced and the brief sign off is agreed and approved.

- Stage 4 (S4): DoW Technical Design Assessment and Coordination. In this stage, an assessment is carried out on the impact of detailing and material selection on waste production. This includes architectural, structural and service joined-up detailing and selection of low waste systems and products.
- Stage 5 (S5): DoW Tender Enforcement In this stage, agreed waste minimisation procedures are incorporated into tender and contract documents, including compliance with the *DoW Strategy* by the contractor, sub-contractors and suppliers. Subsequently, complete and DoW informed design information is integrated into tender documentation.
- Stage 6 (S6): Onsite DoW Monitoring. This stage consists of onsite implementation and monitoring of waste minimisation procedures and actions that were agreed in Stage 1 to 5 and embedded into tender and contractual documents and capture and record DoW lessons learned.

0.2. *Waste Minimisation Knowledge Bank (Know-Waste).* The aim of the *Waste Minimisation Knowledge Bank (Know-Waste)* is to establish an accessible and useable repository that captures and records waste minimisation processes and decisions in each of the Framework's DoW strategic stages. Project waste reduction performance outputs, challenges, solutions and lessons learned are recorded in the project closeout report. The reuse of captured knowledge from one project would benefit future projects to adopt informed and tested DoW processes, decisions and actions; which would in turn contribute towards continuous DoW performance management.

0.3. *Relationship arrows*. Level 0 Framework relationship links are represented by two types of arrows: (1) *Sequential DoW project stage process (vertical) arrows* that represent the chronological relationship of the six strategic DoW stages. (2) *DoW knowledge input and output (horizontal) arrows* that link the strategic DoW stage to *Waste Minimisation Knowledge Bank (Know-Waste).* These comprise two types of arrows: *DoW lessons learned output (continuous) arrows* (to *Know-Waste*); and *DoW knowledge reuse input arrows* (from *Know-Waste*).

### 6.2.5 DoW Framework Level 1

As shown in Figure 6.5 DoW Framework Level 1 is an intermediate decomposition of Level 0 Framework. It provides a breakdown of each of the six Level 0 strategic DoW prompts into associated and consequent Level 1 DoW strategies. Each of the six decomposed strategic DoW stage specific prompts from Level 0 consists of three procedures and elements in Level 1. These are as follows.

1.1 *Consequential DoW strategies and actions* that were devised to address the design waste mapping findings of this research in terms of design waste origins, causes and sources. These were reported in Chapter 4 and 5.

1.2 *DoW decision making milestones.* At the end of each project stage, a review of DoW strategies and actions is undertaken which lead to a DoW decision milestone: ‘Yes’ signals to the design team to proceed to the next stage, as it refers to a satisfactory DoW assessment; otherwise a review and re-assessment of the DoW strategies and actions is required before advancing to the next stage.

1.3 *Relationship arrows.* Level 1 Framework relationship links are represented by two types of arrows: *DoW Process (vertical) Arrows* that represent the chronological and sequential relationship of DoW processes and actions; and *DoW Decision making Arrows* that determine the status of DoW performance at the end of each project; which in turn ascertain whether to proceed to the next project stage or not.

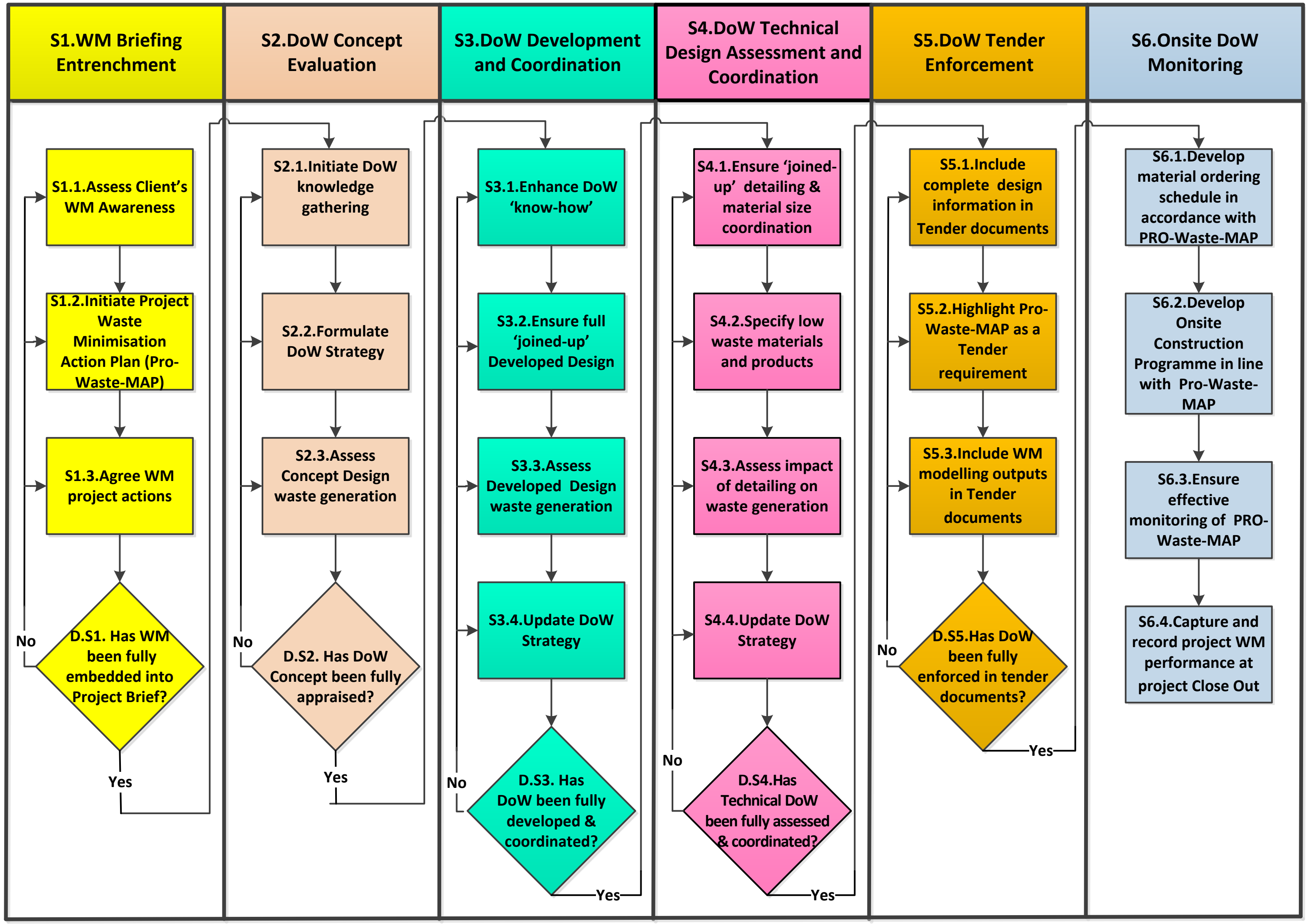



**Figure 6.5: Level 1 DoW Framework**

### 6.2.6 DoW Framework Level 2

DoW Framework Level 2 is a decomposition of Level 1 Framework into six separate Level 2 related Frameworks: Level 2-Stage 1 (Briefing) DoW Framework (Figure 6.3); Level 2-Stage 2 (Concept Design) DoW Framework (Figure 6.4); Level 2-Stage 3 (Design Development) DoW Framework (Figure 6.5).; Level 2-Stage 4 (Technical Design) DoW Framework (Figure 6.6); Level 2-Stage 5 (Tender) DoW Framework (Figure 6.7) and Level 2-Stage 6 (Construction) DoW Framework (Figure 6.8).

**Level 2-Stage 1 (Briefing Stage) DoW Framework**

As shown in Figure 6.6, Level 2-Stage 1 DoW Framework comprises a breakdown of three DoW strategies and actions (S1.1, S1.2 and S1.3) that emanated from Level 1 Framework. These are listed and described below.

- *S1.1. Assess Client's WM Awareness*. This is achieved through four DoW strategies that involve the client to develop DoW strategic objectives and include them in the Project Initial Brief.
- *S1.2.Initiate Project Waste Minimisation Action Plan (Pro-Waste-MAP). The Pro-Waste-MAP* is a significant contribution to knowledge as it allows the design team to: input DoW lessons learned that captured from previous projects and recorded in the *Waste Minimisation Knowledge Bank (Know-Waste);* and set up a WM target and prepare a project *WM responsibility Matrix.*
- *S1.3.Agree WM project actions.* This stage consists of agreeing a project collaboration and communication protocol, such as BIM, to implement *Pro-Waste-MAP* and include it in the final project brief.

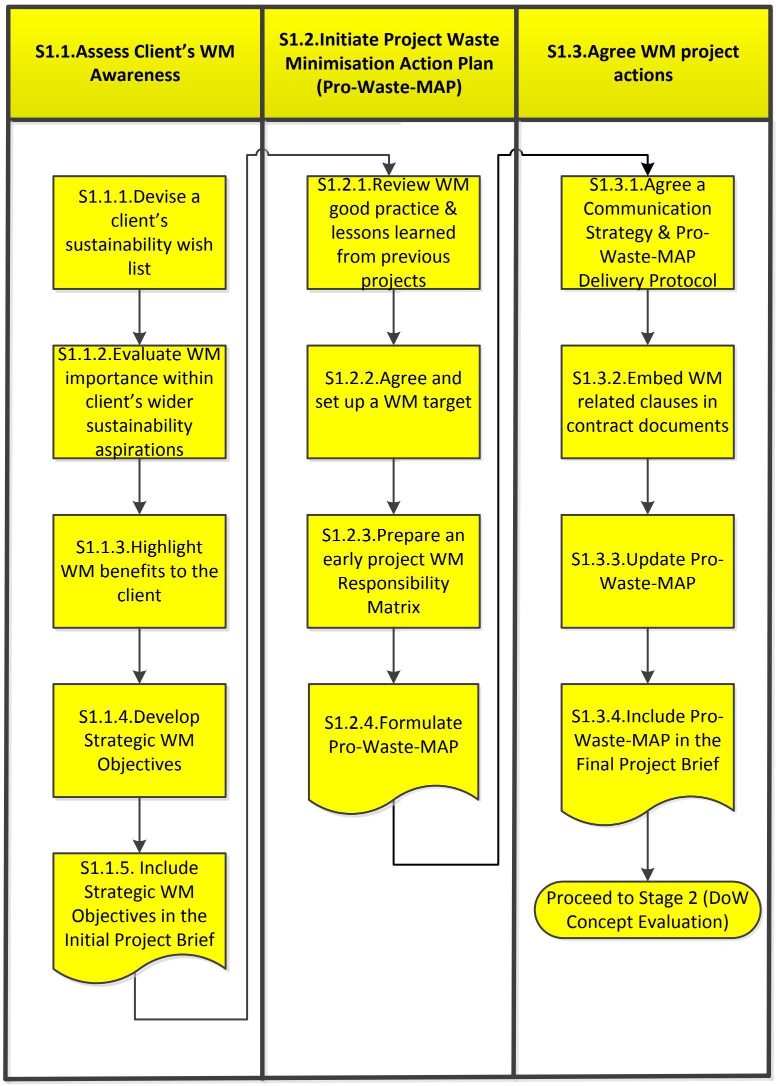



**Figure 6.6: Level 2-Stage 1 (Briefing) DoW Framework**

### Level 2-Stage 2 (Concept Design) DoW Framework

As shown in Figure 6.7, Level 2-Stage 2 (Concept Design) DoW Framework comprises a breakdown of three DoW strategies and actions (S2.1, S2.2 and S2.3) that emanated from Level 1 Framework. These are listed and described below.

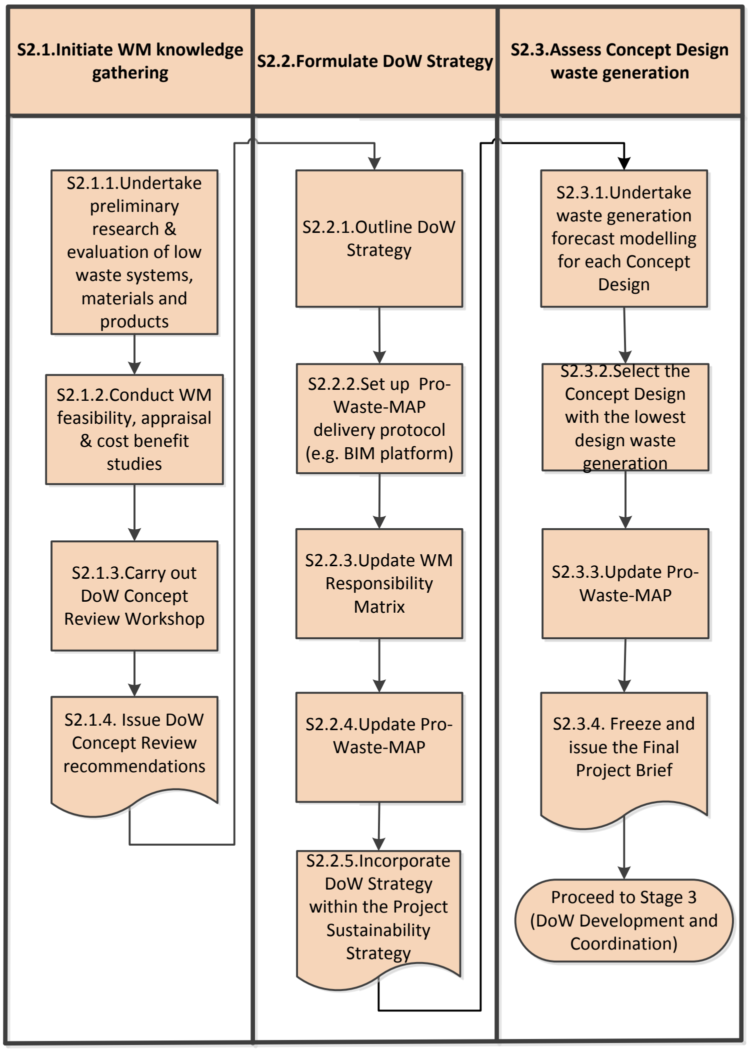



**Figure 6.7: Level 2-Stage 2 (Concept Design) DoW Framework**

- *S2.1.Initiate WM knowledge gathering*. This input and output DoW information from *Pro-Waste-MAP;* supplemented by additional research, feasibility and appraisal studies and DoW Concept Design Review Workshops.
- *S2.2.Formulate DoW Strategy.* This is a pivotal stage in DoW, in which a concurrent *DoW Strategy* is outlined, refined and included in the Project Sustainability Strategy.
- *S2.3.Assess Concept Design waste generation*. This process involves design waste forecast, modelling and simulation studies that enables the selection of a design concept with the least 'virtual' waste generation to be further enhanced in Stage 3 (Design Development).

**Level 2-Stage 3 (Design Development) DoW Framework**

As shown in Figure 6.8, Level 2-Stage 3 (Design Development) DoW Framework comprises a breakdown of four DoW strategies and actions (S31, S3.2, S3.3 and S3.4) that emanated from Level 1 Framework. These are listed and described below.

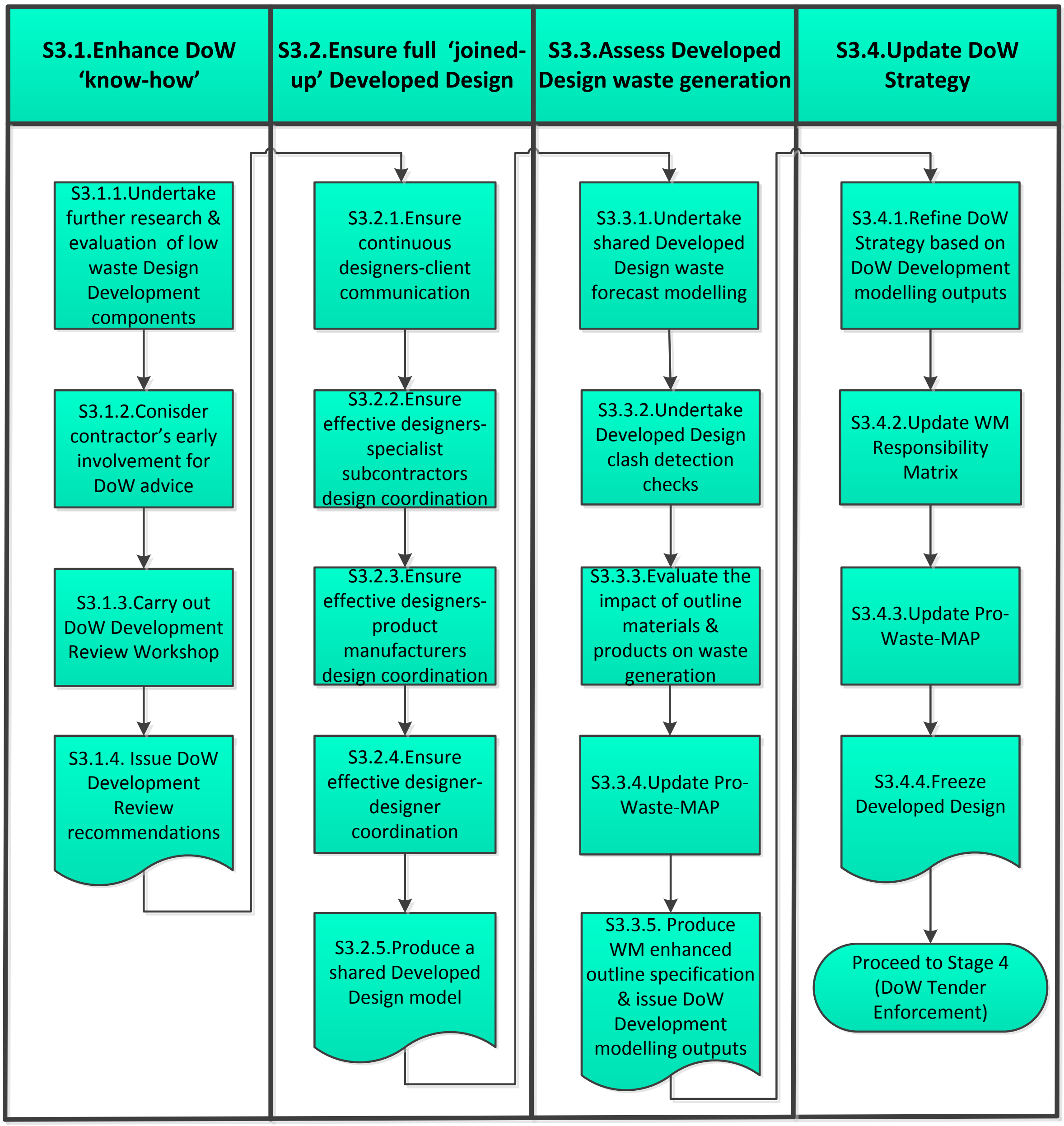



**Figure 6.8: Level 2-Stage 3 (Design Development) DoW Framework**

- *S3.1.Enhance DoW 'know-how'*. This process builds on DoW knowledge acquired in S2.1 and seeks buildability advice to develop a low waste Developed Design.

- S*3.2.Ensure full 'joined-up' Developed Design*. This process focusses on enhancing project stakeholders' DoW collaboration and communication to produce a shared low waste Developed Design.
- *S3.3.Assess Developed Design waste generation*. This follows the same approach as S2.3 through detailed design waste forecast, modelling and simulation and impact evaluation of the outline specification on waste production.
- *S3.4.Update DoW Strategy*. The last DoW actions in Design Development involves: the review and update of the project's *DoW Strategy*, *WM Responsibility Matrix* and *Pro-Waste-MAP;* and agree the Final Project Brief 'sign off'.

**<u>Level 2-Stage 4 (Technical Design) DoW Framework</u>**

As shown in Figure 6.9 Level 2-Stage 4 (Technical Design) DoW Framework comprises a breakdown of four DoW strategies and actions (S4.1, S4.2, S4.3 and S4.4) that emanated from Level 1 Framework. These are listed and described below.

- *S4.1.Ensure full 'joined-up' detailing and material size coordination* and *S4.2.Specify low waste materials and products.* Both processes focus on enhancing detailing and material specification collaboration and communication among project stakeholders.
- S*4.3.Assess impact of detailing on waste generation*. This builds on the findings of design waste forecast, modelling and simulation undertaken in S3.3 in order to issue a complete and coordination detail drawings.
- S*4.4.Update DoW Strategy.* The last DoW actions in Technical DoW stage are related to the finalisation of the project's *DoW Strategy*, *WM Responsibility Matrix* and *Pro-Waste-MAP* and agree the Technical Design 'sign off'.

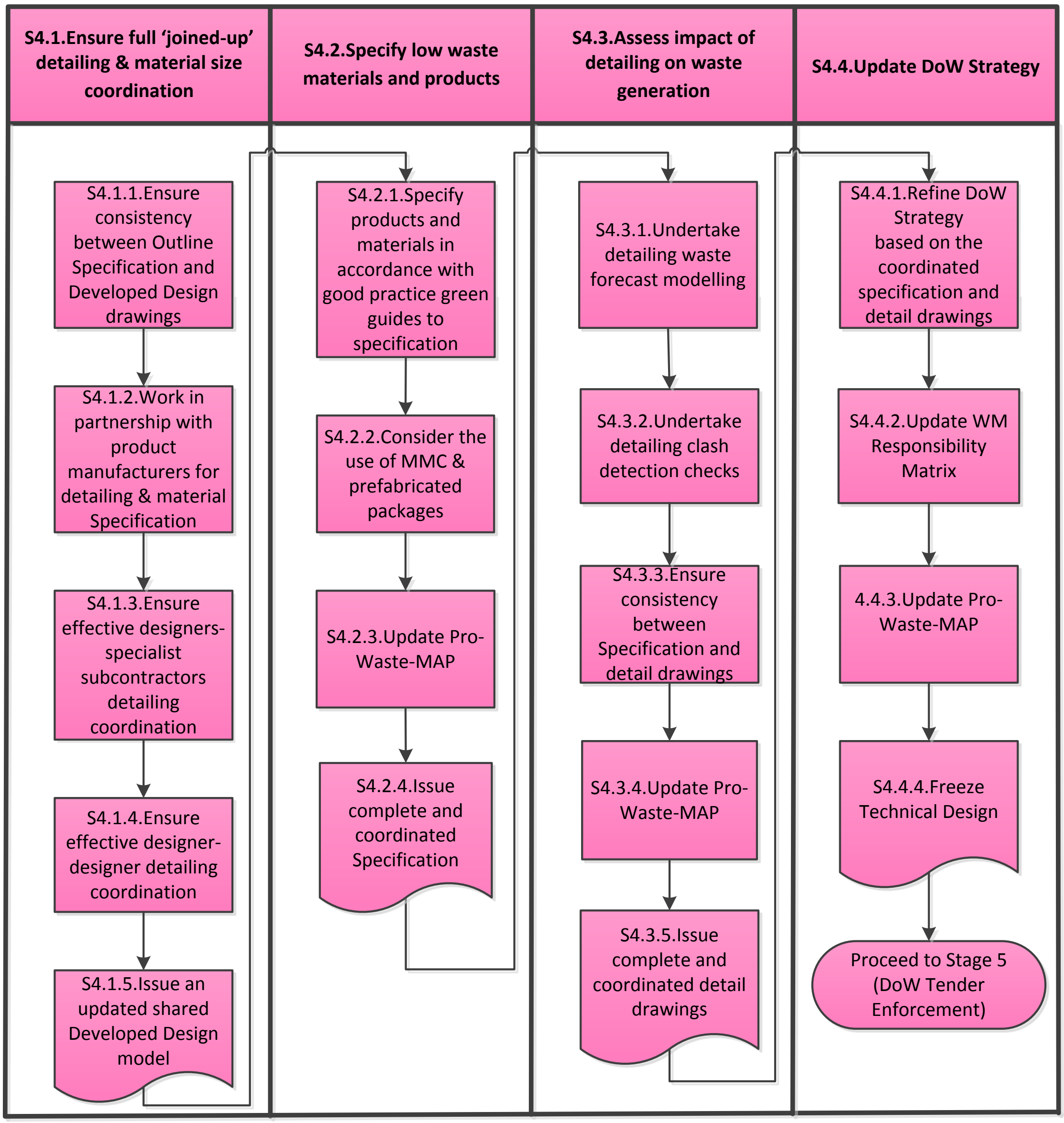



**Figure 6.9: Level 2-Stage 4 (Technical Design) DoW Framework**

## Level 2-Stage 5 (Tender) DoW Framework

As shown in Figure 6.10, Level 2-Stage 5 (Tender) DoW Framework comprises a breakdown of three DoW strategies and actions (S5.1, S5.2 and S5.3) that emanated from Level 1 Framework. These are listed and described below.

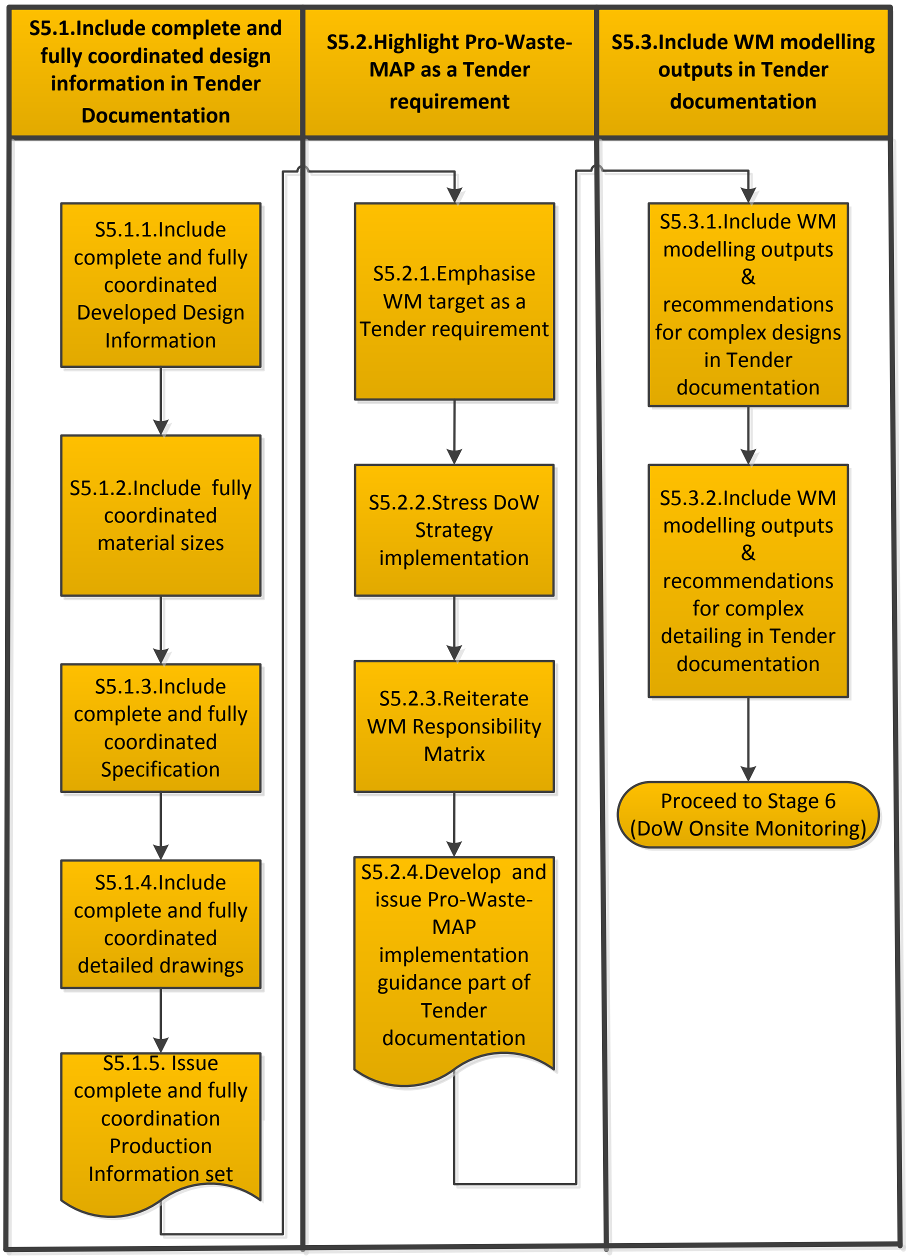



**Figure 6.10: Level 2-Stage 5 (Tender) DoW Framework**

- *S5.1.Include complete and fully coordinated design information in Tender Documentation*. This DoW process will ensure that complete and fully coordinated production information is issued in tender documentation.
- *S5.2.Highlight Pro-Waste-MAP as a Tender requirement*. This DoW action highlights and reinforces the agreed project DoW expected outcomes and reiterates compliance with *Pro-Waste-MAP* requirements.
- *S5.3.Include WM modelling outputs in Tender documentation*. Waste generation forecast outputs that were conducted in the Design Development

and Technical stages, particularly for complex design and details, are included in tender documentation.

**Level 2-Stage 6 (Construction) DoW Framework**

As shown in Figure 6.11, Level 2-Stage 6 (Construction) DoW Framework comprises a breakdown of four DoW strategies and actions (S6.1, S6.2, S6.3 and S6.4) that emanated from Level 1 Framework. These are listed and described below.

- *S6.1.Develop material ordering schedule in accordance with PRO-Waste-MAP.* This DoW action ensures that the material procurement strategy and associated material ordering schedule are developed in accordance with *Pro-Waste-MAP* to avoid alterations to material specification and associated design changes during the construction stage.
- *S6.2.Develop Onsite Construction Programme in accordance with Pro-Waste-MAP*. *Pro-Waste-MAP* requirements are reiterated through training of onsite personnel and via onsite *Pro-Waste-MAP* workshops with sub-contractors.
- *S6.3.Ensure effective monitoring of PRO-Waste-MAP*. This is achieved through regular onsite *PRO-Waste-MAP* progress meetings and updates that lead in the production of a *Pro-Waste-MAP* compliance and monitoring report.
- *S6.4.Capture and record WM performance at project closeout*. The final DoW actions at the end of each project involves:
    - an assessment of the actual project WM performance at project closeout against agreed WM target in the Briefing stage and update *Pro-Waste-MAP* accordingly;
    - produce a project WM Performance, lessons learned and recommendations report; and
    - input the resulting project DoW evaluation findings in the *Waste Minimisation Knowledge Bank (Know-Waste).*

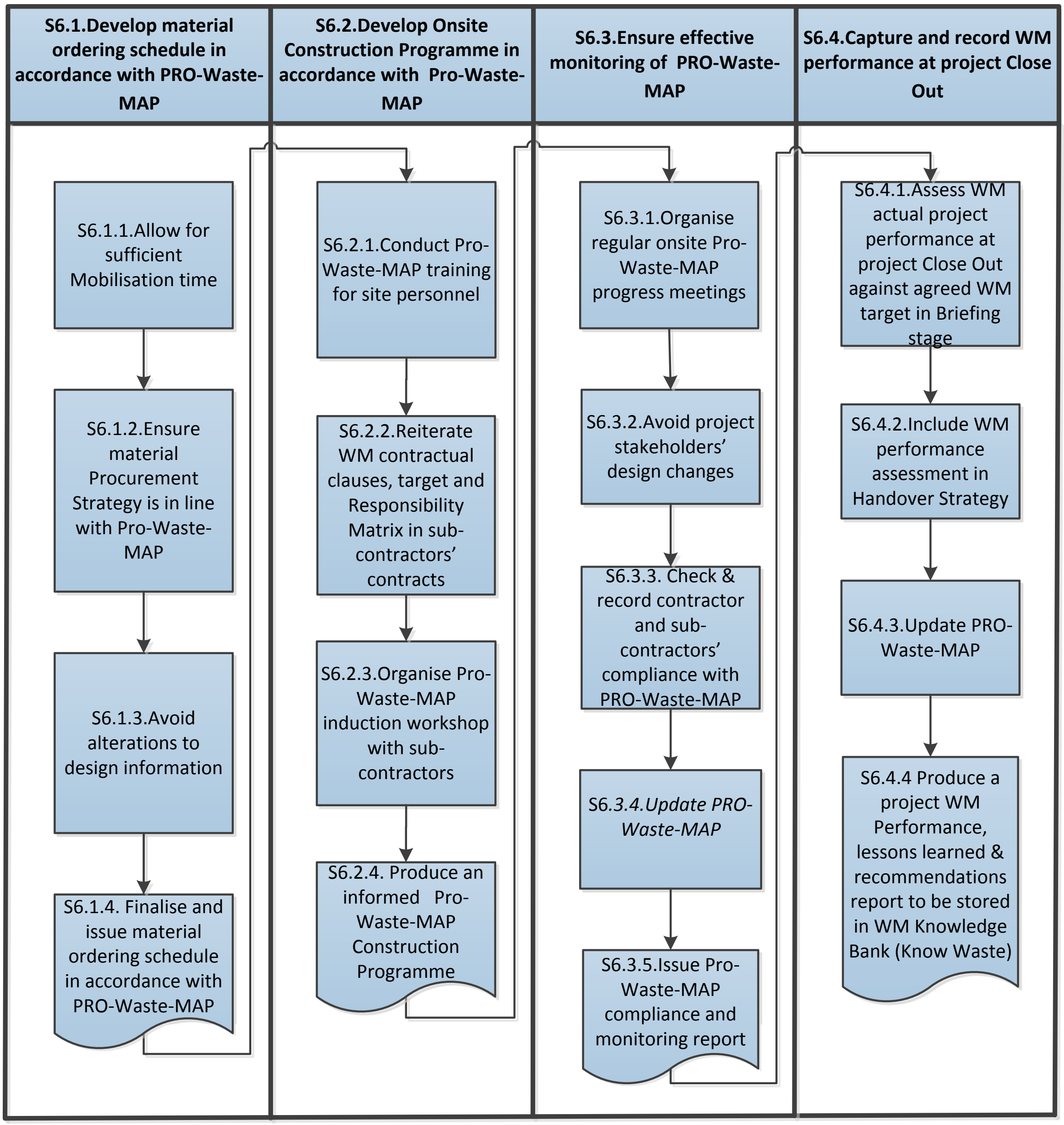



**Figure 6.11: Level 2-Stage 6 (Construction) DoW Framework**

## 6.3 Designing out Waste (DoW) Framework industry review

The aim of the industry review process of the proposed DoW Framework was to assess and refine its structure, clarity, appropriateness and potential impact. The Framework industry review objectives were as follows.

- Examine the clarity of Level 0, 1 and 2 Framework structure and content.

- Assess the appropriateness of the proposed DoW process information flow and actions in Level 0, 1 and 2 Framework.
- Evaluate the Framework's potential adaptability.
- Assess the Framework's potential impact on continuous construction waste minimisation improvement.

The industry review process comprised a questionnaire survey (Appendix 3.1) and a follow-up focus group (Appendix 3.2). The methodological approach of both industry review instruments are described in Section 3.6.2 and the results are discussed in the sections below.

### 6.3.1 DoW Framework industry review sample profile

As discussed in Chapter 3, the Framework industry review questionnaire sampling frame consisted of members of the RIBA Practice Committee (15 architects) and the RIBA Sustainable Futures Group (13 architects). The follow-up industry review focus group engaged eight industry review questionnaire respondents (Table 6.2).

**Table 6.2: Participants' profile of DoW Framework industry review focus group**

| Interviewee Code | Length of architectural practice (years) |
|---|---|
| RIBA 1 | 27 |
| RIBA 2 | 19 |
| RIBA 3 | 36 |
| RIBA 4 | 23 |
| RIBA 5 | 18 |
| RIBA 6 | 31 |
| RIBA 7 | 25 |
| RIBA 8 | 20 |

### 6.3.2 DoW Framework industry review questionnaire results

Out of the dispatched 28 questionnaires, 16 completed surveys were received, representing a 57% response rate. The results of the Framework industry review results are examined below.

Respondents were asked to rate their level of agreement on the clarity the Framework's structure and DoW process flow and the familiarity with its content from

1 (Strongly disagree) to 4 (strongly agree). The results, which are shown in Table 6.3 and 6.4, reveal a high agreement level in which all respondents 'agree' or 'strongly agree' on all aspects of the Framework clarity and content familiarity. Indeed, mean values range from: 3.76 to 3.87 for clarity; 3.84 to 4 for familiarity with content; and 3.61 to 3.90 for the clarity of DoW process information flow. Additionally, there was a greater degree of consistency in rating highly their agreement with the appropriateness of Level 2 (Stage 1 to Stage 6) DoW actions and decisions (mean values from 3.90 to 3.92).

**Table 6.3: Clarity of Level 0 and Level 1 Framework structure and DoW process information flow**

| | DoW Framework Level 0 | DoW Framework Level 1 |
|---|---|---|
| Clarity of the structure | 3.87 | 3.83 |
| Familiarity with content | 4 | 3.87 |
| Clarity of DoW process information flow | 3.90 | 3.76 |

**Table 6.4: Clarity of Level 2 (Stage to Stage 6) Framework structure and DoW process information flow, actions and decisions**

| | DoW Framework Level 2 | | | | | |
|---|---|---|---|---|---|---|
| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 |
| Clarity of the structure | 3.76 | 3.76 | 3.76 | 3.76 | 3.76 | 3.76 |
| Familiarity with content | 3.84 | 3.84 | 3.84 | 3.84 | 3.84 | 3.84 |
| Clarity of DoW process information flow | 3.69 | 3.61 | 3.86 | 3.91 | 3.91 | 3.90 |
| Appropriateness of DoW actions and decisions | 3.90 | 3.90 | 3.90 | 3.90 | 3.90 | 3.92 |

### 6.3.3 DoW Framework industry review focus group results

Qualitative data on the DoW Framework industry review were gathered through a follow-up focus group with eight questionnaire responding architects who are members of two influential RIBA practice and sustainability committees (see Section 3.6.2.2). Textual data on: Framework improvement suggestions; its appropriateness and adaptability; and its potential impact assessment on continuous construction waste minimisation improvement were captured in an A1 flip chart (Appendix 3.2). The findings of the three focus group activities are presented below.

### 6.3.3.1 Suggestions for DoW Framework improvement

**Table 6.5: Focus group participants' suggestions for Framework improvements and consequential refinements and revisions**

| Improvement suggestion | Action |
|---|---|
| *Add keys to Framework Level 0, 1 and 2.* | Process and arrow keys were added to all eight diagrams in the Industry Reviewed DoW Framework (see Figures 6.9 to 6.16) and in the newly added Framework keys (see Appendix 4.1). |
| *Add Framework glossary.* | A new Appendix 4.2 listing Framework terms was produced. |
| *Add supporting tables to relate design waste causes to the proposed Framework DoW actions and decisions.* | Five new tables (see Appendix 4.3.1 to 4.3.5) were produced to correlate the research findings on design waste causes to the proposed Framework DoW actions and decisions. |
| *Distinguish between process and decision making arrows in Framework Level 1.* | Representation of decision making arrows were modified in the Industry reviewed DoW Framework Level 1 (see Figure 6.10) and in the newly added Framework keys (see Appendix 4.1) to differentiate them from process arrows. |
| *Add 'contractual' to S5 (DoW Tender Enforcement) in Framework Level 0 and associated stages in Level 1 and 2.* | The word 'contractual' was added to S5 (Level 0 and Level 1); S5.2 (Level 1 and Level 2) and S5.2.1 and S52.4 (Level 2) in the Industry reviewed DoW Framework diagrams (see Figures 6.9 to 6.16). |
| *Add a new process S2.4 (Update DoW Strategy) in (Framework Level 1).* | S2.4 (Update DoW Strategy) was added in Framework Level 1 and Level Stage 2 (Figure 6.10). |
| *Move S1.3.2 (Framework Level 2) to Framework Level 1, under Stage 5 (S5).* | S1.3.2 was moved from Framework Level 2 to the industry reviewed Level 1 (see Figure 6.10) A new code was assigned to it: S5.4 |
| *Replace 'Concept Design' in S2.3.1 and S2.3.2 (Framework Level 2) by 'design concept'.* | This was revised accordingly in the Industry Reviewed DoW Framework (see Figure 6.12). |
| *Replace 'Freeze and issue Final Project Brief' in S2.3.4 (Framework Level 2) by 'Agree Final Project Brief sign off'.* | This was revised accordingly in the Industry Reviewed DoW Framework (see Figure 6.12) |
| *Replace 'contractor' in S3.1.2 (Framework Level 2) by 'buildability advisor'.* | This was revised accordingly in the Industry Reviewed DoW Framework (see Figure 6.13). |
| *Replace 'Freeze Developed Design' in S3.4.4 (Framework Level 2) by 'Agree Developed Design sign off'.* | This was revised accordingly in the Industry Reviewed DoW Framework (see Figure 6.13) |
| *Replace 'Freeze Technical Design' in S4.4.4 (Framework Level 2) by 'Agree Technical Design sign off'.* | This was revised accordingly in the Industry Reviewed DoW Framework (see Figure 6.14). |
| *Replace 'design information' in S6.1.3 (Framework Level 2) by 'drawings and specification'.* | This was revised accordingly in the Industry Reviewed DoW Framework (see Figure 6.16). |
| *Add 'actual' after 'project' in S6.4.4 (Framework Level 2).* | This was revised accordingly in the Industry Reviewed DoW Framework (see Figure 6.16). |

In the first focus group activity participants were asked to provide written comments to help improving the Framework design. They offered very insightful suggestions to enhance several Framework aspects. As shown in Table 6.5, all participants' suggestions for improvement during the industry review process were recorded, actioned and taken into consideration to produce the industry reviewed DoW Framework. As such, the eight industry reviewed DoW Framework Level 0, 1 and 2 diagrams and their associated keys are listed in Table 6.6 and presented in Appendix 3.3 as new figures.

**Table 6.6: List of industry reviewed DoW Framework appendices**

| Appendix number | Industry reviewed DoW Framework |
|---|---|
| 3.3.1 | Level 0 DoW Framework. |
| 3.3.2 | Level 1 DoW Framework |
| 3.3.3 | Level 2-Stage 1 (Briefing) DoW Framework |
| 3.3.4 | Level 2-Stage 2 (Concept Design) DoW Framework |
| 3.3.5 | Level 2-Stage 3 (Design Development) DoW Framework |
| 3.3.6 | Level 2-Stage 4 (Technical Design) DoW Framework |
| 3.3.7 | Level 2-Stage 5 (Tender) DoW Framework |
| 3.3.8 | Level 2-Stage 6 (Construction) DoW Framework |

#### 6.3.3.2 DoW Framework appropriateness and adaptability

In the second focus group activity, participants were asked for their assessment on the Framework's appropriateness and adaptability to improve design waste minimisation practices (Appendix 3.2). Their comments were fundamentally positive and assuring. Participants believed that the framework should "*add a noticeable value to designing out waste knowledge*" due to limited literature in the field. They reported that the framework should assist architects improve their design waste performance as it enables architects to understand and manage design waste "*though a clear, structured and sequential methodology*" and "*neatly outlined waste minimisation process for each project stage*". There was a consensus among the focus group participants that the enclosed DoW processes and actions to perform under each RIBA Plan of Work stage would make the "*Framework readily useable in design projects*". However, client leadership and active engagement of other designers was deemed critical in a successful implementation of the Framework. They referred to the Framework's Pro-Waste-MAP as "*a novel approach and forward thinking*" to manage designing out waste feedback, lessons learned and knowledge reuse. in  and knowledge bank is  In terms of adaptability and scalability, the participants pointed out that “the design of the Framework is in line with the RIBA Plan of Work stages, which makes it “*suitable for any project size and could be used for new build as well as retrofit projects”.*

#### 6.3.3.3 DoW Framework potential impact on continuous improvement

In the last focus group activity, participants were asked for their views on the potential impact of the Framework on continuous construction waste minimisation improvement (Appendix 3.2).There was a shared view that the Framework has a significant potential to provoke a design waste change management. This was attributed to the sequential and level of details of DoW processes and actions leading to informed decisions at the end of each project stage.  There was a common view among participants that the Framework is a useful, clear and detailed DoW decision making tool. As such, it has the potential to make a noticeable impact on designing waste minimisation continuous improvement. They, however, note that “*a genuine collaborative approach among projects members is required and necessary*”. They suggested that the framework “*could be associated with BREEAM to assist with waste credits*”, and the RIBA could use the framework or convert its content into a code of practice for architects. For example, it would be straightforward to “*incorporate designing out processes of the framework into the RIBA Action Plan to Delivering Construction 2025*”. As such, they recommended that the Framework ‘ Waste Minimisation Knowledge Bank “*could be managed by the RIBA to allow architects to add their best practice, which will eventually become a focal source of DoW guidance*”. They concluded that if implemented by the RIBA, “*the proposed framework would significantly contribute to a proactive and sustainable designing out culture in architectural practices*”.

During the plenary session the author asked the delegates for their thoughts on the use of the DoW Framework within the newly published RIBA Plan of Work 2013 (RIBA, 2013) and whether they foresee any associated problems. All focus group participants concurred that the content of the Framework can easily and automatically be transferred to the RIBA Plan of Work 2013. This was substantiated by RIBA 5 who pointed out that “the RIBA Plan of Work 2013 is just a streamlined version of the RIBA Plan of Work 2007". RIBA 2 went further by saying that "since the Framework is structured in line with the main conventional project stages from briefing through design stages to onsite operations, I believe that the Framework would be compatible with future RIBA Plan of Work versions or other international architectural design practice protocols and procedures".

In the closing address, the author thanked the focus group participants for their attendance, active participation and valuable feedback to enhance the DoW Framework.

## 6.5 Limitations of the DoW Framework context and remit

As stressed in the research aim, the DoW Framework was specifically designed to aid architects embed design waste minimisation strategies in their building design projects. Hence, it is intended to be used by architects rather than other designers and its implementation is limited to building projects rather than civil and infrastructure projects. Additionally, the Framework was developed as a design waste minimisation tool from a project inception to completion. Therefore, it was not devised to minimise waste across a building life cycle stages. As such; the DoW Framework does not contain asset life cycle waste reduction design strategies, such designing for deconstruction.

## 6.6 Summary

This chapter presented a description and explanation of DoW Framework structure and three level components. A detailed account for each Framework Level was provided and supported by respective illustrations based on process mapping flow charts. The industry review quantitative results from the questionnaire and qualitative findings from the focus group revealed that participating architects concurred that the Framework structure and DoW information flow and processes are clear. Additionally, the industry review results indicated that the Framework is appropriate as a designing out waste tool regarding the project type and size. Furthermore, the participants of the industry review focus group opined that the Framework has a significant potential to help architects integrate design waste strategies in their projects and enable them to continuously improve their DoW knowledge practice. The implications of the DoW Framework and other related research findings are discussed within the context of literature in the next chapter.

# CHAPTER 7

# DISCUSSION

## 7. 1 Introduction

This chapter presents a discussion of themes that emerged from the findings of this research. The relationship between the research questions, objectives, philosophical stance and adopted research strategies and methods are summarised In Table 3.1 and discussed in Section 3.2. As noted in Section 2.12, five key questions have arisen from the synthesis of the literature review, which addressed Objective 1, 2 and 3 (see Section 1.3 and Figure 1.1). Subsequently, the five research questions, which address Objectives 4, 5, 6 and 7 (see Sections 1.3 and 2.1) fuelled and guided the stages and processes of this research. These are as follows.

1. What is the current status of construction practice?
2. What are the key construction waste minimisation constraints and enablers?
3. What are the principal construction waste origins?
4. What are the root causes and sources of design waste?
5. How can architects adopt and sustain designing out waste as an integral part of the design process?

A fivefold thematic discussion, which is structured in line with the above questions, is presented below to examine the implications of the findings within the literature context.

## 7.2 Status of construction waste minimisation practice

Although responding architects and contractors concurred that waste is a significant predicament in construction, architectural practices appeared reluctant to implement waste minimisation in their current projects. The findings of this research revealed that waste is not a priority in the design process, as such it is not initially considered at the RIBA Plan of Work stages A and B (Appraisal and Design Brief stages Indeed, responding architects confirmed that waste minimisation strategies are hardly ever implemented during Concept and Developed Design stages. Additionally, they do not consider that waste is generated during the design process, which was a concerning denial, acknowledged by responding contractors. Architects' perspectives on design waste are in sharp contrast to the views of the participating contractors. Furthermore, findings from several studies in the literature revealed that a substantial amount of construction waste is directly or indirectly associated with design activities (Keys *et al.*, 2000 Innes, 2004; WRAP, 2009; Yuan and Shen, 2010; Chen *et al.*, 2011, Panos and Danai, 2012; BSI, 2013; BSI, 2015).

The research findings show that poorly defined responsibilities across the RIBA Plan of Work briefing, design and tender stages are leading to confusion on who should control and monitor waste management. As discussed in Chapter 4, architects argued that waste is an onsite issue for contractors to control. Contractors countered that a failure to address waste generation during Concept, Developed and Technical design stages and poor waste management practice by sub-contractors were the consequences of a failure to allocate roles and responsibilities in contract documents. This was echoed by the findings of Poon *et al.* (2007, p. 468) who revealed that there had been very few endeavours from architects to adopt waste minimisation strategies, "*which were thought to be the responsibility of the contractor*". In addition, Greenwood (2003, p.4) called for a fully integrated waste minimisation system at the contractual stage that "*should identify and communicate the responsibilities for waste minimisation between all project stakeholders*".

Environmental accreditation, such as ISO 14001 certification, acts as a process for achieving continuous environmental improvement. The results of this research, which are presented in Chapter 4 and illustrated in Figure 4.5, reveal that non-ISO 14001 certified architectural firms hardly ever tried to reduce waste. Furthermore, all the architects without ISO 14001 certification had never conducted a waste estimation feasibility study. On the other hand, over 90% of contractors with ISO 14001 certification and 88% of contractors who had a waste management policy argued that they provided proper storage facilities. However, there was no evidence of a link between waste management policies and contractors' practices in terms of reuse and recycle of waste materials. This aligns with the results of a research study by Poon *et al.* (2004a) who revealed that no correlation was established between ISO 14001 accredited contractors and their waste management practices. However, insights into the impact of certified environmental management systems on architects' waste reduction performance is absent from the literature.

## 7.3 Construction waste constraints and enablers

The majority of the participating architects and contractors believed that training is a major enabler to improving waste minimisation practices. The SPSS test results of this research indicate a strong correlation between effective training and implementation of waste minimisation practices. A statistical test was performed to identify the impact of architectural practices' waste related training on the implementation of waste estimation practice during the design stage (Figure 4.6) indicate that responding architects who did not have any training, 68% rarely or had never implemented waste reduction strategies and 79% hardly ever or never conducted a feasibility study of waste estimation. Architects also noted that training to ensure awareness and compliance is a significant challenge, which suggests a general problem with the industry's level of engagement with waste management training.

There was a consensus among both architects and contractors that financial rewards and legislation were key incentives to drive waste minimisation. As such, they called for a reward system to remunerate project stakeholders for good waste minimisation performance. Therefore, increased fiscal measures or fines for failing to reduce waste might have a more positive effect on waste minimisation practices than voluntary approaches. Similar results were provided by Udawatta *et al.*, 2015, who suggested that a possible encouragement to implementing waste minimisation practices would be the introduction of an incentivised financial system for waste reduction and segregation.

From a practical perspective, architects reported that client requirements, training and understanding the underlying causes of waste at Appraisal stage could act as catalysts for change in designing out waste attitudes. However, contractors argued that: incorporating waste minimisation in the design brief; easy ways to recycle; sub-contractor's agreements on waste management practices; and interest from management and awareness of staff could offer improvements. The latter aligns with results from work carried out by Wang *et al.* (2015) whose findings suggested that managerial staff consider time, cost and quality to have a much greater significance than environmental issues. Contrary to the inference of the responding contractors, Lu *et al.* (2015) revealed that sub-contractors are of the view that construction waste management is the contractor's responsibility. The same study also identified poor off-loading, storage of materials and poor design as the main causes of onsite waste generation.

## 7.4 Construction waste origin evaluation

There was an agreement among responding architects and contractors that the main origins of construction waste are related to design, site operations, procurement routes, material handling and sub-contractors' practices. They considered that 'last minute changes due to client requirements' and 'design changes' were the underlying causes of waste during Developed and Technical Design stages. This aligns with the findings of Wang *et al.* (2015); Poon et al (2007 and 2004a); Ekanayake and Ofori (2000); and Faniran and Gaban (1998). The participating architects raised concerns regarding design changes by contractors and their inaccurate ordering practice; whereas contractors regarded poor design, inferior design brief and differences between specification and drawings as significant causes of onsite waste production. Architects held the contractor responsible for 'lack of forward planning' and 'poor reading of design information', including a failure to follow specification and details; whereas contractors argued that waste production was related to buildability, untrained labour, material damage and poor waste management by sub-contractors.

## 7.5 Root causes and sources of design waste

A holistic approach that considers the impact of multifaceted project dynamics from the inception phase to the construction stage on design waste causes and sources is absent from the literature. These have been explored in this research.
Six overarching thematic design waste causes emerged from the research findings, which are discussed below.

### 7.5.1 Imperceptible waste minimisation at project inception

The research findings reveal that there is a strong relationship between misinformed clients on waste minimisation benefits, namely cost saving measures and consequential design waste causes during Appraisal and Design Brief stages and the subsequent processes and activities during Concept, Developed and Technical Design and Tender Action stages Indeed, waste minimisation strategic recommendations are not routinely issued in briefing documents, written into contracts and enforced in tender documents. This in turn has led to confusion over stakeholders' waste minimisation roles and responsibilities throughout all project stages.

### 7.5.2 Insufficient designing out waste drivers

Since designers are not legally required to design out waste in their projects, responding architects maintained that waste minimisation is often a moral expectation from the architect, which is often not sufficient pressure to consider it in design. They added that financial rewards would have more effects on designing out initiatives. On the other hand, responding contractors believed that failure to conduct waste minimisation feasibility appraisals and cost benefit studies during the briefing stages by architects and quantity surveyors respectively is a significant waste cause.

### 7.5.3 Lack of architects' understanding of design waste causes and sources

The findings of the questionnaire surveys and interviews suggest that architects do not initiate minimisation measures During RIBA Plan of Work Stages, A, B, C, D, E and F because of the assumption that waste occurs during the Construction stage and is rarely generated during the design process. This perception has partially resulted in limited architects' waste reduction input during the design process and recommendations in tender stages.

### 7.5.4 Limited waste related benchmarking data and guidance

Responding architects and contractors agreed that existing construction waste benchmarking data is piecemeal and not universally applied, making it difficult to confidently set waste reduction baselines and targets at Appraisal and Design Brief stages. Although responding architects recognised that few existing designing out waste guides, such WRAP (2009), are helpful, they emphasised that there is a lack of robust methods to assist them making informed designing out waste decisions in a holistic manner that considers all design dynamics in construction projects. There was a common view among participating architects that they are prepared to work with the client, consultants and the contractor to produce low waste designs; However, "*they do not know how to do it*", as A3 noted (see Table 5.1).

### 7.5.5 Inadequate project stakeholders' coordination and communication

Poor coordination and communication among project stakeholders has been highlighted in this research as a common design waste cause across all project stages. This encompasses: inadequate client-architect communication; lack of joined-up design coordination between the architect and consultants, material sizing and detailing information; uncoordinated architect-specialist contractor design information; and ineffective coordination between the architect and material manufacturers.

### 7.5.6 Time constraints

Time constraints were deemed by all responding architects and contractors as an overarching design waste cause across all project stages. Tight project schedules disallow architect and consultants to conduct feasibility and cost benefit studies. Similarly, insufficient design time schedules act as a setback to research designing out waste strategies and assess the impact of design options on waste generation. Equally, limited timescales during specification, detailing and tender stages result usually in incomplete and uncoordinated design information forcing architects in some cases to revert to off-shelf design, specification and detailing solutions used in previous projects. Additionally, not signing off the design at the end of 'Design Development' stage, which was indicated by all respondents as a significant trigger for design changes during the construction stage, was highlighted as a direct consequence of time constraints.

## 7.6 Adopting and sustaining designing out waste as an integral part of the design process

A limited number of studies explored ways to minimise construction waste through design. These could be broadly categorised into two clusters: offsite buildability techniques and design guides. Several studies explored the impact of prefabrication on waste reduction through a combination of research methods, including simulation (Baldwin *et al.*, 2009; Shen *el al.*, 2009; Zhang *et al*., 2012; Li *et al.*, 2014 and Wang *et al.*, 2015). They agreed that designing in partial or full prefabricated construction techniques lead to less onsite if compared with the use of traditional construction techniques. Although these studies confirmed that offsite buildability techniques are low waste design strategies, they considered prefabrication as an independent design activity without assessing other designing out waste strategies that are required collectively to address design waste origins, causes and sources, as identified and discussed in Chapter 5.

A small number of guides and standards have been developed in the last few years to help designers adopt waste reduction in their projects. These contain: design waste minimisation principles for buildings (WRAP, 2009) and civil engineering projects (WRAP, 2010a); and recommendations for architects in BS 8895 Part 1 and 2 (BSI, 2013 and 2015). As discussed in Chapter 2, WRAP guides and BS 8895 are useful documents for designers to brood over waste predicaments in construction projects. However, they offer broad design waste reduction guiding principles and procedures without associating them to their respective design waste determinants. This was echoed by the participating architects who agreed that WRAP's guide is useful in promoting designing out waste awareness. However, they argued the guide does not act as a designing out waste implementation methodology, as it is not clear how to apply its five principles across all stages of a typical building project. Additionally, guides and methods that adopt an integral and holistic approach to incorporate design waste processes, actions and decisions across all project stages are absent from the literature. This was rationalised by a participating architect who stated that "a process chart that aids the architect in terms of defining potential areas of design waste causes and sources would be helpful and insightful" (A6, see Table 5.1). A10 (Table 5.1) went further by stating that "there is little or highly incoherent information specifically for architects to assist them with a detailed waste minimisation methodology". Such a method was devised in this research through the development and validation of a Design out Waste (DoW) Framework.

The DoW Framework, which was informed by the findings of design waste mapping investigations and reviewed by members of the RIBA Practice Committee and Sustainable Futures Group, provides a holistic and sequential designing out waste decision making tool to embed waste reduction strategies across the RIBA Plan of Work stages. The novel DoW Framework should enable architects to comprehend and assess the impact of their design on onsite waste generation. It should also assist them in the formulation of informed design waste minimisation actions and decisions in each design stage that would align with an integrated closed-loop designing out waste approach. Furthermore, the Framework's Waste Minimisation Knowledge Bank (Know-Waste) should facilitate the reuse of captured waste minimisation knowledge from past projects to benefit future briefs and designs, which will in turn enhance and sustain continuous designing out waste performance.

## 7.7 Summary

This chapter has discussed the emerging themes from the research findings within the context of literature. The themes were structured against five questions that emerged from the synthesis of the literature review, which are summarised at the end of Chapter 2. The findings of this research suggest a lack of architects' engagement with designing out waste practice. This attitude appears to be hindered by: architects' perception that design does not generate waste; their limited understanding of design waste generators; and limited availability of informed guidance. Other designing out waste blockers include: lack of client's waste minimisation objectives in project briefs; undefined waste minimisation responsibilities; incoherent coordination; and communication between project members and time constraints.

The next chapter presents the research conclusions, contributions to the knowledge; and recommendations for industry, government and further research.

# CHAPTER 8

# CONCLUSIONS AND RECOMMENDATIONS

## 8.1 Introduction

This chapter, which contains five sections, presents the research conclusions and recommendations. The first section discussed the fulfilment of the research aim and objectives, supported by a table that synthesises the relationship between the objectives, attainment methods and resulting outputs (Table 8.1). The second section states the main contributions of this research to existing knowledge. The last two sections forward recommendations for project industry, government and further research respectively.

## 8.2. Attainment of research aim and objectives

The findings of the literature review in Chapter 2 in relation to construction waste minimisation drivers; construction waste quantification and source evaluation; and current and emerging construction waste research trends, which addressed Objectives 1, 2 and 3, gave rise to five research questions (discussed in Section 2.12) that guided the subsequent data collection and analysis stages of the research (see Section 3.2 and Table 3.1).

The aim of the research was to develop and validate a Designing out Waste (DoW) Framework that would assist architects to holistically integrate waste minimisation strategies into the design process of buildings. Seven objectives were proposed to achieve the research aim. The fulfilment of each objective is summarised in Table 8.1 and respective conclusions are discussed below.

### 8.2.1 Attainment of Objective 1

The first research objective was to identify and assess construction waste minimisation pressures for change. This was fulfilled through a review of government, academic and industry literature on construction waste management drivers. These included environmental, policy and legislative, economic and business forces that have been helping to shape construction waste management attitudes and practices.

**Table 8.1: Research objectives, research questions attainment methods and resulting outputs**

| Objective | | Research question | Research Method | Research output |
|---|---|---|---|---|
| 1 | Identify and assess construction waste minimisation pressures for change. | N/A | **Literature review** on construction waste management environmental, legislative, economic and business drivers. | - Chapter 2 (Section 2.3).<br>- Publications: Osmani (2012a; 2012b & 2015). |
| 2 | Identify and categorise existing construction waste quantification and source evaluation trends. | N/A | **Literature review** on construction waste quantification, composition, source evaluation and classification and design waste causes. | - Chapter 2 (Section 2.4, 2.5 & 2.6).<br>- Publications: Osmani (2007c; 2007d & 2008b). |
| 3 | Determine and classify current and emerging research and industry construction waste minimisation approaches and tools. | N/A | **Literature review** on construction waste management research and industry trends and tools; and current design waste minimisation approaches and potential strategies. | - Chapter 2 (Section 2.7, 2.8 & 2.9).<br>- Publications: Osmani (2007a; 2007b; 2008c & 2013b). |
| 4 | Identify and evaluate current onsite waste management responsibilities and practices. | 1, 2 & 3 | **Questionnaire survey** involving Top 100 UK contractors. | - Chapter 3 (Section 3.5.1.).<br>- Chapter 4.<br>- Publications: Osmani (2007a; 2009 & 2011). |
| 5 | Determine the extent of the integration of waste minimisation strategies into the current architectural design practice. | 1, 2 & 3 | **Questionnaire survey** involving Top 100 UK architectural practices. | - Chapter 3 (Section 3.5.1).<br>- Chapter 4.<br>- Publications: Osmani (2008a & 2011). |
| 6 | Identify design waste root causes and sources and associated origins across the RIBA Plan of Work stages. | 3 & 4 | **Semi-structured interviews** with 12 architects (partners and associates) and 12 contractors (sustainability and environmental managers). | - Chapter 3 (Section 3.5.5).<br>- Chapter 5.<br>- Publications: Osmani (2013b). |
| 7 | - Construct a Designing out Waste (DoW) Framework to assist architects in embedding design waste reduction strategies in each RIBA Plan of Work stage.<br><br>- Validate the Designing out Waste (DoW) Framework. | 5 | - **Process mapping.**<br><br>- **Questionnaire and follow up focus group**. | - Chapter 3 (Section 3.6).<br>- Chapter 6.<br>- Contribution to BS 8895 development: Osmani (2012c & 2014).<br>- 1 journal paper in progress. |

As shown in Table 8.1, the findings related to the first objective were discussed in Section 2.3 and reported in three published outputs. A number of factors have increased pressure on the construction industry to improve its waste minimisation performance. Indeed, the key drivers for change, which include: the introduction of waste legislation and legal enforcement; and the rising tide of clients' awareness of environmental requirements are putting pressure on the construction industry to improve its waste minimisation practices. Additionally, it was estimated that: waste costs up to 4% of a project turnover; the UK construction industry spends over £1 billion on disposal costs; and £1.5 billion was associated with delivered materials to the site, unused and subsequently landfilled.

The cumulative effect of all of legislative, business and economic influences have been acting as clear pressures to push the construction industry to adopt material resource efficiency and waste reduction practices. Such developments come at a critical time because recent data show construction waste production is unsustainable. Indeed, the construction and demolition activities generate 120 million tonnes of waste each year, of which an estimated 10-15% was attributed to unused and skipped materials and products. The combined pressures for change have contributed to a gradual transition away from landfilling towards a more effective onsite waste management, which is being led by several industry initiatives, including that of BUILDUK. The latter represents over 30 leading contractors operating in the UK. It aims at promoting the UK construction industry and supporting its members in delivering excellence by encouraging contractors to work together with their clients and supply chains to promote change and best practice, including waste management and minimisation.

At present, legislative and fiscal measures are undoubtedly the major drivers for construction waste reduction in the UK, which were directly related to the rising Landfill Tax, which stands at £82.60 per tonne from April 2015. This aimed at making current unstainable waste disposal too costly. It has been argued in the literature that this reactive trend is likely to increase and so will the costs associated with waste generation and disposal. That said; current legislation fails to impose responsibilities on architects to minimise waste at a project level. Design waste reduction was deemed in the reviewed literature as by far most practical way to reduce waste during the pre-construction stage, rather than trying to put in place waste mitigation and management measures later on during the construction stage.

### 8.2.2 Attainment of Objective 2

The second research objective was to identify and categorise existing construction waste quantification and source evaluation trends. This was accomplished via a critical review of literature of construction waste quantification, composition, source evaluation and classification and design waste causes. As highlighted in Table 8.1, the findings related to the second objective were discussed in Sections 2.4, 2.5 and 2.6 and reported in three published outputs.

It is widely accepted in the literature that a better understanding of construction quantification and composition could assist project stakeholders in establishing informed construction waste targets and benchmarks. However, there was no agreement on common waste streams that are generated in a typical construction project. This was associated with a number of factors, including the type of construction processes that are different from project to project. For example, a project using offsite construction tends to produce less concrete waste streams.

There is a consensus in the literature that construction waste is commonly generated across all project stages from inception to completion. Different and broad approaches to the classification of construction waste source evaluation are gleaned from the literature, which were summarised in Table 2.1. However, an agreed approach for the classification of construction waste origins, causes and sources is absent from literature.

Similarly, the literature identified several design waste causes, which were highlighted in Table 2.2. These range from design changes and inadequate project stakeholders' coordination and communication to limited use of design standardisation and designers' unfamiliarity with alternative methods and materials. However, the literature failed to distinguish between design waste origins, causes and sources and classify them in accordance with each project stage.

### 8.2.3 Attainment of Objective 3

The third research objective was to determine and classify current and emerging research and industry construction waste minimisation trends. This was fulfilled through an examination of the literature related to current and emerging construction waste management academic and industry approaches and tools; construction waste minimisation through design; and potential strategies to reduce design waste.
As noted in Table 8.1, the findings that are associated with the third objective were discussed in Section 2.7, 2.8 and 2.9 and reported in four published outputs.

This research contributed to existing knowledge through the classification and organisation of current and emerging approaches to manage and minimise construction waste into 16 clusters. These were summarised in Table 2.3, which shows that the current thinking of waste minimisation practices is heavily focussed on managing onsite wastes that have already been produced. As such, tools and methods, such as SMARTWaste, were developed to record and audit onsite waste streams. These, however, do not associate onsite waste to its source evaluation, particularly design waste.

A large amount of literature revealed that there are significant opportunities for designing out waste in the construction, maintenance and refurbishment of buildings. However, guidance documents, which are currently available to assist designers embed waste reduction strategies in their projects, are limited and their contents are rather generic. These include WRAP (2009, 2010a) and BSI (2013, 2015), which contain broad principles such as ‘design for offsite construction’. However, they do not encompass a structured approach for designing out processes, actions and decisions in each design stage.

### 8.2.4 Attainment of Objective 4

The fourth research objective was to identify and evaluate current onsite waste management responsibilities and practices. This was achieved through a questionnaire survey that was sent to the top 100 UK contractors to investigate existing onsite waste management responsibilities, organisational and auditing methods and challenges. The methodological approach of the questionnaire survey is described in Section 3.5.1 and the respective results were discussed in Chapter 4 and reported in three published outputs.

Contrary to current architects' waste minimisation practices, the questionnaire results indicated that contractors are pursuing a proactive approach to managing onsite waste through well-defined waste management policies. However, it appeared that few attempts were made to reuse onsite waste, particularly excavated soil. Responding contractors reported that the main design waste causes are 'design changes' by the client or the architect. They also identified: 'poor design'; 'inadequate design brief'; and not working to standard dimensions as main causes of consequential onsite waste generation. They believed that waste could be substantially reduced through three focussed activities: low waste design processes; better waste management practices by sub-contractors; and in a change of culture to improve companies and individuals' attitudes and perceptions.

### 8.2.5 Attainment of Objective 5

The fifth research objective was to determine the extent of the integration of waste minimisation strategies into the current architectural design practice. This was achieved through a questionnaire survey that was sent to the top 100 UK architectural practices to ascertain their views on design waste minimisation practices within their profession and the associated barriers. The methodological approach of the questionnaire survey is described in Section 3.5.1 and the respective quantitative and qualitative results were discussed in Chapter 4 and reported in two published outputs.
The findings of the questionnaire revealed that the participating architects are aware of the importance of waste minimisation. However, they acknowledged that waste minimisation is not considered during design.

The research findings also suggest that architects are showing a growing interest in environmental accreditation that could potentially help towards a better waste minimisation performance. However, there was no clear relationship between companies having ISO 14001 certification and implementing actual waste minimisation activities. That said, architects reported that they are restrained by internal and external factors, namely: clients' requirements; lack of training; uncertainty regarding organisational waste minimisation responsibilities, perceptions of waste; and limited understanding of the underlying causes of design waste.

### 8.2.6 Attainment of Objective 6

The sixth research objective was to identify design waste root causes and sources and their associated origins across the RIBA Plan of Work stages. This was fulfilled through semi-structured interviews involving 24 questionnaire respondents. They consisted of 12 responding partners and associates from architectural practices and 12 responding sustainability and environmental managers from contracting companies. The interview methodological approach is described in Section 3.5.2 and the respective qualitative results were discussed in Chapter 5 and reported in one published journal paper.

The findings of the questionnaire survey were augmented via in-depth semi-structured interviews, which provided the qualitative research for the study. The results of the interviews culminated in the development of detailed design waste maps across all project phases from Appraisal to Construction stages. These were presented in Chapter 5 and summarised in Figure 5.1. In each design waste map, design waste causes were related to their respective origins and sources. Within the context of this research and as noted in Chapter 2, waste 'causes' refer to direct and/or indirect waste generators (e.g. design changes). Waste 'sources' are associated with waste generation provenance and project stakeholders' contributory responsibility (e.g. client). Finally, waste 'origins' are denoted to project stages (e.g. Briefing) or processes (e.g. architectural detailing) during which waste 'causes' and 'sources' are identified and associated.

The interviewees agreed that that designing out waste has never been the most glamorous end of sustainable design. Moreover, results suggested that architects' passive designing out waste engagement is:

- affected by a wide practice of not having waste minimisation as a brief requirement, no baseline setting and lack of designers' understanding of design waste causes;
- hindered by limited 'know-how' and incoherent coordination and communication between project members; and
- impeded by time constraints and disjointed design information.

Cumulatively, the above holdups disallow due waste minimisation consideration, implementation and monitoring during the design stages.

### 8.2.7 Attainment of Objective 7

The last research objective was to construct and validate a Designing out Waste (DoW) Framework to assist architects in embedding design waste reduction strategies in each RIBA Plan of Work stage. This was accomplished through the design, development and industry review of the Designing out Waste (DoW) Framework.

The methodological approach of the DoW Framework design, which was based on process mapping, is described in Section 3.6.1 and its development and associated structure, content and levels are presented in Chapter 6. Additionally, the DoW Framework industry review methods, which are discussed in Section 3.6.2, included a questionnaire and follow-up focus group with members of two influential RIBA committees. The results of the DoW Framework industry review are reported in Chapter 6.

The design and content of the DoW Framework were dictated by the collected quantitative and qualitative data from the top 100 UK architects and contractors. Furthermore, it was structured in accordance with the findings of the resulting design waste mapping across the RIBA Plan of Work stages (see Appendix 4). As such and in addressing the last research objective, the aim of the DoW Framework was to adopt a holistic and sequential design decisions to embed waste reduction strategies across the RIBA Plan of Work stages and provide a means by which architects can analyse the waste implications of their design decisions. Equally, the aim of the industry review process of the proposed DoW Framework was to assess and refine its structure, clarity, appropriateness and potential impact.

As explained in Chapter 6, the DoW Framework, which is guided by a coding reference system levels and illustrated by process mapping diagrams, is composed of three cascading, interrelated and complementary levels: Level O (high level); Level 1 (a decomposition of Level 0); and Level 2 (six decompositions of Level 1 in line with the key RIBA Plan of Work stages: Briefing; Concept Design; Design Development; Technical Design; Tender and Construction). Each Framework level contains designing out waste processes, sub-processes, decision making milestones and actions in association with the findings of design waste causes. The participating architects in the industry review process provided a number of valuable improvement and refinement suggestions, which are summarised in Table 6.5. Their recommendations were incorporated in the industry reviewed DoW Framework (Figure 6.9 to Figure 6.16).

## 8.3. Contribution to knowledge

The research contributions to knowledge, which are discussed below, are twofold: theory and industry practice.

### 8.3.1 Contribution to theory

Throughout the duration of the PhD programme, several papers that address the research questions of this study were published, which have each resulted in contributions to theory (see list of publications in Appendix 5). The specific research contributions to theory are discussed below.

#### 8.3.1.1 Classification of construction waste management research trends

As highlighted in Chapter 1 and discussed in Chapter 2, the past two decades witnessed a surge in global construction waste management research. This led to a plethora of studies covering a diverse and wide range of related topics., This research contributed to existing theories through the classification of the current and emerging construction waste management research approaches into 16 clusters, which were summarised in Table 2.3; discussed in Section 2.7 and reported in four published outputs from this research (see Table 8.1 and Appendix 5).

#### 8.3.1.2 Contribution to design waste knowledge

This research extends previous work on construction waste prevention through a structured stakeholders-oriented approach to analyse design waste determinants. This research is the first attempt to gauge architects' perspectives on construction waste minimisation by design. As such, Journal Paper 3 (see Appendix 5), which was published in *Waste Management*, provided new knowledge on origins of design waste and novel perspectives on designing out waste. Its contribution to knowledge has been evidenced through 151 Google Scholar Citations by end of April 2016. This research has also established a cohesive relationship between design waste causes and their sources and origins, which is a novel contribution to knowledge that has been reported in several published articles that emanated from this research, as shown in Table 8.1). This should stimulate further research associated with waste reduction at source. Ultimately, the research tested the theory, which underpinned the research philosophical stance, that uninformed design has a significant on onsite construction generation, which requires new understandings of design waste causes and consequential designing out knowledge,

### 8.3.2 Contribution to designing out waste practice improvement

#### 8.3.2.1 Project life cycle design waste mapping

One of the novelties of this research lies in a detailed exploration and assessment of design waste origins, causes and sources that led to the development of five comprehensive design waste maps across the RIBA Plan of Work stages, which were presented in Chapter 5. Specifically, this research has identified three key design waste causes that were not acknowledged in the literature.

- Although architects were aware of the importance of waste minimisation, they believed that waste is produced primarily during site operations and rarely generated during the design stages. As such, few attempts had been made to reduce waste during the design stages. As a result, participating architects concurred that waste minimisation is not considered during design.

- Architects were unaware of design waste generators.
- This research identified four types of 'design changes': client-led; architect-led; contractor-led; and sub-contractors-led alterations during site operations that led to onsite waste generation.

Therefore, the findings of this research in relation to design waste mapping across all project stages should help architects pinpoint design waste causes and sources and assess the impact of their design on onsite waste generation. Additionally, the design waste mapping results should act as a waste generation reference platform to assist construction project stakeholders in the formulation of informed building waste minimisation frameworks and strategies.

The resulting design waste mapping of this research could also be incorporated into design practice guides (e.g. a revised version of the RIBA Green Overlay) and new standards. Indeed, BS 8895-2, which was published in August 2015 referred to Osmani (2013), in which the design waste mapping results of this research were reported.

#### 8.3.2.2 An industry reviewed Designing out Waste Framework

As reported in Chapter 4 and reiterated in Chapter 5, participating architects acknowledged that there is a shortage of comprehensive design waste minimisation guides and methods. As such, the major contribution of this research relates to a significant potential advancement of designing out waste knowledge and practices through the development of an industry reviewed Designing out Waste (DoW) Framework.

The design and development of the DoW Framework adopted a sequential approach to integrate waste minimisation enhanced design processes throughout the RIBA Plan of Work stages. Each stage of the DoW Framework provides a design platform to organise, review and refine designing out waste actions and define associated decisions before proceeding to the next design stage.

As shown in Appendix 4.3, the Framework's DoW actions and decisions were informed by the findings of design waste mapping in which design waste causes and sources were identified in each project stage (design waste origin). The DoW Framework also allows clients, designers and contractors to capture lessons learned through the *Project Waste Minimisation Action Plan (Pro-Waste MAP)*. Finally, the Framework enables a continuous improvement of designing out waste practice from project to project via its *Waste Minimisation Knowledge Bank (Know-Waste)*. This was supported by experienced architects and members of two decisive RIBA committees during the Framework industry review process by stating that "designing out waste feedback, lessons learned and knowledge reuse through the framework Pro-Waste-MAP and knowledge bank is a novel approach and forward thinking". They concluded that the proposed DoW Framework could "significantly contribute to a proactive and sustainable designing out culture in architectural practices".

## 8.4 Recommendations for industry and government

Within the context of the findings and conclusions of this research, several recommendations for industry and government are outlined below.

### 8.4.1 Recommendations for industry

In recognition of the responsibility of the architectural profession, through its leading role in sustainable project performance and a key player in capturing client's requirements onto viable project briefs, architects should be leading the way to inform clients on waste minimisation benefits and associated waste control strategies. The interview results reveal that effective waste minimisation measurement is closely related to the provision of a waste management plan that guides the project activities from inception to completion. This was titled in the DoW Framework as 'Project Waste Minimisation Action Plan (Pro-Waste-MAP). .This should be initiated and led by the client during the inception stage and entrenched in briefing documents. This should in turn pave the way for architects and consultants to generate coordinated design waste reduction solutions during pre-construction stages. Equally, it should enable contractors and sub-contractors to avoid design changes during site operations. It should also contain lessons learned at the end of the construction stage to inform future project briefs.

This research identified poorly defined waste control and management responsibilities as a major impediment for project stakeholders to adopt an integrated and sustainable waste minimisation approach. A waste management responsibility matrix, which was part of the DoW Framework, should be: devised by the architect in coordination with the client and consultants in the briefing stage; included in the project waste minimisation plan; and updated by designers throughout the design process, and implemented by the contractor and sub-contractors during the construction stage.

This research identified the absence of feasibility and cost benefit studies in the early stages of a project as partly responsible for the lack of client's waste minimisation awareness and engagement during the briefing stage. As such, the quantity surveyor should be able to identify potential benefits and communicate this to the client, as it has been reported in several instances throughout the course of this research by participating architects and contractors.

There was a consensus in the literature that design changes during site operations are the most significant onsite waste cause. This was confirmed by the participating architects and contractors who went further by identifying different design change sources, including clients, designers, contractors and sub-contractors. Design changes could be avoided though: a clear strategy by architects to capture client's requirements in the appraisal stage; the production of detailed brief and coordinated design documents between the architect and consultants; and inclusion of complete and fully coordinated design information before the start of site operations.

The findings of this research suggest that efficient waste minimisation requires the commitment and cooperation of all project members. As such, a coherent client-architect; architect-consultants; and designers-contractor coordination mechanism has the potential to avoid unnecessary duplication of effort and rework. Indeed, inadequate design coordination and communication was cited as a reoccurring construction waste cause in the literature. This was echoed in the responses of the research participating architects and contractors who agreed that onsite waste can indirectly occur as a result of ineffective: client-architect; architect-supplier; and designer-designer coordination and communication. A project collaboration and communication protocol, such as a BIM platform, should be agreed by all project stakeholders to be used as a basis to implement the project waste minimisation plan. This should help reducing design and detailing amendments and subsequent onsite waste generation.

Off-cuts as a result of inadequate material size coordination were identified as major waste causes in this research. Therefore, stronger linkages should be established and sustained between designers and material manufacturers and suppliers to harmonise material sizes and optimise industry modular coordination. Similarly, a close waste minimisation working relationship between the contractor and sub-contractors should be corroborated through contractual agreements and recommendations for potential work packages where waste could be minimised.

The proposed DoW Framework contains ‘Waste Minimisation Knowledge Bank (Know-Waste)’, which is a converging waste minimisation knowledge management repository across all project stages. This should be initiated by the client at inception stage and used by designers, contractors and sub-contractors from inception to completion in every project to facilitate the capture of waste minimisation lessons learned and feedback for sharing and reusing them in the planning, processes, activities and decisions in future projects.

The architects and contractors who participated in this research believed that training and accessible sources of information are critical in improving designing out waste and onsite waste management practices. As such architects, structural engineers, service engineers, quantity surveyors, contractors, sub-contractors and material suppliers should undertake regular waste control training for their staff and operatives. Training methods could include: design and onsite waste review workshops; waste forecast and modelling exercises; toolbox talks; and best practice fact sheets.

### 8.4.2 Recommendations for government

Since the government repealed Site Waste Management Plans (SWMPs) Regulations in December 2013, construction sites will no longer need to have a site waste management plan in place before work can begin (see Section 2.3.2). As discussed in Chapter 2, despite the construction industry's mixed response to removal of SWMPS Regulations, BUILDUK, which represents the largest main contractors and their leading trade associations, decided to retain them. For BUILDUK, the use of SWMPs has become best practice enabled cost savings through better waste management whilst increasing a company's environmental credentials. Furthermore, this research revealed that legislation and financial rewards were seen as the major enablers that could significantly drive construction waste reduction practices. Therefore, the government could play a pivotal role in driving construction waste minimisation agenda through a combination of financial reward systems for waste minimisation performance and waste production regulations to improve the industry environmental performance and reduce landfilled waste. At present, there are no legislative requirements for designers to initiate waste minimisation in their projects. As a similar approach to the development of previous joint government and industry initiatives, such as the Strategy for Sustainable Construction (HM Government, 2008a), partnerships between the government and professional bodies of the design industry, such as RIBA, ICE and CIBSE, should be sought to produce designing out waste policies and guidance to support designers with their design waste performance. These should include expected improvement outcomes and bring some coherence to the many schemes and methods aimed at delivering sustainable construction waste minimisation.

This research revealed that there is limited design designing out literature and best practice sharing. This could be incentivised by the government through commissioning designing out waste best practice research and demonstration pilot studies. Additionally, waste minimisation should be a briefing, tender and contractual requirement in public projects in order deliver government-led exemplar designing out waste practice. Such projects should: facilitate the dissemination of design waste reduction best practice; reinforce designing out waste confidence; and compel much needed design waste-related cultural changes.

## 8.5 Recommendations for further research

The following recommendations are suggested for further follow-up research.

This research developed a DoW Framework to be used by architects to improve their designing waste performance. Similar frameworks could be formulated for other building designers, particularly structural and building service engineers.

This research has shown that legislation has been proven by far to be a strong catalyst in improving construction management. Further research could explore improvement measures that are not legislation driven.

This research engaged the top 100 UK architectural practices and contracting firms. Complementary research could investigate attitudes and knowledge of design and construction SMEs toward waste minimisation and develop associated tools and guides to help them reduce waste and save money.

The client being unaware of the benefits, especially associated costs with waste reduction measures, was identified by participating architects and contractors as a major design waste cause during Appraisal and Design brief stages. Further research could be conducted to develop waste minimisation business models for client organisations.

The research has also revealed that: limited architect's involved in Design and Build contracts and inadequate coordination and communication among project stakeholders are significant design waste causes. Therefore, research could be carried out to develop collaborative waste minimisation methods and tools.

Not designing to standard material sizes and incoherent joined-up design and detailing have been recognised in this research as significant waste causes. Hence, research is recommended to develop methods to harness material manufacturing modular coordination and ensure full-joined-up design and detailing information.

The findings of this research suggest that design changes during the construction stage result in significant amounts of onsite waste. As such, research could be conducted to devise analysis and modelling tools to minimise design changes and assess impacts of alterations to design and material specification on waste production.

Further research could also be initiated to develop supporting simulation methods to review and refine the proposed DoW Framework waste forecasting modelling actions.

The DoW Framework includes guidance to reuse captured knowledge from past projects to continuously enhance architects' waste minimisation practice in future projects. Research is recommended to explore the synergies between waste minimisation practice and knowledge management.

Finally, research is recommended to develop the architecture and an online version of the proposed '*Waste Minimisation Knowledge Bank (Know-Waste*)' to provide architects and other project stakeholders with an accessible and live electronic designing out waste platform.

## REFERENCES

Agyekum, K., Ayarkwa, J. and Adjei-Kumi, T. (2013) Minimizing materials wastage in construction: a lean construction approach. *Journal of Engineering and Applied Science* **5**(1), 125-146.

Allen Consulting Group (2002) *The 'triple bottom line': a collaborative exploration*. Public sector collaborative research project, Canberra, Australia.

Alwi, S., Hampson, K. and Mohamed, S. (2002) Waste in the Indonesian construction. *Proceedings of the First International Conferences of CIB W107: Creating a Sustainable Construction Industry in Developing Countrie*s, 11-13 November 2002, South Africa, 305-315.

Amaratunga, D., Baldry, D., Sarshar, M. and Newton, R. (2002) Quantitative and qualitative research in built environment: application of 'mixed' research approach", *Work Study* **51**(1) 17-31.

Axinn, W.G. and Pearce, L.D. (2006) *Mixed method data collection strategies*, Cambridge University Press, New York.

Baldwin, A.N., Poon, C., Shen, L., Austin, S. and Wong, I. (2009) Designing out waste in high-rise residential buildings: analysis of pre-casting methods and traditional construction. *Renewable Energy* **34**(9), 2067-2073.

Bakshan, A., Srour, I., Chehab, G. and El-Fadel, M. (2015) A field based methodology for estimating waste generation rates at various stages of construction projects. *Resources, Conservation and Recycling* **100,** 70–80.

Barkemeyer, R., Holt, D., Preuss, L. and Tsang, A. (2014) What happened to the 'development' in sustainable development? Business guidelines two decades after Brundtland. *Sustainable Development* **22**(1), 15-32.

Bazeley, P. and Jackson, K. (2013) *Qualitative data analysis with NVivo*, Sage Publications, London.

Begum, R.A., Siwar, C., Pereira, J.J. and Jaafar, A.H. (2009) Attitude and behavioral factors in waste management in the construction industry of Malaysia. *Resources, Conservation and Recycling* **53**(6), 321-328.

Berg, B.L. and Lune, H. (2011) *Qualitative research methods for the social sciences*, Pearson, London.

Blaikie, N.W.H. (2000) *Designing social research: the logic of anticipation*, Polity Press, Cambridge.

Blakstad, O. (2013) *Experimental Research*, Kindle Edition, London

Blaxter, L., Hughes, C. and Tight, M. (2010) *How to research*, Open University Press, Berkshire.

Blok, V., Long,T.B., Gaziulusoy, A.I., Ciliz, N., Lozano, R., Huisingh, D., Csutora, M. and C Boks, C. (2015) From best practices to bridges for a more sustainable future: advances and challenges in the transition to global sustainable production and consumption. *Journal of Cleaner Production*. In Press.

TRL (2010) *ConstructCLEAR*, TRL Software, Wokingham, UK.

Bossink, B.A.G. and Brouwers, H.J.H. (1996) Construction waste: quantification and source evaluation. *Journal of Construction Engineering and Management* **122**(1), 55-60.

Brace, I. (2013) *Questionnaire design: how to plan, structure and write survey material for effective market research,* Kogan Page, London.

BRE - Building Research Establishment (2001) *SMARTWaste*. BRE, Watford.

BRE - Building Research Establishment (2002) *Waste audit client report for Greenwich Millennium Village*. BRE, Watford.

BRE - Building Research Establishment (2007) *SMARTStart*, BRE, Watford.

BRE - Building Research Establishment (2008) *Sustainable construction: simple ways to make it happen*, BRE, Watford.

BRE - Building Research Establishment (2009) *BreMap,* BRE. Watford.

BRE - Building Research Establishment (2015) *The Green guide explained,* BRE. Watford.

Brennan, M.C.E. (2015) *Sustainable construction in the 21st century: an educational perspective to shifting the paradigm*. PhD thesis, Liverpool John Moores University, Liverpool.

Burmeister, L., Clark, A., Gonzalez, A. and Greenfield, A. (2010) *Unlocking the value: transforming the Connecticut materials economy*, Yale University School of Forestry and Environmental Studies Department, USA.

Bryman, A. (2012) *Social research methods*, 4th ed., Oxford University Press, Oxford.

Bryman, A. and Bell, E. (2011) *Business research methods*, 3rd ed., Oxford University Press, Oxford.

Bryman, A. and Cramer, D. (2005) *Quantitative data analysis with SPSS 12 and 13*, Routledge, East Sussex.

BSI (2013) *BS 8895-1 Designing for material efficiency in building projects: code of practice for Strategic Definition and Preparation and Brief*, BSI, London.

BSI (2015) *BS 8895-2 Designing for material efficiency in building projects: code of practice for concept and developed design*, BSI, London.

Buckingham. A. and Saunders, P. (2004) *The survey methods workbook: from design to ana*lysis, Polity Press, Cambridge.

BUILDUK (2014) *Smarter environmental regulation*, BUILDUK, London.

Chandrakanthi, M., Hettiaratchi, P., Prado, B. and Ruwanpura, J. (2002) Optimization of the waste management for construction projects using simulation. *Proceedings of 2002 Simulation Winter Conference*, 8–11 December 2002, San Diego, USA, 1771-1777.

Chen Z.; Li, H. and Wong, C.T.C. (2002) An application of bar-code system for reducing construction wastes. *Automation in Construction* **11**(5), 521-533.

Chen, Z., Li, H., Kong, S.C.W., Hong, J. and Xu, Q. (2006) E-commerce system simulation for construction and demolition waste exchange. *Automation in Construction* **15**(6), 706-718.

Cheng, C. P. and Ma, Y.H. (2013) A BIM-based system for demolition and renovation waste estimation and planning. *Waste Management* **33**(6), 1539-1551.

Chen J and Chen M (2011) Construction waste management: current status and directions for further study. *Applied Mechanics and Materials* **71–78**, 4628-4633.CIC -Construction Industry Council (2007) *CIC Scope of Services explained.* Construction Industry Council, London.

Chevalier, J.M. (2013) *Participatory action research theory and methods for engaged inquiry*, Routledge, London.

Chun-Li, P., Scorpio, D.E. and Kibert, C.J. (1997) Strategies for successful construction and demolition waste recycling operations. *Construction Management and Economics* **15(1)**, 49–58.

Constructing Excellence (2013) *Constructing Excellence position on Site Waste Management Plans.* Constructing Excellence, London.

Ciegis, R., Ramanauskiene, J. and Markinkus, B. (2009) The concept of sustainable development and its use for sustainability scenarios. *Inzinerine Ekonomika-Engineering Economics* **2**, 28-37.

Coventry, S. and Guthrie, P. (1998) *Waste minimisation and recycling in construction: design manua*l, CIRIA SP134, CIRIA, London.

Coventry, S., Shorter, B. and Kingsley M. (2001) *Demonstrating waste minimisation benefits in construction*, C536, CIRIA, London.

Craven D.J, Okraglik H.M and Eilenberg I.M. (1994) Construction waste and a new design methodology. *Proceedings of the First Conference of CIB TG 16 on Sustainable Construction*, 6-9 November 1994, Tampa, USA, 89-98.

Creswell, J.W. (2009) *Research design: qualitative, quantitative and mixed methods approach*, Sage Publications, London.

Creswell, J.W. (2013) Q*ualitative inquiry and research design: choosing among five traditions*, Sage Publications, London.

Creswell, J.W. (2014) *Research design: qualitative and quantitative approaches*, Sage Publications, London.

Creswell, J.W. and Clark V.L.P. (2011) Designing and conducting mixed methods research, Sage publications, California.

CRISP (2000) *Construction for sustainable development: research and innovation needs*, Strategy Panel, London.

Dadhich, P., Genovese, A., Kumar, N. and Acquaye, A. (2015) Developing sustainable supply chains in the UK construction industry: a case study. *International Journal of Production Economics*, **164**, 271-284.

Dainty, A.R.J. (2008) Methodological pluralism in construction management research. In A. Knight and L. Ruddock eds., *Advanced Research Methods in the Built Environment*, Blackwell Publishing Ltd, 1 -13.

Dainty, A.R.J. and Brooke, R.J. (2004) Towards improved construction waste minimisation: a need for improved supply chain integration? *Structural Survey* **22**(1), 20-29.

DEFRA - Department for Environment, Food and Rural Affairs (2007) *The Waste Strategy for England,* DEFRA, London.

DEFRA - Department for Environment, Food and Rural Affairs (2013) *DEFRA public consultations: proposed repeal of construction Site Waste Management Plans Regulations (2008): Summary of responses and Government response*, DEFRA, London.

DEFRA - Department for Environment, Food and Rural Affairs (2015) *UK Statistics on Waste*, DEFRA, London.

Denzin, N.K. and Lincoln, Y.S. (2011) *The SAGE handbook of qualitative research*, Sage Publications, Los Angeles.

Ding, T. and Xiao, J. (2015) Estimation of building-related construction and demolition waste in Shanghai. *Waste Management* **34** (11), 2327–2334.

Easterby-Smith, M., Thorpe, R. and Jackson, P. (2012) *Management research: an introduction*, 4th ed., Sage Publication, London.

Eikelboom, R. T., Ruwiel, E. and Goumans, J. J. M. (2001) The Building Materials Decree: an example of a Dutch regulation based on the potential impact of materials on the environment. *Waste Management* **21**(3), 295-302.

Ekanayake, L.L. and Ofori, G. (2000) Construction material source evaluation. *Proceedings of the Second Southern African Conference on Sustainable Development in the Built Environment*, 23-25 August 2000, Pretoria, South Africa, pp.1-6.

Elkington, J. (1998) Accounting for the triple bottom line. *Measuring Business Excellence* **2**(3), 18-22.

Emmanuel, R. (2014) Estimating the environmental suitability of wall materials: preliminary results from Sri Lanka, *Building and Environment* **39**(10), 1253-1261.

Emuze, F., Smallwood, J. and Han, S. (2014) Factors contributing to non-value adding activities in South African construction. *Journal of Engineering, Design and Technology* **12**(2), 223-243.

Environment Agency (2013) *How to comply with your environmental permit*, Environment Agency, Bristol, UK.

Envirowise (1999) *Waste mapping: your route to more profit*, Didcot, UK.

Eriksson, P.E. and Westerberg, M. (2011) Effects of cooperative procurement procedures on construction project performance: a conceptual framework. *International Journal of Project Management* **29**(2), 197-208.

EPA - Environmental Protection Agency (2009) *Construction and demolition materials amounts*, Office of Resource Conservation and Recovery, EPA, Columbia, USA.

European Commission (2008) *Waste Framework Directive 2008/98/EC,* European Commission, Brussels.

Eurostat (2015) *Waste statistics*, European Commission, Brussels.

Faniran, O.O. and Caban, G. (1998) Minimizing waste on construction project sites.

*Engineering Construction and Architectural Management* **5**(2), 182-188.

Fellows, R. and Liu, A. (2003) *Research methods for construction,* 2nd ed., Wiley-Blackwell, Oxford.

Fellows, R. and Liu, A. (2008) *Research methods for construction*, 3rd ed., Wiley-Blackwell, Oxford.

Fishbein, B.K. (1998) *Building for the future: strategies to reduce construction and demolition waste in municipal projects*, Inform Publications, New York.

Fitzgerald, B. and Howcroft, D. (1998) Towards dissolution of the research debates: from polarisation to polarity. *Journal of Information Technology* **13**(4), 313-326.

Flick, U. (2007) *Designing qualitative research*, Sage Publications, London.

Formoso, C.T., M.ASCE, L.S., Cesare, C.D. and Isatto, E.L. (2002) Material waste in building industry: main causes and prevention. *Journal of Construction Engineering and Management* **128** (4), 316-325.

Forum for the Future (2008) *Sustainable wealth creation within environmental limits*, London.

Fowler, F.J. (2002) Survey research methods, 2nd ed., Sage Publications Los Angeles.

Fowler, F.J. (2014) *Survey research methods,* 5th ed., Sage Publications Los Angeles.

Frazer, L. and Lawley N. (2000) *Questionnaire design and administration: a practical guide*, Wiley, Brisbane.

Gamage, I.S.W., Osmani, M. and Glass, J. (2009) An investigation into the impact of procurement systems on waste generation: the contractors' perspective. *Proceedings of 25th Annual ARCOM Conference*, 7-9 September 2009, Nottingham, UK, Association of Researchers in Construction Management, 1031-1040.

Gastaldi, D., Canonico, F., Capelli, L., Buzzi, L., Boccaleri, E. and Irico, S. (2015) An investigation on the recycling of hydrated cement from concrete demolition waste. *Cement and Concrete Composites* **61**, 29-35.

Gavilan, R.M. and Bernold, L.E. (1994) Source evaluation of solid waste in building construction. *Journal of Construction Engineering and Management* **20**(3), 536–552.

GCB - Green Construction Board (2014) *Five years of focus on waste (2008-2012): achievements and changes*, Green Construction Board, London.

Gibson, W.J. and Brown, A. (2009) *Working with qualitative data*, Sage Publications, London.

Gill, J. and Johnson, P. (2010) *Research method for managers*, Sage publications, London.

Glesene, C. (1999) *Becoming qualitative researchers: an introduction*, Longman, New York.

Goldkuhl, G. (Pragmatism versus interpretivism in qualitative information (2012 systems research. *European Journal of Information Systems* **21**(2), 135-146.

Govindan, K., Shankar, M. and Kannan, D. (2015) Sustainable material selection for the construction industry: a hybrid multi criteria decision making approach. *Renewable and Sustainable Energy Reviews*. In Press.

Greenwood, R. (2003) *Construction waste minimisation: good practice guide*, Cribe, Cardiff.

Grover, V. and Kettinger, W.J. (1998) *Business process change: concepts, methods and technologies*, Idea Group Publishing, Harrisburg.

Guthrie, P. and Mallett, H. (1995) *Waste minimisation and recycling in construction*, Publication 122, CIRIA, London.

Guthrie, P., Woolveridge, C. and Coventry, S. (1998) *Managing materials and components on site*, CIRIA, London.

Hantrais, L. (2009) *International comparative research: theory, methods and practice*, Kindle Edition, London.

Hao, J.L., Hill, M.J. and Shen, L.Y. (2008) Managing construction waste on-site through system dynamics modelling: the case of Hong Kong. *Engineering, Construction and Architectural Management* **15**(2), 103-113.

Healy, M. and Perry, C. (2000) Comprehensive criteria to judge validity and reliability of qualitative research within the realism paradigm. Q*ualitative Market Research: An International Journal* **3**(3), 118-126

Hepworth, M., Grunewald, P. and Walton G.L. (2014) Research and practice: a critical reflection on approaches that underpin research into people's information behaviour. *Journal of Documentation* **70** (6), 1039-1053.

HM Government (2008a) *Strategy for sustainable construction*, London.

HM Government (2008b) *Site Waste Management Plans Regulations 2008*, London.

HM Government (2011) *Waste (England and Wales) Regulations 2011*, London.

HM Government (2013) *Construction 2025: industrial strategy for construction, government and industry in partnership*, London.

HM Government (2014).Environmental Permitting (England and Wales) (Amendments) Regulations 2014, London.

HM Government (2015) *The Landfill Tax (Amendment) Regulations 2015*, London.

Hong Kong Environmental Protection Department (2013) *Hong Kong government environmental report*, Hong Kong.

Hughes, J.A. (1990) *The philosophy of social research*, Longman, London.

Hwang, B. and Yeo, Z.B. (2011) Perception on benefits of construction waste management in the Singapore construction industry. *Engineering, Construction and Architectural Management* 18(4), 394-406.

Ilozor, B. D. (2009) Differential management of waste by construction sectors: a case study. *Construction Management and Economics* **27**, 763-770.

Innes, S. (2004) Developing tools for designing out waste pre-site and on-site. *Proceedings of Minimising Construction Waste Conference: Developing Resource Efficiency and Waste Minimisation in Design and Construction*, New Civil Engineer, London.

Jaillon, L., Poon, C.S. and Chiang, Y.H. (2009) Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong. *Waste Management* **29**(1), 309-320.

Joachim, O.I., Kamarudin, N., Aliagha, G.U. and Ufere, K.J. (2015) Theoretical explanations of environmental motivations and expectations of clients on green building demand and investment. *IOP Conference Series: Earth and Environmental Science* **23**, 1-16.

Jones, P. (1999) *The Future of waste minimisation*, BIFA, Feltham, UK.

Karhu, V., Matti K. and Pertti L. (1997) C*onstruction process model: generic present-state systematisation by IDEF 0*, VTT, Finland.

Kibert, C.J. (1994) Establishing principles and a model for sustainable construction. *Proceedings of the First International Conference of CIB TG 16 on Sustainable Construction* -CIB TG 16, 6-9 November 1994, Tampa, USA, 1-10.

Kern, A.P., Dias, M.F., Kulakowski, M.P. and Gomes, L.P. (2015) Waste generated in high-rise buildings construction: a quantification model based on statistical multiple regression. *Waste Management* **39**, 35-44.

Keys, A., Baldwin, A.N. and Austin, S.A. (2000) *Designing to encourage waste minimisation in the construction industry*. CIBSE (Chartered Institute of Building Services Engineers), London.

Knoeria C, Binder CR and Althaus H (2011) Decisions on recycling: construction stakeholders' decisions regarding recycled construction materials. *Resources. Conservation and Recycling* **55**(11), 1039-1050.

Koskela, L. (1992) *Application of new production theory in construction*, Technical Report No.72, CIFE, Stanford University, USA.

Kulathunga, U., Amaratunga, R.D.G., Haigh, R. and Rameezdeen, R. (2005) Sources of construction waste materials in Sri Lankan sites. *Proceedings of PRoBE conference,* 16-17 November 2005, Glasgow, 601-610.

Kulatunga, U., Amaratunga, D. Haigh, R. and Rameezden, R. (2006) Attitudes and Perceptions of construction workforce on Construction Waste in Sri Lanka. *Management and Environmental Quality* **17**(1), 57-72.

Kvale, S. and Brinkmann, S. (2009) *Interviews: learning the craft of qualitative research interviewing*, Sage Publications, Los Angeles.

Langston, C.A. and Ding, G.K. (2001) *Sustainable practices in the built environment*. Butterworth Heinemann, Oxford.

Lee, S., Diekmann, J., Songer, A.D. and Brown, H. (1999) Identifying waste: applications of construction process analysis. *Proceedings of the Seventh Annual Conference of the International Group for Lean Construction (IGLC-7)*, 26-28 July 1999, Berkeley, USA, 63-72.

Leedy, P.D. and Ormrod, J.E. (2012) *Practical research: planning and design*, Pearson, Boston.

Li, M. and Yang, J. (2014) Analysis of interrelationships between critical waste factors in office building retrofit projects using interpretive structural modelling. *International Journal of Construction Management* **14**(1), 20-36.

Li, Y. and Zhang, X. (2012) Comparison and analysis of international construction waste management policies. *Proceedings of the Construction Research Congress,* 21-23 May 2012, Indiana, USA, 1672-1681.

Li, Z., Shen, G. Q. and Alshawib, M. (2014) Measuring the impact of prefabrication on construction waste reduction: an empirical study in China. *Resources, Conservation and Recycling* **91**, 27-39.

Lingard, H., Graham, P. and Smithers, G. (2000) Employee perceptions of the solid waste management system operating in a large Australian contracting organization: implications for company policy implementation. *Construction Management and Economics* **18**(4), pp. 383-393.

Lingard, H., Gilbert, G. and Graham, P. (2001) Improving solid waste reduction and recycling performance using goal setting and feedback. *Construction Management and Economics* **19**(8), 809-817.

Lincoln, Y.S. and Guba, E.G. (1985) *Naturalistic inquiry*, Sage Publication, Thousand Oaks, California.

Liu, Z. (2014) *BIM-aided-waste minimisation framework,* PhD thesis, Loughborough University.

Liu, Z., Osmani, M., Demian, P. and Baldwin, A. (2015) A BIM-aided-construction waste minimisation framework, *Automation in Construction* **59**, 1-23.

Love, P.E.D., Holt, G.D. and Li, H. (2002) Triangulation in construction management research. *Engineering, Construction and Architectural Management* **9**(4), 294-303.

Lu W and Yuan H (2010) Exploring critical success factors for waste management in construction projects of China. *Resources, Conservation and Recycling* **55**(2), 201-208.

Lu, W. and Tam, V. W.Y. (2013) Construction waste management policies and their effectiveness in Hong Kong: a longitudinal review. *Renewable and Sustainable Energy Reviews* **23**, 214-223.

Lu, W., Peng, Y., Webster, C. and Zuo, J. (2015) Stakeholders' willingness to pay for enhanced construction waste management: a Hong Kong study. *Renewable and Sustainable Energy Reviews* **47**, 233–240.

Marzouk, M. and Azab, S. (2014) Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics. *Resources, Conservation and Recycling* **82**, 41-49.

McDonald, B. and Smithers, M. (1998) Implementing a waste management plan during the construction phase of project: a case study. *Journal of Construction Management and Economics* **16**(1), 71-78.

McGrath, C. (2001) Waste minimisation in practice. *Resource, Conservation and Recycling* **32**(3-4), 227-238.

Mendis, D., Hewage. K.N. and Wrzesniewski, J. (2015) Contractual obligations analysis for construction waste management in Canada. *Journal of Civil Engineering and Management* **21**(7), 866-880,

Mills, T.H., Showalter, E. and Jarman, D. (1999) A cost-effective waste management plan. *Cost Engineering* **41**(3), 35-43.

Mingers, J. and Gill, A. (1997) *Multi-methodology: the theory and practice of combining management science methodologies,* Wiley, Chichester.

Muhwezi, L., Chamuriho, L. M. and Lema, N. M. (2012) An investigation into materials wastes on building construction projects in Kampala, Uganda. *Journal of Engineering Research* **1**(1), 11-18.

Murphy, J.P. (1990) *Pragmatism*, West view Press, Chicago.

Neuman, W.L. (2011) S*ocial research methods: qualitative and quantitative approaches*, Pearson, Boston.

Oppenheim, A. N. (2000) Q*uestionnaire design, interviewing and attitude measurement,* Printer Publishers, London.

O'Reilly, A. (2012) Using BIM as a tool for cutting construction waste at source. *Construction Research and Innovation* **3**(1), 28-31.

Osmani M (2013a) Innovation in cleaner production through waste recycling in composites. *Management of Environmental Quality* **24**(1), 1–9.

Osmani, M. (2013b) Design waste mapping: a project life cycle approach Waste and Resource Management, **166** (3),114-127.

Oyedele, L.U, Ajayi, S.O. and Kadiri K.O. (2014) Use of recycled products in UK construction industry: An empirical investigation into critical impediments and strategies for improvement. *Resources, Conservation and Recycling* **93**, 23-31.

Panos, K. and Danai, G. I. (2012) Survey regarding control and reduction of construction waste. *Proceedings PLEA 2012: Opportunities, Limits and Needs Towards an Environmentally Responsible Architecture*, 7-8 November 2012, Lima, Peru.

Parkin, S. (2000) Context and drivers for operationalizing sustainable development, *Proceedings of the ICE - Civil Engineering* **138** (6), 9-15.

Passer, A., Wall, J., Kreiner, H., Maydl, P. and Höfler, K. (2015) Sustainable buildings, construction products and technologies: linking research and construction practice. *The International Journal of Life Cycle Assessment* **20** (1), 1-8.

Patton, M.Q. (2002) *Qualitative evaluation and research methods*, Sage Publications, London.

Pekuri, A., Pekuri, L. and Haapasalo, H. (2015) Business models and project selection in construction companies. *Construction Innovation* **15** (2) 180-197.

Pink, S., Tutt, D. and Dainty, A. (2013) *Ethnographic research in the construction industry*, Routledge, London.

Pinto T.P. and Agopyan V. (1994) Construction waste as raw materials for low-cost construction products. *Proceedings of the First Conference of CIB TG 16 on Sustainable construction*, 6-9 November 1994, Tampa, USA, 335-342.

Polat, G. and Ballard, G. (2004) Waste in Turkish construction: need for lean construction techniques. *Proceedings of the 12th Annual Conference on Lean Construction* (*IGLC 12),* 3-5 August 2004, Helsingør, Denmark, 1-14.

Polesie, P., Frödell, M. and Josephson, P. (2009) Implementing standardisation in medium sized construction firms: facilitating site managers' feeling of freedom through a bottom-up approach, *Proceedings for the 17th Annual Conference of the International Group for Lean Construction*, 15-17 July 2009, Taiwan, 317-326.

Poon, C.S., Yu, A.T.W. and Ng, L.H. (2001) On-site sorting of construction and demolition waste in Hong Kong. *Resources, Conservation and Recycling* **32**(2), 157-172.

Poon, C.S., Yu, A.T.W. and Jaillon, L. (2004a) Reducing building waste at construction sites in Hong Kong. *Construction Management and Economics* **22**(5), 461-470.

Poon, C.S; Yu, A.T.W; Wong, S.W. and Cheung, E. (2004b) Management of construction waste in public housing projects in Hong Kong. *Construction Management and Economics* **22**(7), 975-689.

Poon, C.S. (2007) Reducing construction waste. *Waste Management* **27**(12), 1715-1716.

Poon, C. S., Yu, A. T. W., Wong, A. and Yip, R. (2013) Quantifying the impact of 'Construction Waste Charging Scheme' on construction waste management in Hong Kong. *Journal of Construction Engineering and Management* **139**, 466-479.

Porwal, A. and Hewage, K. N. (2012) Building information modelling based analysis to minimize waste rate of structural reinforcement. *Journal of Construction Engineering and Management* **138**, 943-954.

Porwal, A. and Hewage, K. (2012).Building Information Modeling -based analysis to minimize waste rate of structural reinforcement, *Journal of Construction Engineering and Management* **138**(8), 943–954.

Punch, K.F. (2014) *Introduction to social research: quantitative and qualitative approaches*, Sage Publications, London.

Raynsford, N. (2000) Sustainable construction: the government's role. *Proceedings of ICE - Civil Engineering* **38**, 16-22.

RIBA - Royal Institute of British Architects (2007) *RIBA outline plan of work 2007*, RIBA, London.

RIBA - Royal Institute of British Architects (2011) *Green overlay to the RIBA outline plan of work*, RIBA, London.

RIBA - Royal Institute of British Architects (2012) *BIM overlay to the RIBA outline plan of work,* RIBA, London.

RIBA - Royal Institute of British Architects (2013) *RIBA plan of work 2013, RIBA*, London.

RIBA - Royal Institute of British Architects (2015) *Delivering construction 2025: RIBA action plan*, RIBA, London.

Robson, C. (2011) *Real world research: a resource for users of social research methods in applied settings*, Wiley, Chichester.

Ross, D.T., Brackett, J.W., Bravoco, R.R. and Schoman, K.E. (1980) A*rchitects manual ICAM definition method 'IDEF0*', DR-80-ATPC, Academic Press, San Diego.

Rounce, G. (1998) Quality, waste and cost considerations in architectural building design management. *International Journal of Project Management* **16**(2), 123-127.

Rybicka, J., Tiwari, A., Del Campo, P.A. and Howarth, J. (2015) Capturing composites manufacturing waste flows through process mapping. *Journal of Cleaner Production* **91**, 251-26.

Sáez, P. V., Merino, M. R., Porras-Amores, C. and González, A. S. (2014) Assessing the accumulation of construction waste generation during residential building construction works. *Resources, Conservation and Recycling* **93**, 67–74.

Sage, A.P. (1998) Risk management for sustainable development. *Proceedings of the International Conference on Systems and Cybernetics*, 11-14 October 1998, San Diego, USA, 4815-4819.

Sanders J. and Wynn, P. (2004) Attitudes towards waste minimisation amongst labour only sub-contractors. *Structural Survey* **22**(3), 148-155.

Sangiorgi, C., Lantieri, C. and Dondi, G. (2015) Construction and demolition waste recycling: an application for road construction. *International Journal of Pavement Engineering* **16**(6), 530-537.

Santos, A. Formoso, C. T. and Tookey J. E. (2002) Expanding the meaning of standardisation within construction processes. *The TQM Magazine* **14**(1) 25-33.

Saunders, M., Lewis, P. and Thornhill, A. (2012) *Research methods,* 6th ed., Prentice Hall, London.

Serpell, A., Venturi, A. and Contreras, J. (1995) Characterization of waste in building construction projects. *Proceedings of Lean Construction Conference*, Rotterdam, Netherlands, 16-19 October 1995, 67-77.

Shant A. Dajadian, D. and Koch, C. (2014) Waste management models and their applications on construction sites *International Journal of Construction Engineering and Management* **3**(3), 91-98.

Shen, L. Y., Tam V.W. Y., Tam C. M. and Drew D. (2004) Mapping approach for examining waste management on construction sites. *Journal of Construction Engineering and Management* **130**(4), 469-614.

Shen, L.Y., Tam, V. W. Y. and Li, C. (2009) Benefit analysis on replacing in situ concreting with precast slabs for temporary construction works in pursuing sustainable construction practice. *Resources, Conservation and Recycling* **53**(3), 145-148.

Silverman, D. (2010) *Doing qualitative research: a practical handbook*, Sage Publications, London.

Skoyles, E.R. and Skoyles, J.R. (1987) *Waste prevention on site*, Mitchell Publishing, London.

Smith, B. and Thomas, A. (1998) Axiology. In *Routledge Encyclopaedia of Philosophy*, Routledge, London.

Smith, L. and Ball, P. (2012) Steps towards sustainable manufacturing through modelling material, energy and waste flows. *International Journal of Production Economics* **140(**1), 227-238

Smith, R.A.; Kersey and Griffiths, P.J. (2003) *The construction industry mass balance: resource, wastes and emissions*. Report VR4, Viridis, Crowthorne, Berkshire, UK.

Spence, R. and Mulligan, H. (1995) Sustainable development and the construction industry. *Habitat Internationa*l **19**(3), 279-292.

Stewart C. and Cash, W. (2006) *Interviewing principles and practices*, 11th ed., McGraw-Hill, New York.

Stringer, E.T. (2007) *Action research*, Sage Publications, London.

Tam, V.W.Y., Tam, C.M. and Ng, W.C.Y. (2007) Prefabrication implementation for different project types and procurement methods in Hong Kong. *Journal of Engineering, Design and Technology* **5**(1) 68-80.

Tam, V. W.Y., Li, J. and Cai, H. (2014) System dynamic modeling on construction waste management in Shenzhen, China. *Waste Management and Research* **32**(5), 441-453.

Tan, W. (2008) *Practical research methods*, Pearson Education, Singapore.

Tan, Y., Ochoa, J. J., Langston, C. and Shen, L. (2015) An empirical study on the relationship between sustainability performance and business competitiveness of international construction contractors. *Journal of Cleaner Production* **93**, 273-278.

Tashakkori, A. and Teddlie, C. (2010) *Sage handbook of mixed methods in social and behavioral research*, Sage Publications, Los Angeles.

Treloar, G.J., Gupta, H. and Love, P.E.D. (2003) An analysis of factors influencing waste minimisation and use of recycled materials for the construction of residential buildings. *Management of environmental Quality* **14**(1), 134-145.

Teo, M.M. and Loosemore, M. (2001). A theory of waste behaviour in the construction industry. *Construction Management and Economics* **19**(7), 741-51.

Udawatta, N., Zuo, J., Chiveralls, K. and Zillante, G. (2015) Attitudinal and behavioural approaches to improving waste management on construction projects in Australia: benefits and limitations. *International Journal of Construction Management* **15**(2), 137-147.

Urquhart, C. (2013) *Grounded theory for qualitative research: a practical guide*, Sage Publications, London.

Walliman, N. (2006) *Social research methods,* Sage Publications, London.

Wang, J., Yuan, H., Kang, X. and Lu W. (2010) Critical success factors for on-site sorting of construction waste: A china study. *Resources, Conservation and Recycling* **54**(11), 931-936.

Wang, J., Li, Z. and Tam, V.W.Y. (2015) Identifying best design strategies for construction waste minimization. *Journal of Cleaner Production* **92**, 237-247.

Wilkinson, S.J., Remoy, H. and Langston, C. (2014) *Sustainable Building Adaptation: Innovations in Decision-making*. Wiley-Blackwell, London.

WCED -World Commission on Environment and Development (1987) *Our Common Future: Report of the United Nations World Commission on Environment and Development*, United Nations, New York.

Wong, F.W.H., Lam, P.T.I., Chan, A.P.C. and Chan, E.H.W. (2006) A review of buildability performance in Hong Kong and strategies for improvement. *Surveying and Built Environment* **17(**2), 37- 48.

WRAP - Waste and Resources Action Programme (2007) *Current practices and future potential in modern methods of construction*, WRAP, Banbury, UK.

WRAP - Waste and Resources Action Programme (2008a) *Halving waste to landfill: are you committed?* WRAP, Banbury, UK.

WRAP - Waste and Resources Action Programme (2008b) *True cost of waste in whole life costing*, WRAP, Banbury, UK.

WRAP - Waste and Resources Action Programme (2008c) *Net Waste Tool*, WRAP, Banbury, UK

WRAP - Waste and Resources Action Programme (2009) *Designing out waste: a design team guide for buildings*, WRAP, Banbury, UK.

WRAP - Waste and Resources Action Programme (2010a) *Designing out waste: a design team guide for Civil Engineering*, WRAP, Banbury, UK.

WRAP - Waste and Resources Action Programme (2010b), *WRAP SWMP tracker*, WRAP, Banbury, UK.

WRAP - Waste and Resources Action Programme (2013) *Construction procurement guidance*, WRAP, Banbury, UK.

Wu, Z., Yu, A.T.W., Shen, L. and Liu, G. (2014) Quantifying construction and demolition waste: An analytical review. *Waste Management* **34**(9), 1683-1692.

Wu, Z., Shen, L., Yu, A.T.W. and Zhang, X. (2015) A comparative analysis of waste management requirements between five green building rating systems for new residential buildings. *Journal of Cleaner Production*. In Press.

Yahya, K. and Boussabaine, A.H. (2006) Eco-costing of construction waste. *Management of Environmental Quality* **17**(1), 6-19.

Yuan H.P. and Shen L.Y. (2010) Trend of the research on construction and demolition waste management. *Waste Management* **31**(4), 670-679.

Yuan, H.P., Shen, L.Y., Hao, J. J.L. and Lu, W.S. (2011) A model for cost–benefit analysis of construction and demolition waste management throughout the waste chain. *Resources, Conservation and Recycling* **55**, 604-612.

Yuan, H.P., Chini, A.R., Luc, Y.and Liyin Shen, L. (2012) A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste. *Waste Management* **32**(3), 521-531.

Ye, B. and Yuan, H. (2014) An overview of construction and demolition waste management regulations in the central China. *Proceedings of ICCREM 2014: Smart*

*Construction and Management in the Context of New Technology*, September 27-28, 2014 Kunming, China, 45-52.

Yin, R.K. (2014) *Case study research: design and methods*, Sage Publications, Los Angeles.

Zhang, X., Wu, Y. and Shen, L. (2012) Application of low waste technologies for design and construction: a case study in Hong Kong. *Renewable and Sustainable Energy Reviews* **16**, 2973-2979.

Zutshi, A. and Creed, A.(2015) An international review of environmental initiatives in the construction sector. *Journal of Cleaner Production* **98**, 92-106.

# APPENDICES

- **APPENDIX 1: QUESTIONNAIRE SURVEY DOCUMENTS**
- **APPENDIX 2: INTERVIEW DOCUMENTS**
- **APPENDIX 3: FRAMEWORK INDUSTRY REVIEW DOCUMENTS**
- **APPENDIX 4: POST FRAMEWORK INDUSTRY REVIEW DOCUMENTS**

# APPENDIX 1: QUESTIONNAIRE SURVEY DOCUMENTS

- Appendix 1.1: Questionnaire cover letter (architects)
- Appendix 1.2: Questionnaire cover letter (contractors)
- Appendix 1.3: Questionnaire survey (architects)
- Appendix 1.4: Questionnaire survey (contractors)

# Appendix 1.1

# Questionnaire cover letter (architects)

*Mohamed Osmani*
*Department of Civil & Building Engineering*

Name…………………………………………………………………………………………………….
Address………………………………………………………………………………………………….
…………………………………………………………………………………………………………….
Dear ………

**Waste minimisation design practices**

I am currently undertaking a part-time doctoral study entitled 'Designing out Waste in Construction'. The aim of the research is to develop a deigning out waste framework to facilitate and sustain the integration of waste minimisation strategies during the building design process.

Existing and forthcoming legislation are driving construction companies to seek new ways of diverting waste away from landfill by using more sustainable options such as minimisation, reuse and recycle.

The aim of the enclosed questionnaire, destined for practising architects, is to: investigate causes leading to construction waste generation; and explore waste minimisation design practices within the profession and associated barriers.

I would be grateful if you could complete the enclosed questionnaire and return it in the self-addressed stamped envelope provided. It is estimated that it should take about twenty minutes to complete. Please be assured that any data provided will be used for this project only.

I would be happy to send you a copy of the data analysis if you provide your email address in Section One of the enclosed questionnaire. This will give you comparative insights into waste sources and origins, waste management responsibilities, current onsite waste management and minimisation practices, barriers, incentives and best practice in the industry.

**Please note that the information provided will be treated with strict confidence. The names of participating individuals and companies will not be cited or disclosed in the thesis and any associated research outputs.**

Thank you very much for your time and effort in completing the enclosed questionnaire. I look forward to receiving your response.

Yours sincerely,

Mohamed Osmani
School of Civil and Building Engineering
Loughborough University, Loughborough
Leicestershire LE11 3TU
Email: M.Osmani@lboro.ac.uk
Tel: 01509 228155
Fax: 01509 223981

# Appendix 1.2

# Questionnaire cover letter (contractors)

*Mohamed Osmani*
*Department of Civil & Building Engineering*

Name…………………………………………………………………………………………………….
Address………………………………………………………………………………………………….
……………………………………………………………………………………………………..

Dear ………

**Onsite construction waste management practices**

I am currently undertaking a part-time doctoral study entitled 'Designing out Waste in Construction'. The aim of the research is to develop a deigning out waste framework to facilitate and sustain the integration of waste minimisation strategies during the building design process.

Existing and forthcoming legislation are driving construction companies to seek new ways of diverting waste away from landfill by using more sustainable options such as minimisation, reuse and recycle.

The aim of the enclosed questionnaire, destined for building contractors, is to: investigate causes leading to construction waste generation; and examine current contractors' responsibilities and methods of onsite waste management.

I would be grateful if you could complete the enclosed questionnaire and return it in the self-addressed stamped envelope provided. It is estimated that it should take about twenty minutes to complete. Please be assured that any data provided will be used for this project only.

I would be happy to send you a copy of the data analysis if you provide your email address in Section One of the enclosed questionnaire. This will give you comparative insights into waste sources and origins, waste management responsibilities, current onsite waste management and minimisation practices, barriers, incentives and best practice in the industry.

**Please note that the information provided will be treated with strict confidence. The names of participating individuals and companies will not be cited or disclosed in the thesis and any associated research outputs.**

Thank you very much for your time and effort in completing the enclosed questionnaire. I look forward to receiving your response.

Yours sincerely,

Mohamed Osmani
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Loughborough University, Loughborough
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Fax: 01509 223981

# Appendix 1.3

# Questionnaire survey (architects)

# Waste minimisation design practices

The aim is to ascertain architects' views on waste minimisation design practices within the profession and the associated barriers. **Please note that the information provided will be treated with strict confidence. The names of participating individuals and companies will not be cited or disclosed in the thesis and any associated research outputs.**

## 1. Background Information

- Your name: ……………………………………….. Your position:……………………………….
- Company name (optional):……………………………………………………………………….
- Telephone: ………………………………..Email: ……………………………………………
- Approximate number of company employees:………………………………………………...
- Please state the approximate annual turnover for your company. Please tick one box only.

  □ Less than £1m □ £1-4.99m □ £5-9.99m □ £10-19.99m
  □ £20-49.99m □ £50-99.99m □ £100-499.99m □ over £500m

## 2. Causes of Waste

**2.1** Please rank from 1 to 5 the following **causes of waste**, where 1 indicates 'not a waste cause'; 2: 'insignificant'; 3: 'minor'; 4: 'significant'; and 5 indicates 'major waste cause'. Please circle your selection.

| **During design stages** | **Cause of waste** | | | | |
|---|---|---|---|---|---|
| | **Not a cause** | | **Minor** | | **Major cause** |
| ▪ Unclear specification | 1 | 2 | 3 | 4 | 5 |
| ▪ Design changes | 1 | 2 | 3 | 4 | 5 |
| ▪ Detailing errors | 1 | 2 | 3 | 4 | 5 |
| ▪ Lack of information on the drawings | 1 | 2 | 3 | 4 | 5 |
| ▪ Last minute changes due to client's requirements | 1 | 2 | 3 | 4 | 5 |
| ▪ Delays drawing revision and distribution | 1 | 2 | 3 | 4 | 5 |
| **Others (please list below)** | | | | | |
| ▪ ………………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ ………………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ ………………………………… | 1 | 2 | 3 | 4 | 5 |

| **During site operations** | **Cause of waste** | | | | |
|---|---|---|---|---|---|
| | **Not a cause** | | **Minor** | | **Major cause** |
| ▪ Delays in forwarding information on sizes of materials to be used | 1 | 2 | 3 | 4 | 5 |
| ▪ Improper storing space and methods | 1 | 2 | 3 | 4 | 5 |
| ▪ Unused materials and products | 1 | 2 | 3 | 4 | 5 |
| ▪ Waste from application processes | | | | | |
| ▪ (i.e. over-preparation of mortar) | 1 | 2 | 3 | 4 | 5 |
| ▪ Off-cuts from cutting materials | 1 | 2 | 3 | 4 | 5 |
| ▪ Weather conditions | 1 | 2 | 3 | 4 | 5 |
| **Others (please list below)** | | | | | |
| ▪ ………………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ ………………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ ………………………………… | 1 | 2 | 3 | 4 | 5 |

**2.2** In your experience, at which RIBA Plan of Work stages is **waste generated**? Please rank from 1 to 5, where 1 indicates 'no waste generation'; 2: 'insignificant'; 3: 'minor'; 4: 'significant'; and 5 indicates 'major waste generation'. Please circle your selection.

| | | No waste | | Minor | | Major waste |
|---|---|---|---|---|---|---|
| **A** | (Appraisal) | 1 | 2 | 3 | 4 | 5 |
| **B** | (Design Brief) | 1 | 2 | 3 | 4 | 5 |
| **C** | (Concept Design) | 1 | 2 | 3 | 4 | 5 |
| **D** | (Design Development) | 1 | 2 | 3 | 4 | 5 |
| **E** | (Technical Design) | 1 | 2 | 3 | 4 | 5 |
| **F** | (Production information) | 1 | 2 | 3 | 4 | 5 |
| **G** | (Tender documentation) | 1 | 2 | 3 | 4 | 5 |
| **H** | (Tender Action) | 1 | 2 | 3 | 4 | 5 |
| **J** | (Mobilisation) | 1 | 2 | 3 | 4 | 5 |
| **K** | (Construction to practical Completion) | 1 | 2 | 3 | 4 | 5 |

**2.3** Are there any other comments you wish to make regarding '**Origins and Causes of Waste**'?
……………………………………………………………………………………………………………
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## 3. Waste Management Responsibilities

**3.1** What are your company's existing **waste management responsibilities**? Please tick all that apply.

□ Waste management goal setting
□ Analysing site waste to be generated
□ Issuing guidelines for waste segregation
□ Designating waste disposal operators
□ Issuing guidelines for hazardous waste management
□ Organising waste management meetings
□ Preparing a list of each waste material to be salvaged, reused or recycled
□ None
□ **Others (please specify below)**
…………………………………………………………………………………………………
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…………………………………………………………………………………………………

**3.2** What are your company's existing **responsibilities in dealing with hazardous waste**? Please tick all that apply.

□ Implementing waste classification in accordance with European Waste Catalogue six digit code
□ Implementing hazardous waste labelling
□ Issuing guidelines for segregation of hazardous from non-hazardous waste
□ Designating operators for hazardous waste transfer to authorised facilities
□ **Others (please specify below)**
…………………………………………………………………………………………………
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…………………………………………………………………………………………………

**3.3** Are there any other comments you wish to make regarding '**Waste Management Responsibilities**'?
…………………………………………………………………………………………………………
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# 4. Waste Minimisation Design Practices

**4.1** Is your company **ISO 14001** accredited? Please tick. □ Yes □ No □ In the process

**4.2** What are your main **sources of information** on waste management and minimisation? Please tick all that apply.

□ Training courses □ Personal research
□ Professional bodies □ Media/articles
□ **Other (please specify below)**
……………………………………………………………………………………………………

**4.3** The following is a list of **waste minimisation strategies**. Please rank from 1 to 5 the extent to which each has been used in recent/current design projects, where 1 indicates 'never been used'; 2: 'rarely used'; 3: 'used in some projects'; 4: 'used in most projects'; and 5 indicates 'used in all projects'. Please circle your selection.

| | **Never used** | | | | **Used in all projects** |
|---|---|---|---|---|---|
| ▪ Feasibility study of waste estimation | 1 | 2 | 3 | 4 | 5 |
| ▪ Designing for deconstruction | 1 | 2 | 3 | 4 | 5 |
| ▪ Use of standard dimensions and units | 1 | 2 | 3 | 4 | 5 |
| ▪ Use of prefabricated units. | 1 | 2 | 3 | 4 | 5 |
| ▪ Specifying reclaimed/recycled materials | 1 | 2 | 3 | 4 | 5 |
| ▪ Use of standard materials to avoid cutting | 1 | 2 | 3 | 4 | 5 |
| ▪ Avoidance of late variations in design | 1 | 2 | 3 | 4 | 5 |
| ▪ Guidance for hazardous waste management | 1 | 2 | 3 | 4 | 5 |
| **Others (please list below)** | | | | | |
| ▪ ……………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………… | 1 | 2 | 3 | 4 | 5 |

**4.4** To what extent are the above waste minimisation strategies **applied** in your projects during the various stages of the RIBA Plan of Work? Please rank from 1 to 5, where 1 indicates 'never been applied'; 2: 'rarely applied'; 3: 'applied in some projects'; 4: 'applied in most projects'; and 5 indicates 'applied in all projects'. Please circle your selection.

| | **Never** | | | | **Applied in all projects** |
|---|---|---|---|---|---|
| **A** (Appraisal) | 1 | 2 | 3 | 4 | 5 |
| **B** (Design Brief) | 1 | 2 | 3 | 4 | 5 |
| **C** (Concept Design) | 1 | 2 | 3 | 4 | 5 |
| **D** (Design Development) | 1 | 2 | 3 | 4 | 5 |
| **E** (Technical Design) | 1 | 2 | 3 | 4 | 5 |
| **F** (Production Information) | 1 | 2 | 3 | 4 | 5 |
| **G** (Tender documentation) | 1 | 2 | 3 | 4 | 5 |
| **H** (Tender action) | 1 | 2 | 3 | 4 | 5 |
| **J** (Mobilisation) | 1 | 2 | 3 | 4 | 5 |
| **K** (Construction to practical completion) | 1 | 2 | 3 | 4 | 5 |
| **L** (After practical completion) | 1 | 2 | 3 | 4 | 5 |

**4.5** Are there any other comments you wish to make regarding '**Waste Minimisation Design Practices**'?
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## 5. Barriers and Incentives

**5.1** Please rank from 1 to 5 the following **barriers** that impede construction waste minimisation practices, where 1 indicates 'not a barrier'; 2: 'insignificant barrier'; 3: 'minor'; 4: 'significant'; and 5 indicates 'major barrier'. Please circle your selection.

| | Not a barrier | | Minor | | Major barrier |
|---|---|---|---|---|---|
| ▪ Lack of interest from clients | 1 | 2 | 3 | 4 | 5 |
| ▪ Poor defined individual responsibilities | 1 | 2 | 3 | 4 | 5 |
| ▪ Lack of training | 1 | 2 | 3 | 4 | 5 |
| ▪ Waste accepted as inevitable | 1 | 2 | 3 | 4 | 5 |
| **Others (please list below)** | | | | | |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |

**5.2** Please rank from 1 to 5 the following **incentives** that might drive waste minimisation, where 1 indicates 'not an incentive'; 2: 'insignificant incentive'; 3: 'minor'; 4:'significant'; and 5 indicates 'a significant incentive'. Please circle your selection.

| | Not an incentive | | Minor | | Major incentive |
|---|---|---|---|---|---|
| ▪ Waste management plan in place | 1 | 2 | 3 | 4 | 5 |
| ▪ Legislation | 1 | 2 | 3 | 4 | 5 |
| ▪ Training | 1 | 2 | 3 | 4 | 5 |
| ▪ Financial rewards | 1 | 2 | 3 | 4 | 5 |
| **Others (please list below)** | | | | | |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |

**5.3** Are there any other comments you wish to make regarding '**Barriers and Incentives**'?
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## 6. Further Comments

Please use the space provided below to add any other observations/comments.
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## 7. Further Research

- Would you like to receive a **copy of the questionnaire analysis**? Please tick. □ Yes □ No
- We will be carrying out interviews with selected respondents to discuss waste management and minimisation best practice. Would you be willing to share examples of **good practice** to be used as case studies for this research? Please tick. □ Yes □ No

**Please return the completed questionnaire in the self-addressed envelope provided.**

**Thank you very much for your time and effort in completing this questionnaire**

Mohamed Osmani, Department of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire LE11 3TU.
Email: M.Osmani@lboro.ac.uk Tel.: 01509 228155 Fax: 01509 223981

# Appendix 1.4

# Questionnaire survey (contractors)

# Onsite construction waste management practices

The aim of the questionnaire is to investigate current contractors' responsibilities and methods of onsite waste management. **Please note that the information provided will be treated with strict confidence. The names of participating individuals and companies will not be cited or disclosed in the thesis and any associated research outputs.**

## 1. Background Information

- Your name ………………………………… Your position:……………………………………
- Company name (optional):………………………………………………………………………
- Telephone: …………………………………Email: ……………………………………………
- Approximate number of company employees:………………………………………………...
- Please state the approximate annual turnover for your company. Please tick one box only.

| | | | |
|---|---|---|---|
| □ Less than £1m | □ £1-4.99m | □ £5-9.99m | □ £10-19.99m |
| □ £20-49.99m | □ £50-99.99m | □ £100-499.99m | □ over £500m |

## 2. Causes and Types of Waste

**2.1** Please rank from 1 to 5 the following **causes of waste**, where 1 indicates 'not a waste cause'; 2: 'insignificant'; 3: 'minor'; 4: 'significant'; and 5 indicates 'major waste cause'. Please circle your selection.

| **During design stages** | **Cause of waste** | | | | |
|---|---|---|---|---|---|
| | **Not a cause** | | **Minor** | | **Major cause** |
| ▪ Unclear specification | 1 | 2 | 3 | 4 | 5 |
| ▪ Design changes | 1 | 2 | 3 | 4 | 5 |
| ▪ Detailing errors | 1 | 2 | 3 | 4 | 5 |
| ▪ Lack of information on the drawings | 1 | 2 | 3 | 4 | 5 |
| ▪ Last minute changes due to client's requirements | 1 | 2 | 3 | 4 | 5 |
| ▪ Delays drawing revision and distribution | 1 | 2 | 3 | 4 | 5 |
| **Others (please list below)** | | | | | |
| ▪ …………………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ …………………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ …………………………………… | 1 | 2 | 3 | 4 | 5 |

| **During site operations** | **Cause of waste** | | | | |
|---|---|---|---|---|---|
| | **Not a cause** | | **Minor** | | **Major cause** |
| ▪ Delays in forwarding information on sizes of materials to be used | 1 | 2 | 3 | 4 | 5 |
| ▪ Improper storing space and methods | 1 | 2 | 3 | 4 | 5 |
| ▪ Unused materials and products | 1 | 2 | 3 | 4 | 5 |
| ▪ Waste from application processes (e.g. over-preparation of mortar) | 1 | 2 | 3 | 4 | 5 |
| ▪ Off-cuts from cutting materials | 1 | 2 | 3 | 4 | 5 |
| ▪ Weather conditions | 1 | 2 | 3 | 4 | 5 |
| **Others (please list below)** | | | | | |
| ▪ …………………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ …………………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ …………………………………… | 1 | 2 | 3 | 4 | 5 |

**2.2** Please rank from 1 to 5 the **level of waste production** of the following building materials, where 1 indicates 'no waste production; 2: 'insignificant'; 3: 'minor'; 4: 'significant'; and 5 indicates 'major waste production' in relation to the total amount of onsite waste produced. Please select 'Yes' or 'No' if the produced waste is segregated.

| | No waste | | Minor | | Major | Waste segregation |
|---|---|---|---|---|---|---|
| Concrete | 1 | 2 | 3 | 4 | 5 | □ Yes □ No |
| Timber | 1 | 2 | 3 | 4 | 5 | □ Yes □ No |
| Plasterboard | 1 | 2 | 3 | 4 | 5 | □ Yes □ No |
| Plastic | 1 | 2 | 3 | 4 | 5 | □ Yes □ No |
| Packaging | 1 | 2 | 3 | 4 | 5 | □ Yes □ No |
| **Others (please list below)** | | | | | | |
| ▪ …………………… | 1 | 2 | 3 | 4 | 5 | □ Yes □ No |
| ▪ …………………… | 1 | 2 | 3 | 4 | 5 | □ Yes □ No |
| ▪ …………………… | 1 | 2 | 3 | 4 | 5 | □ Yes □ No |

**2.3** Are there any other comments you wish to make regarding '**Waste Types and Origins**'?
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

# 3. Waste Management Responsibilities

**3.1** What are your company's existing **waste management responsibilities**? Please tick all that apply.

□ Waste management goal setting
□ Analysing site waste to be generated
□ Implementing waste segregation
□ Designating waste disposal operators
□ Issuing guidelines for hazardous waste management
□ Preparing a list of each waste material to be salvaged, reused or recycled
□ None
□ **Others (please specify below)**
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

**3.2** What are your company's existing **responsibilities in dealing with hazardous waste**? Please tick all that apply.

□ Implementing waste classification in accordance with European Waste Catalogue six digit code
□ Implementing hazardous waste labelling
□ Issuing guidelines for segregation of hazardous from non-hazardous waste
□ Designating operators for hazardous waste transfer to authorised facilities
□ **Others (please specify below)**

**3.3** Are there any other comments you wish to make regarding '**Waste Management Responsibilities**'?
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

# 4. Onsite Waste Management Practices

**4.1** Is your company **ISO 14001** accredited? Please tick. □ Yes □ No □ In the process

**4.2** What are your main **sources of information** on waste management? Please tick all that apply.

□ Training courses □ Personal research □ Professional bodies □ Media/articles
□ **Other (please specify)** ……………………………………………………………………………

**4.2** Does your company have a **waste management plan/policy**? Please tick. □ Yes □ No

**4.3** Do you use any of the following **waste management tools**? Please tick all that apply.

□ Site Waste Management Plans (SWMPs)
□ SmartWaste
□ In-house waste management plan
□ **Other (please specify)**…………………………………………………………………………….

**4.4** Please rank from 1 to 5 the **impacts** of the following taxes on your current waste minimisation practices, where 1 indicates 'no impact'; 2: 'insignificant'; 3: 'minor'; 4: 'significant'; and 5 indicates 'major impact'. Please circle your selection.

| | **No impact** | | **Minor** | | **Major impact** |
|---|---|---|---|---|---|
| Landfill Tax: | 1 | 2 | 3 | 4 | 5 |
| Aggregate Levy: | 1 | 2 | 3 | 4 | 5 |

**4.5** How much does your company **pay** annually/per project for the following taxes? Please tick the appropriate box if the figure is accurate or estimated.

Landfill Tax: £…………………… per…………… □ Accurate □ Estimated
Aggregate Levy: £…………………… per…………… □ Accurate □ Estimated

**4.6** The following is a list of onsite **waste management strategies**. Please rank from 1 to 5 the extent to which each has been used in recent/current building projects, where 1 indicates 'never been used'; 2: 'rarely used'; 3: 'used in some projects'; 4: 'used in most projects'; and 5 indicates 'used in all projects'. Please circle your selection.

| | **Never used** | | | | **Used in all projects** |
|---|---|---|---|---|---|
| ▪ Set waste reduction targets | 1 | 2 | 3 | 4 | 5 |
| ▪ Provide easy access for delivery vehicles | 1 | 2 | 3 | 4 | 5 |
| ▪ Appropriate storage of materials | 1 | 2 | 3 | 4 | 5 |
| ▪ Waste segregation | 1 | 2 | 3 | 4 | 5 |
| ▪ Onsite reuse of waste materials | 1 | 2 | 3 | 4 | 5 |
| ▪ Offsite reuse of waste materials | 1 | 2 | 3 | 4 | 5 |
| ▪ Recycle of waste materials | 1 | 2 | 3 | 4 | 5 |
| **Others (please list below)** | | | | | |
| ▪ ……………………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………………… | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………………… | 1 | 2 | 3 | 4 | 5 |

**4.7** Are there any other comments you wish to make regarding '**Onsite Waste Management Practices**'?
…………………………………………………………………………………………………………
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………………………………………………………………………………………………

## 5. Barriers and Incentives

**5.3** Please rank from 1 to 5 the following **barriers** that impede construction waste minimisation practices, where 1 indicates 'not a barrier'; 2: 'insignificant barrier'; 3: 'minor'; 4: 'significant'; and 5 indicates 'major barrier'. Please circle your selection.

| | Not a barrier | | Minor | | Major barrier |
|---|---|---|---|---|---|
| ▪ Lack of interest from clients | 1 | 2 | 3 | 4 | 5 |
| ▪ Poor defined individual responsibilities | 1 | 2 | 3 | 4 | 5 |
| ▪ Lack of training | 1 | 2 | 3 | 4 | 5 |
| ▪ Waste accepted as inevitable | 1 | 2 | 3 | 4 | 5 |
| **Others (please list below)** | | | | | |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |

**5.4** Please rank from 1 to 5 the following **incentives** that might drive waste minimisation, where 1 indicates 'not an incentive'; 2: 'insignificant incentive'; 3: 'minor'; 4:'significant'; and 5 indicates 'a significant incentive'. Please circle your selection.

| | Not an incentive | | Minor | | Major incentive |
|---|---|---|---|---|---|
| ▪ Waste management plan in place | 1 | 2 | 3 | 4 | 5 |
| ▪ Legislation | 1 | 2 | 3 | 4 | 5 |
| ▪ Training | 1 | 2 | 3 | 4 | 5 |
| ▪ Financial rewards | 1 | 2 | 3 | 4 | 5 |
| **Others (please list below)** | | | | | |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |
| ▪ ……………………………………………. | 1 | 2 | 3 | 4 | 5 |

**5.3** Are there any other comments you wish to make regarding '**Barriers and Incentives**'?

……………………………………………………………………………………………………………
……………………………………………………………………………………………………………
………………………………………………………………………………………………

## 6. Further Comments

Please use the space provided below to add any other observations/comments.

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……………………………………………………………………………………………………………
……………………………………………………………………………………………………………
…………………………………………………………………………………………………………

## 7. Further Research

- Would you like to receive a **copy of the questionnaire analysis**? Please tick. □ Yes □ No
- We will be carrying out interviews with selected respondents to discuss waste management and minimisation best practice. Would you be willing to share examples of **good practice** to be used as case studies for this research? Please tick. □ Yes □ No

**Please return the completed questionnaire in the self-addressed envelope provided.**

### Thank you very much for your time and effort in completing this questionnaire

Mohamed Osmani, Lecturer in Architectural Engineering and Design Management, Department of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire LE11 3TU.
Email: M.Osmani@lboro.ac.uk Tel.: 01509 228155 Fax: 01509 223981

# APPENDIX 2: INTERVIEW DOCUMENTS

- **Appendix 2.1: Interview schedule**
- **Appendix 2.2: Interview probes**

# Appendix 2.1

## Interview schedule

*Mohamed Osmani*
*Department of Civil & Building Engineering*

Loughborough University

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## Design waste mapping interview schedule

The aim of the interview is to investigate the potential root causes and sources of ‘design waste’ across the RIBA Plan of Work stages.

- ‘Design waste’ is defined in this research as ‘the waste arising from building sites due to the design process, including opportunities to reduce waste by all projects’ stakeholders throughout the RIBA Plan of Work stages’.
- Construction waste ‘causes’ refer to direct and/or indirect waste generators (e.g. design changes; unclear specification).
- Construction waste ‘sources’ are associated with waste generation provenance and project stakeholders’ contributory responsibility (e.g. client, architect).

<u>Interview Agenda</u>

1. Background information (4 questions): 5 minutes

2. Waste minimisation (4 questions): 10 minutes

3. ‘Design waste’ mapping (5 questions): 30 minutes

4. Further comments (1 question): 5-10 minutes

**<u>Confidentiality Note</u>:**

**Please note that the information provided will be treated with strict confidence. The names of participating individuals and companies will not be cited or disclosed in the thesis and any associated research outputs.**

*Mohamed Osmani*
*Department of Civil & Building Engineering*

Loughborough University

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**1. Background information**

The following four questions summarise the interviewee's work experience; responsibilities and views on waste minimisation significance in the building industry.

**1.1** How long have you been working as an architect?

**1.2** What is your current role in the company?

**1.3** What are the primary types of building projects you work on?

A. □ Residential □ Offices □ Retail/leisure
□ Health □ Education □ Industrial
Others:…………………………………………………………………

B. □ New □ Renovation/Refurbishment

C. □ Private □ Public

**1.4** How important is waste minimisation in the projects you are involved in currently?

**2. Waste minimisation**

The aim of the following questions is to broadly identify causes of building waste throughout projects' life cycle; and investigate the architects' contribution to drive waste minimisation.

**2.1** In your view, what are the major causes and sources of onsite building waste?

**2.2** Which of the project's life cycle activities significantly contribute to waste production; i.e. pre-design; design; procurement; site operations?

**2.3** At what stage (s) do you think waste minimisation should be considered? Why?

**2.4** To what extent should architects drive building waste minimisation?

*Mohamed Osmani*
*Department of Civil & Building Engineering*

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**3. 'Design waste' mapping**

The aim of this section is to track building waste backwards through the architectural design process; and identify its potential creation across the RIBA Plan of Work stages.

**3.1** Based on your experience, what are the 'design waste' causes and sources during the RIBA Plan of Work stages A & B: Appraisal and Design Brief?

**3.2** Based on your experience, what are the 'design waste' causes and sources during the RIBA Plan of Work stages C & D: Concept and Design Development?

**3.3** Based on your experience, what are the 'design waste' causes and sources during the RIBA Plan of Work stages E & F: Technical Design and Production Information?

**3.4** Based on your experience, what are the 'design waste' causes and sources during the RIBA Plan of Work stages G & H: Tender Documentation and Action?

**3.5** Based on your experience, what are the 'design waste' causes and sources during the RIBA Plan of Work stages J & K: Mobilisation and Construction?

**4. Further comments**

Are there other issues or comments regarding 'design waste' that you would like to add?

## Thank you for your time

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Fax: 01509 223981

# Appendix 2.2

# Interview probes

## Design waste mapping interview probes

### 1. Background information

**1.2** How long have you been working as an architect?

**1.2** What is your current role in the company?

**1.3** What are the primary types of building projects you work on?

A. □ Residential □ Offices □ Retail/leisure
□ Health □ Education □ Industrial
Others:……………………………………………………………

B. □ New □ Renovation/Refurbishment

C. □ Private □ Public

**1.4** How important is waste minimisation in the projects you are involved in currently?

*Probes*

- *Any different from your previous jobs?*
- *Any different from types of building projects?*

### 2. Waste minimisation

**2.1** In your view, what are the major causes and sources of onsite building waste?

*Probes:* *responsibilities not identified; various stakeholders; knowledge/expertise*

**2.2** Which of the project's life cycle activities significantly contribute to waste production; i.e. pre-design; design; procurement; site operations?

*Probes:* *reasons; mitigation process*

**2.3** At what stage (s) do you think waste minimisation should be considered? Why?

*Probes:* *if design, which stage (s)?*

**2.4** To what extent should architects drive building waste minimisation?

*Probes:* *client's awareness + associated benefits; contract language; waste assessment (pre-design audit of waste to be generated); design; detailing; specification; coordination & collaboration.*

**3. 'Design waste' mapping**

**3.1** Based on your experience, what are the 'design waste' causes and sources during the RIBA Plan of Work stages A & B: Appraisal and Design Brief?

*Probes:*

- *Contractual procedures*
- *No allocated fees*
- *Feasibility study*
- *Real or perceived cost implications*
- *No reference to best practice*
- *Appraisal & recommendations*

**3.2** Based on your experience, what are the 'design waste' causes and sources during the RIBA Plan of Work stages C & D: Concept and Design Development?

*Probes:*

- *Time constraint*
- *Not designing to minimise waste in mind*
- *Insufficient knowledge/expertise*
- *No pre-construction waste assessment*
- *Design complexity*
- *Not working to standard manufacturing dimensions*
- *Not designing for deconstruction (end of life reuse)*
- *Late input from consultants*
- *No contractor on board*

**3.3** Based on your experience, what are the 'design waste' causes and sources during the RIBA Plan of Work stages E & F: Technical Design and Production Information?

*Probes:*

- *Detailing complexity*
- *Errors in construction details*
- *Lack of details for all building components*
- *Unclear/incorrect specification*
- *Unsuitable specification of materials*
- *Not specifying materials which do not need to be cut on site*
- *Not specifying recyclable materials (containing high recycled content); i.e. steel with high recycled content*
- *Unfamiliarity of alternative materials and products(reused, recycled, reclaimed)*

**3.4** Based on your experience, what are the ‘design waste’ causes and sources during the RIBA Plan of Work stages G & H: Tender Documentation and Action?

*Probes:*

- *Lack of architect’s recommendations in tender documents*
- *Contractors’ responsibilities not defined*
- *Lack of architect’s recommendations in tenders negotiations*
- *Lack of tenders’ agreements on waste minimisation procedures*
- *Lack of briefing project team on waste minimisation*
- *Lack of documents/mechanisms for implementation and monitoring*
- *Sub-contractors’ responsibilities not defined*

**3.5** Based on your experience, what are the ‘design waste’ causes and sources during the RIBA Plan of Work stages J & K: Mobilisation and Construction?

*Probes:*

- *Design changes by client*
- *Design changes by architect*
- *Design changes by contractor*
- *Design errors*
- *Detailing errors*
- *Lack of information on drawings*
- *Slow drawing revision and distribution*
- *Speed of construction*
- *Inaccurate ordering*

**4. Further comments**

Are there other issues or comments regarding ‘design waste’ that you would like to add?

## APPENDIX 3: FRAMEWORK INDUSTRY REVIEW DOCUMENTS

- Appendix 3.1: Framework industry review questionnaire survey
- Appendix 3.2: Framework industry review focus group activities
- Appendix 3.3: Industry reviewed Framework
    - Appendix 3.3.1: Industry reviewed Level 0 DoW Framework
    - Appendix 3.3.2: Industry reviewed Level 1 DoW Framework
    - Appendix 3.3.3: Industry reviewed Level 2-Stage 1 (Briefing) DoW Framework
    - Appendix 3.3.4: Industry reviewed Level 2-Stage 2 (Concept Design) DoW Framework
    - Appendix 3.3.5: Industry reviewed Level 2-Stage 3 (Design Development) DoW Framework
    - Appendix 3.3.6: Industry reviewed Level 2-Stage 4 (Technical Design) DoW Framework
    - Appendix 3.3.7: Industry reviewed Level 2-Stage 5 (Tender) DoW Framework
    - Appendix 3.3.8: Industry reviewed Level 2-Stage 6 (Construction) DoW Framework

# Appendix 3.1

# Framework industry review questionnaire survey

*Mohamed Osmani*
*School of Civil & Building Engineering*

**Designing out Waste Framework Industry Review Questionnaire**

**1. Background information**

- Name: ………………………………………………………………………………………….
- Position:……………………………………………………………………………………………
- Company: ………………………………………………………………………………...........
- Telephone: ………………………………………………………………………………………..
- Email: ……………………………………………………………………………………………….
- RIBA Committee/Group:…………………………………………………………………………

**2. Level 0 Designing out Waste Framework**

Please refer to the enclosed Level 0 Designing out Waste Framework (Appendix 0) to answer the following question.

Please rate from 1 to 4 your agreement level for the following statements (1 = Strongly Disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree). Please circle your selection.

| | Strongly Disagree | | | Strongly Agree |
|---|---|---|---|---|
| ▪ The structure of Level 0 Framework is clear | 1 | 2 | 3 | 4 |
| ▪ The content presented in Level 0 Framework is familiar | 1 | 2 | 3 | 4 |
| ▪ The DoW process information flow in Level 0 Framework is clear and sequential in line with conventional design process | 1 | 2 | 3 | 4 |

Please use the space below to suggest amendments/improvements to 'Level 0 Designing out Waste Framework'.
……………………………………………………………………………………………………………
……………………………………………………………………………………………………………

**3. Level 1 Designing out Waste Framework**

Please refer to the enclosed Level 1 Designing out Waste Framework (Appendix 1) to answer the following question.

Please rate from 1 to 4 your agreement level with the following statements (1 = Strongly Disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree). Please circle your selection.

| | Strongly Disagree | | | Strongly Agree |
|---|---|---|---|---|
| ▪ The structure of Level 1 Framework is clear | 1 | 2 | 3 | 4 |
| ▪ The content presented in Level 1 Framework is familiar | 1 | 2 | 3 | 4 |
| ▪ The DoW process information flow in Level 1 Framework is clear and sequential in line with conventional design process | 1 | 2 | 3 | 4 |
| ▪ DoW actions and decisions in Level 1 Framework are appropriate | 1 | 2 | 3 | 4 |

Please use the space below to suggest amendments/improvements to 'Level 1 Designing out Waste Framework'.
……………………………………………………………………………………………………………
……………………………………………………………………………………………………………

*Mohamed Osmani*
*School of Civil & Building Engineering*

Loughborough University

**4. Level 2 Designing out Waste Framework**

Please refer to the enclosed Level 2 Designing out Waste Framework (Appendix 2.1 to 2.6) to answer the following question.

Please rate from 1 to 4 your agreement level with the following statements (1 = Strongly Disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree). Please circle your selection.

| | Strongly Disagree | | | Strongly Agree |
|---|---|---|---|---|
| **Level 2-Stage 1 Framework** (please refer to Appendix 2.1) | | | | |
| ▪ The structure of Level 2-Stage 1 Framework is clear | 1 | 2 | 3 | 4 |
| ▪ The content presented in Level 2-Stage 1 Framework is familiar | 1 | 2 | 3 | 4 |
| ▪ The DoW process information flow in Level 2-Stage 1 is clear and sequential in line with conventional design process | 1 | 2 | 3 | 4 |
| ▪ DoW actions and decisions in Level 2-Stage 1 are appropriate | 1 | 2 | 3 | 4 |
| **Level 2-Stage 2 Framework** (please refer to Appendix 2.2) | | | | |
| ▪ The structure of Level 2-Stage 2 Framework is clear | 1 | 2 | 3 | 4 |
| ▪ The content presented in Level 2-Stage 2 Framework is familiar | 1 | 2 | 3 | 4 |
| ▪ The DoW process information flow in Level 2-Stage 2 is clear and sequential in line with conventional design process | 1 | 2 | 3 | 4 |
| ▪ DoW actions and decisions in Level 2-Stage 2 are appropriate | 1 | 2 | 3 | 4 |
| **Level 2-Stage 3 Framework** (please refer to Appendix 2.3) | | | | |
| ▪ The structure of Level 2-Stage 3 Framework is clear | 1 | 2 | 3 | 4 |
| ▪ The content presented in Level 2-Stage 3 Framework is familiar | 1 | 2 | 3 | 4 |
| ▪ The DoW process information flow in Level 2-Stage 3 is clear and sequential | 1 | 2 | 3 | 4 |
| ▪ DoW actions and decisions in Level 2-Stage 3 are appropriate | 1 | 2 | 3 | 4 |
| **Level 2-Stage 4 Framework** (please refer to Appendix 2.4) | | | | |
| ▪ The structure of Level 2-Stage 4 Framework is clear | 1 | 2 | 3 | 4 |
| ▪ The content presented in Level 2-Stage 4 Framework is familiar | 1 | 2 | 3 | 4 |
| ▪ The DoW process information flow in Level 2-Stage 4 is clear and sequential in line with conventional design process | 1 | 2 | 3 | 4 |
| ▪ DoW actions and decisions Level 2-Stage 4 Framework are appropriate | 1 | 2 | 3 | 4 |

**Level 2-Stage 5 Framework** (please refer to Appendix 2.5)

| | | | | |
|---|---|---|---|---|
| ▪ The structure of Level 2-Stage 5 Framework is clear | 1 | 2 | 3 | 4 |
| ▪ The content presented in Level 2-Stage 5 Framework is familiar | 1 | 2 | 3 | 4 |
| ▪ The DoW process information flow in Level 2-Stage 5 is clear and sequential in line with conventional design process | 1 | 2 | 3 | 4 |
| ▪ DoW actions and decisions Level 2-Stage 5 Framework are appropriate | 1 | 2 | 3 | 4 |

**Level 2-Stage 6 Framework** (please refer to Appendix 2.6)

| | | | | |
|---|---|---|---|---|
| ▪ The structure of Level 2-Stage 6 Framework is clear | 1 | 2 | 3 | 4 |
| ▪ The content presented in Level 2-Stage 6 Framework is familiar | 1 | 2 | 3 | 4 |
| ▪ The DoW process information flow in Level 2-Stage 6 is clear and sequential in line with conventional design process | 1 | 2 | 3 | 4 |
| ▪ DoW actions and decisions Level 2-Stage 6 Framework are appropriate | 1 | 2 | 3 | 4 |

Please use the space below to suggest amendments/improvements to 'Level 2 Designing out Waste Framework'.
…………………………………………………………………………………………………………
…………………………………………………………………………………………………………
…………………………………………………………………………………………………………
…………………………………………………………………………………………………………

**5. Further Comments**

Please use the space below to add any other comments regarding the framework (e.g.. improvement measures, implementation strategy, impact)

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**Thank you for taking part in the DoW Framework industry review process**

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# Appendix 3.2

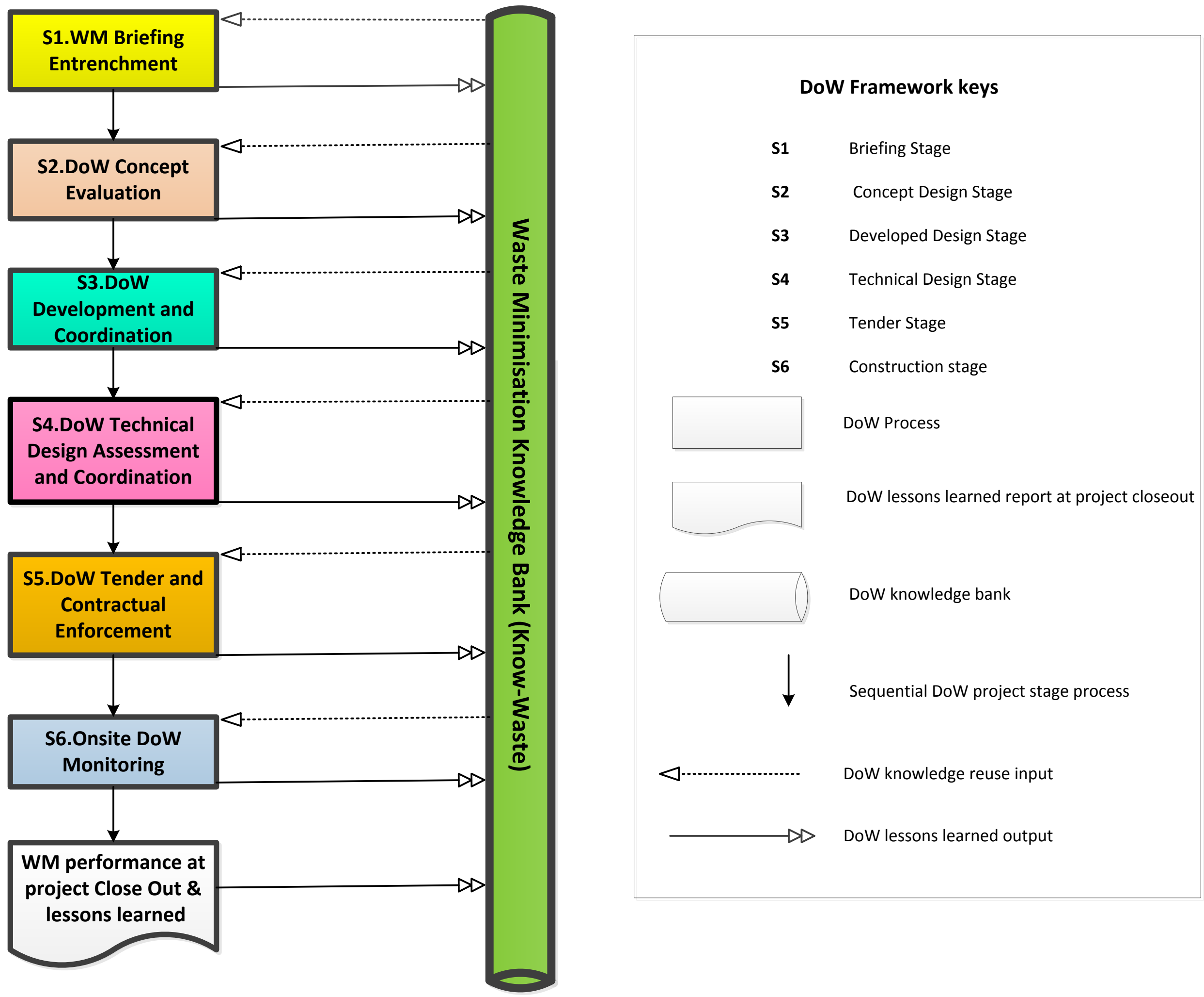
## Framework industry review focus group activities

# Designing out Waste (DoW) Framework Industry Review Focus Group flip chart

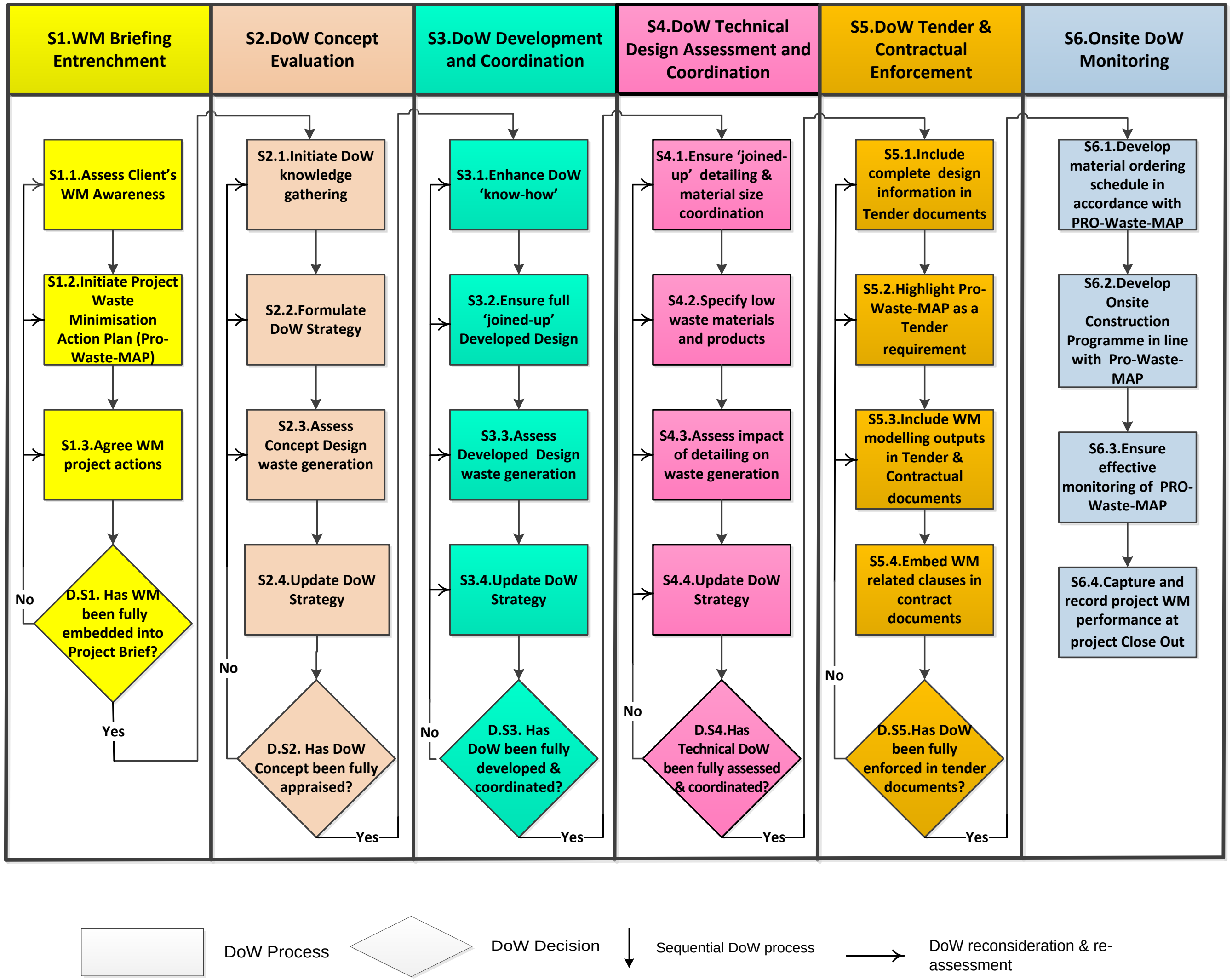
| Suggestions for Framework enhancement | Framework appropriateness and adaptability | Framework potential impact on continuous construction waste minimisation improvement |
|---|---|---|
| | | |

## Appendix 3.3: Industry reviewed Framework

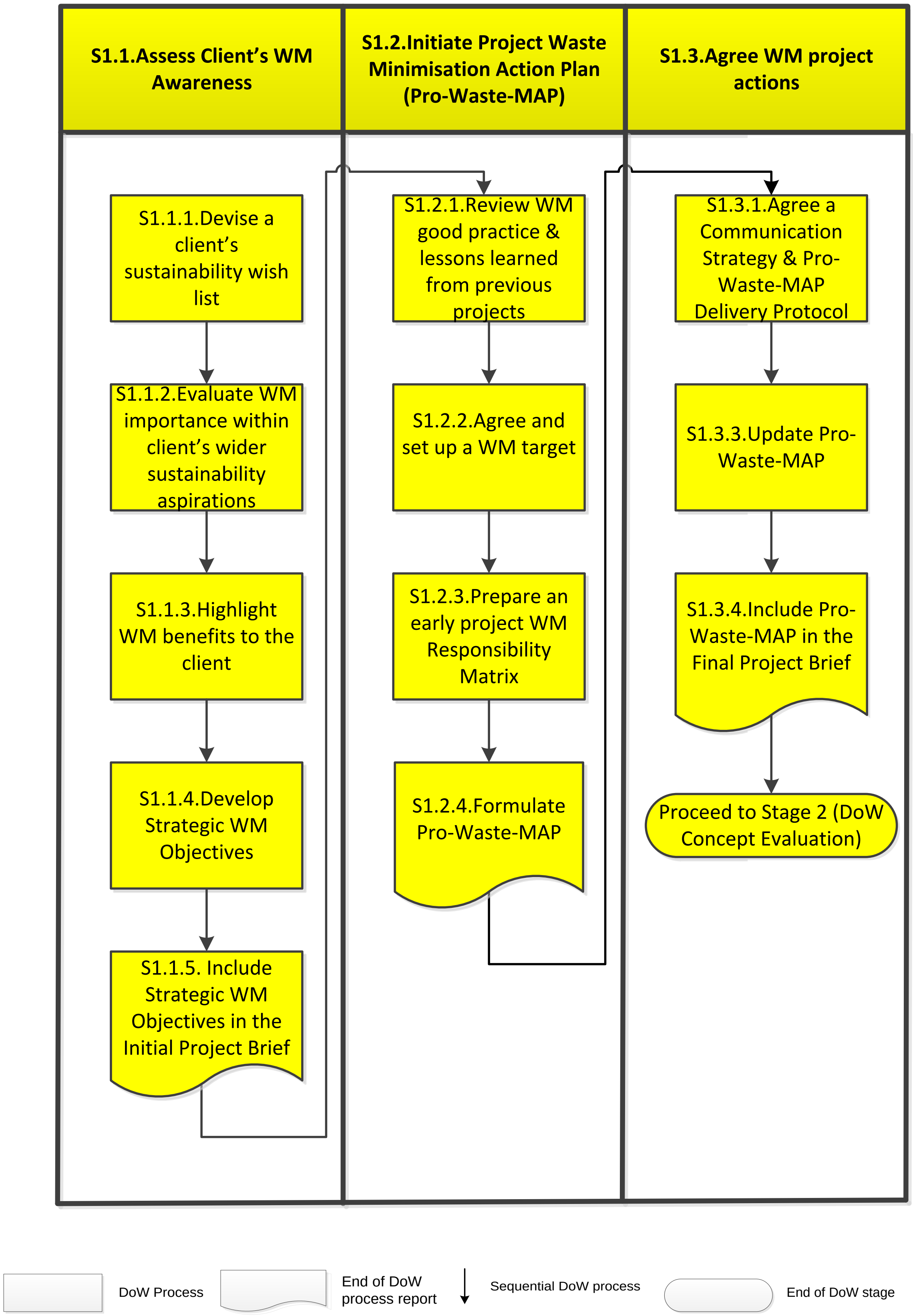
- Appendix 3.3.1: Industry reviewed Level 0 DoW Framework
- Appendix 3.3.2: Industry reviewed Level 1 DoW Framework
- Appendix 3.3.3: Industry reviewed Level 2-Stage 1 (Briefing) DoW Framework
- Appendix 3.3.4: Industry reviewed Level 2-Stage 2 (Concept Design) DoW Framework
- Appendix 3.3.5: Industry reviewed Level 2-Stage 3 (Design Development) DoW Framework
- Appendix 3.3.6: Industry reviewed Level 2-Stage 4 (Technical Design) DoW Framework
- Appendix 3.3.7: Industry reviewed Level 2-Stage 5 (Tender) DoW Framework
- Appendix 3.3.8: Industry reviewed Level 2-Stage 6 (Construction) DoW Framework



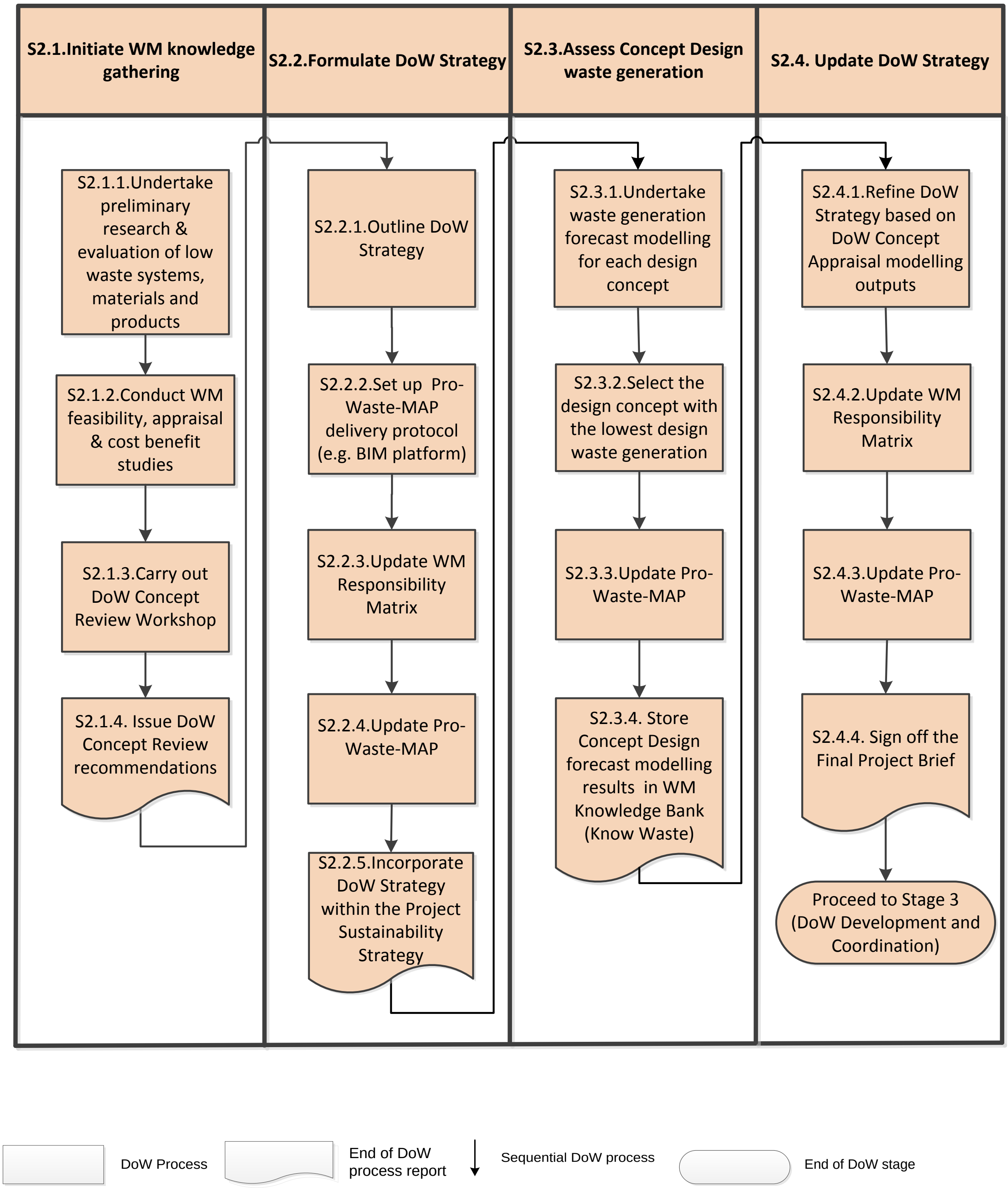

**Appendix 3.3.1: Industry reviewed Level 0 DoW Framework**



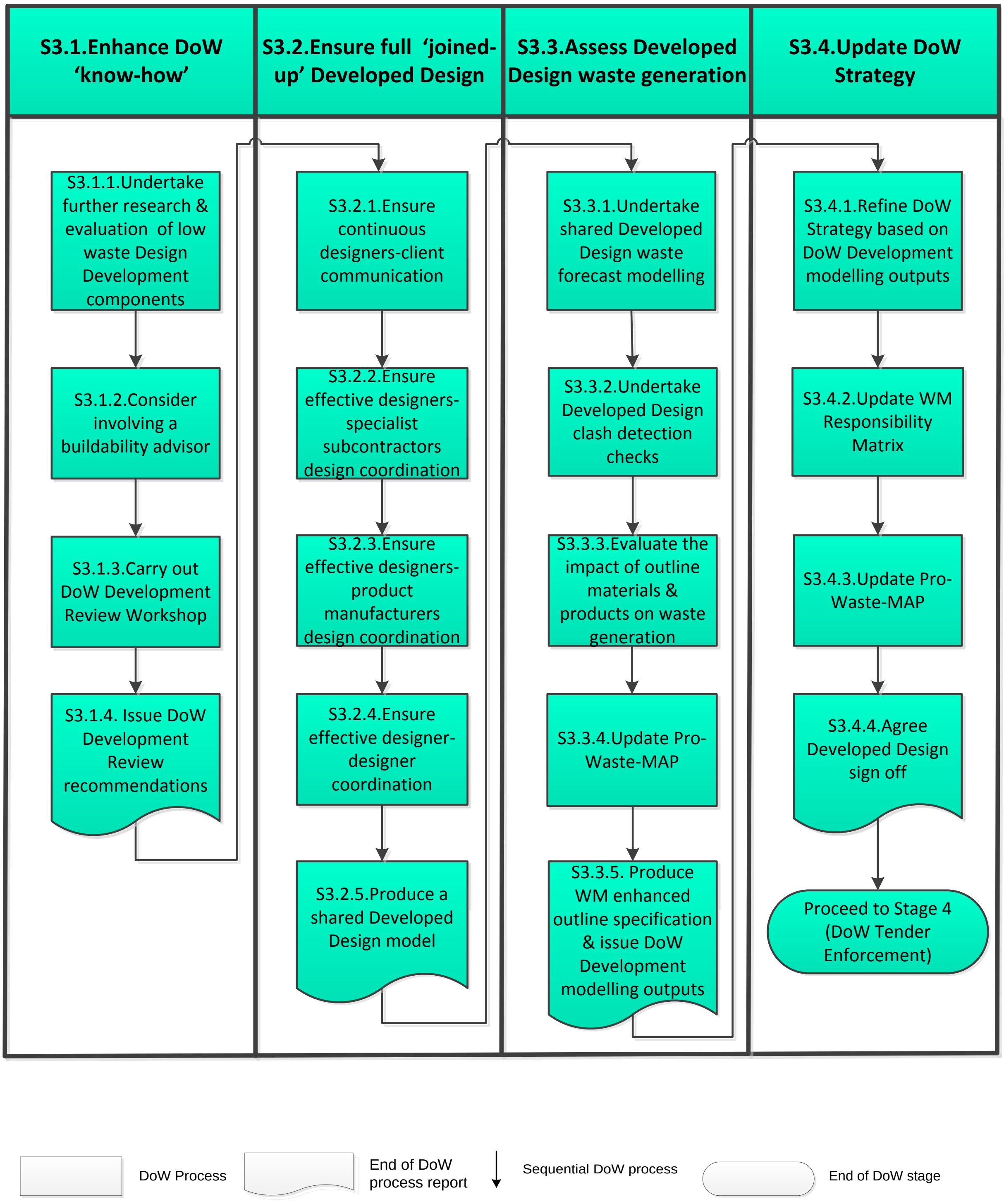

**Appendix 3.3.2: Industry reviewed Level 1 DoW Framework**



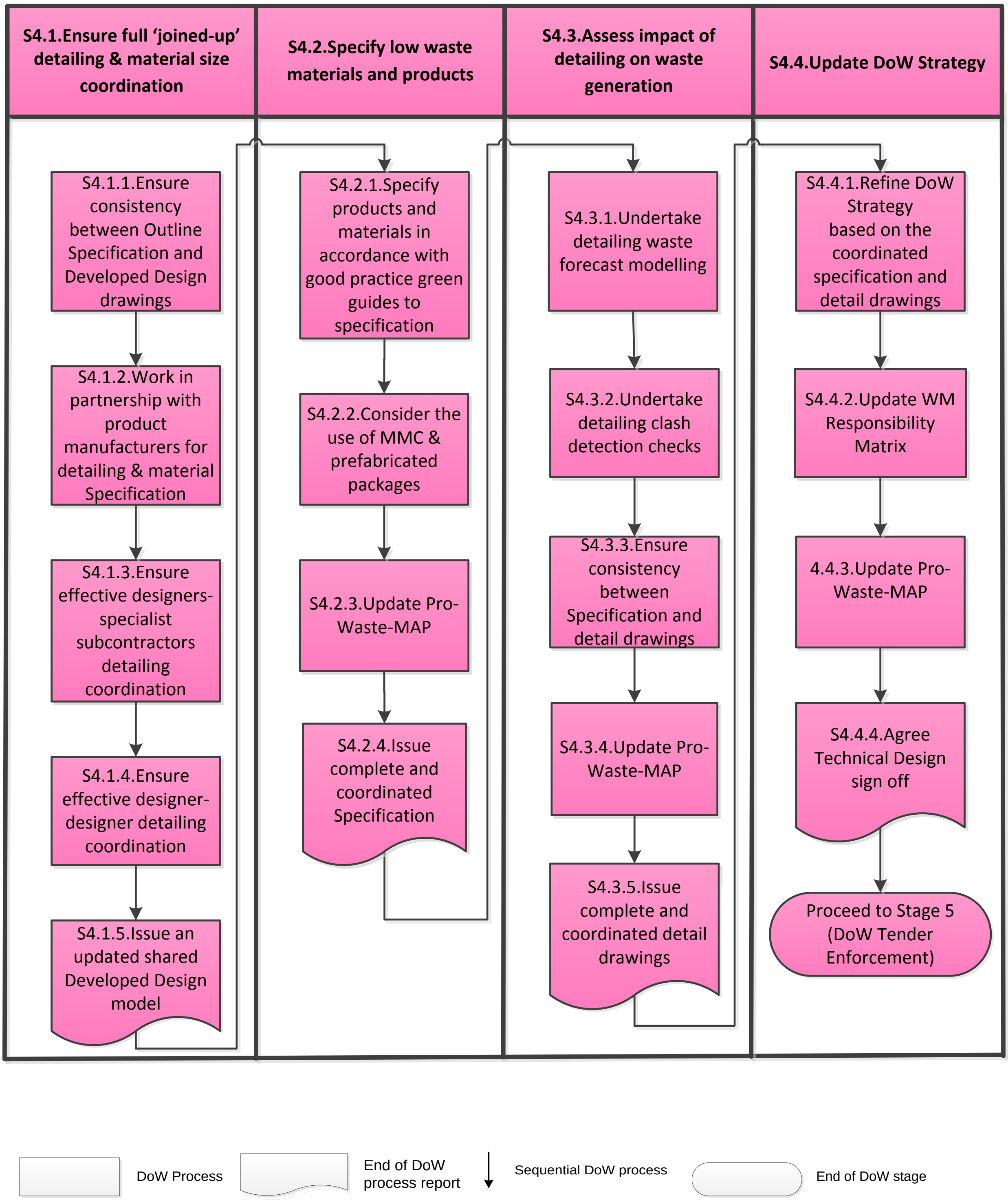

**Appendix 3.3.3: Industry reviewed Level 2-Stage 1 (Briefing) DoW Framework**



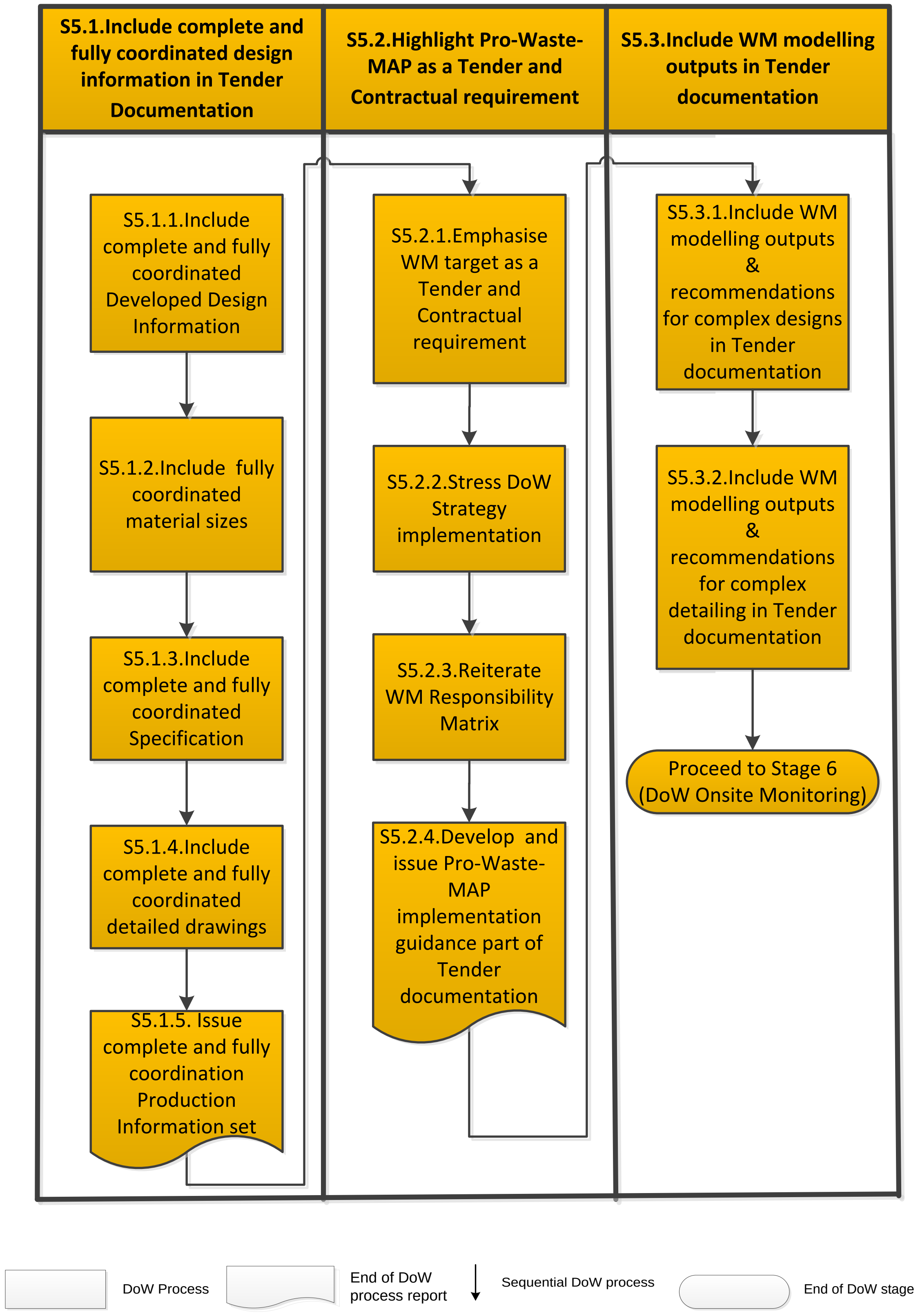

**Appendix 3.3.4: Industry reviewed Level 2-Stage 2 (Concept Design) DoW Framework**



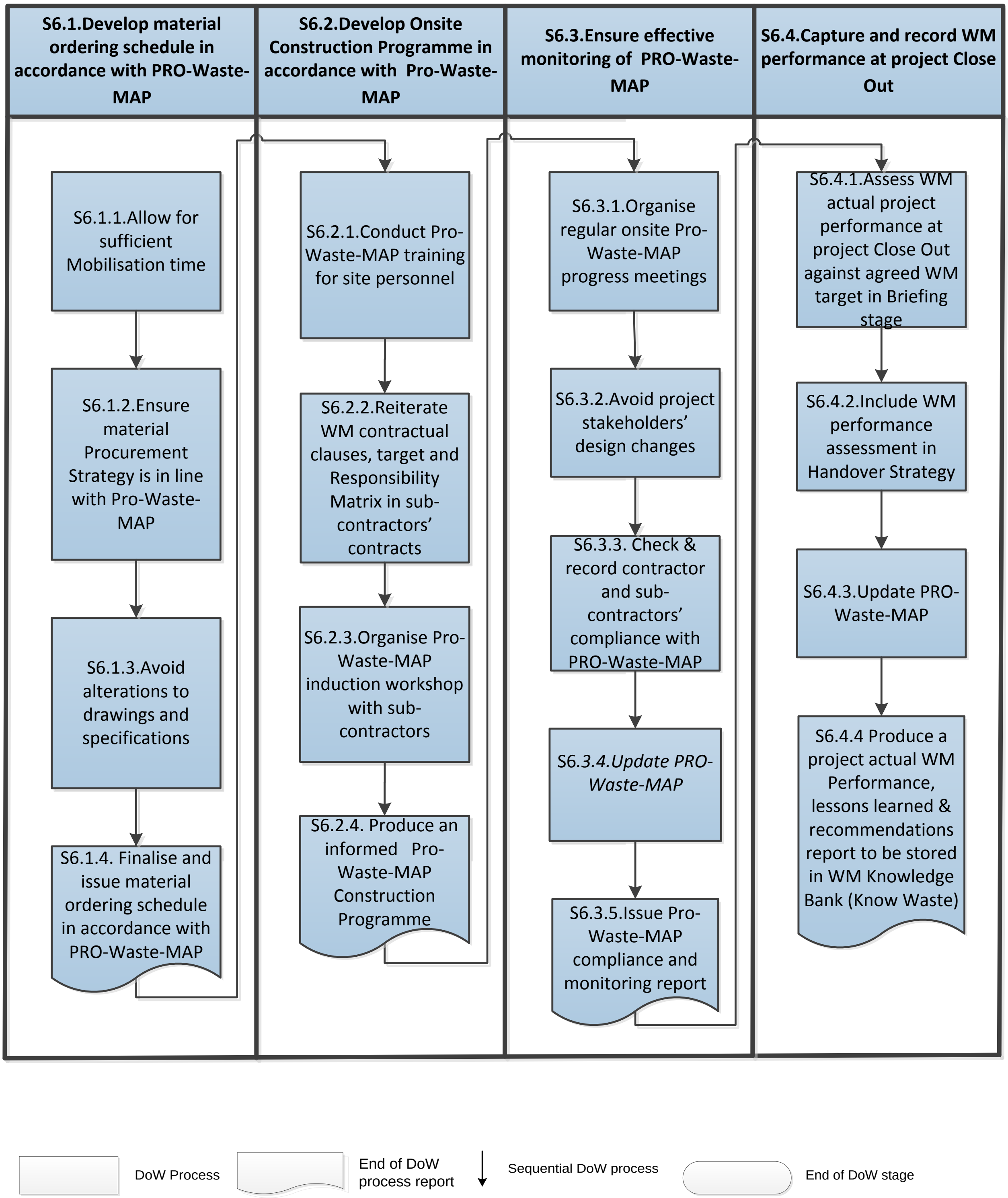

**Appendix 3.3.5: Industry reviewed Level 2-Stage 3 (Design Development) DoW Framework**




**Appendix 3.3.6: Industry reviewed Level 2-Stage 4 (Technical Design) DoW Framework**




**Appendix 3.3.7: Industry reviewed Level 2-Stage 5 (Tender) DoW Framework**




**Appendix 3.3.8: Industry reviewed Level 2-Stage 6 (Construction) DoW Framework**

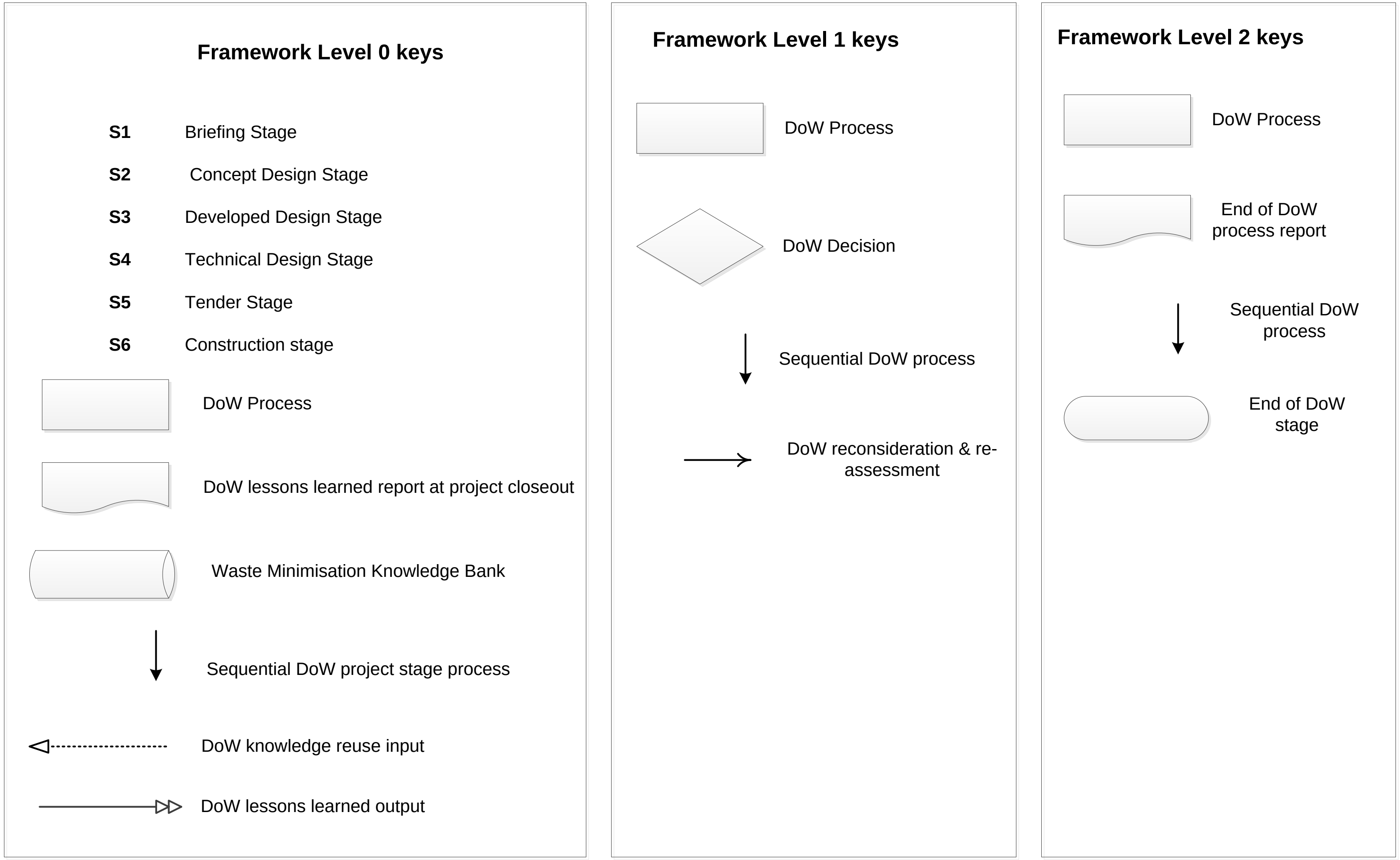
# APPENDIX 4: POST FRAMEWORK INDUSTRY REVIEW DOCUMENTS

- Appendix 4.1 Framework keys
- Appendix 4.2 Framework glossary
- Appendix 4.3 Waste causes versus Framework actions

# Appendix 4.1

# Framework keys

## DoW Framework keys



# Appendix 4.2

## Framework glossary

# Framework glossary

The link between the Designing out Waste (DoW) Framework stages and the RIBA Plan of Work 2007 stages are summarised in the table below.

| Designing out Waste (DoW) Framework Stage | RIBA Plan of Work 2007 Stage |
|---|---|
| S1. WM Briefing entrenchment | Appraisal and Design Brief |
| S2. DoW Concept Evaluation | Concept Design |
| S3.DoW Development and Coordination | Design Development |
| S4.DoW Technical Design Assessment and Coordination | Technical Design and Production Information |
| S5.DoW Tender and Contractual Enforcement | Tender Documentation an d Action |
| S6.Onsite DoW Monitoring | Mobilisation and Construction to Practical Completion |

The abbreviations of the Designing out Waste (DoW) Framework are:

- **WM**: Waste Minimisation
- **DoW**: Designing out Waste
- **Know-Waste**: Waste Minimisation Knowledge Bank
- **Pro-Waste-MAP**: Project Waste Minimisation Action Plan

## Appendix 4.3: Design waste causes versus Framework actions

- **Appendix 4.3.1:** Design waste causes versus DoW Framework actions during Briefing stage
- **Appendix 4.3.2:** Design waste causes versus DoW actions during Concept and Design Development stage
- **Appendix 4.3.3:** Design waste causes versus DoW actions during Technical stage
- **Appendix 4.3.4 :** Design waste causes versus DoW actions during Tender stage
- **Appendix 4.3.5:** Design waste causes versus DoW actions during Construction stage

# Appendix 4.3.1

# Design waste causes versus DoW Framework actions during Briefing stage

**Appendix 4.3.1** Design waste causes versus DoW Framework actions during Briefing stage

| Waste Cause | DoW Framework Action |
| --- | --- |
| **Not a brief requirement** | |
| Not client-driven | S1.1; S1.2; S1.3 |
| No specific WM-related briefing requirements | S1.1.5; S1.2.4; S1.3.4 |
| Client unaware of WM benefits | S1.1.2; S1.1.3 |
| Time constraints | N/A |
| Poorly defined WM responsibilities | S1.2.3; S1.3.1 |
| WM not embedded in contact documents | S1.3.2 |
| **Insufficient incentives and enablers** | |
| WM not a legislative requirement for designers | N/A |
| No designing out waste financial incentives | N/A |
| No WM feasibility studies | S2.1.2 |
| Lack of recognised WM benchmarking and baselines | S1.2.1 |
| No WM target setting | S1.2.2 |
| **Lack of early collaborative engagement** | |
| Limited early interaction and coordination among project team | S1.2.4; S1.3.1 |
| WM not embedded in appraisal studies | S2.1.2 |

# Appendix 4.3.2

## Design waste causes versus DoW actions during Concept and Design Development

Appendix 4.3.2 Design waste causes versus DoW actions during Concept and Design Development stage

| Waste Cause | DoW Framework Action |
|---|---|
| **Insufficient design timescale** | |
| Restricted design stage timescale leading to off the shelf design solutions | N/A |
| Limited research and best practice review | S2.1; S3.1 |
| **Lack of architects' engagement** | |
| Not a design priority | S2.1; S2.3 |
| No waste management plan | S1.2.4; S2.3.3; S3.4.3 |
| Design complexity | S2.3.1; S3.3.1 |
| Not designing to standard material sizes | S3.2.3; S3.3.3 |
| No evaluation of impact of design solutions on waste generation | S2.3; S3.3 |
| Limited involvement of architects' in design development | S3.2.2; S3.2.4; S3.25 |
| **Limited knowledge and guidance** | |
| Lack of understanding of design waste causes and sources | S2.1; S2.3; S3.1; S3.3 |
| Insufficient designing out waste 'know-how' | S2.2; S2.3; S3.3; S3.4 |
| Limited design designing out literature and best practice sharing | S2.1; S3.1 |
| **Lack of partnering commitment and coordination** | |
| Inadequate client-architect coordination | S3.2.1 |
| Poor coordination and communication between designers | S3.2.2; S3.2.4 |
| Lack of contractor's early involvement | S3.1.2 |
| Design not frozen at the end of Design Development | S3.4.4 |

# Appendix 4.3.3

## Design waste causes versus DoW actions during Technical stage

**Appendix 4.3.3** Design waste causes versus DoW actions during Technical stage

| Waste Cause | DoW Framework Action |
|---|---|
| **Inadequate coordination and communication** | |
| Lack of full design team coordination | S4.1.5; S4.3.4; S4.3.5 |
| Incoherent ‘joined-up’ detailing between designers | S4.1.3; S4.1.4 |
| Lack of material size coordination between designers | S4.1.2; S4.2.4 |
| Weak linkages between architects and material manufacturers | S4.1.2 |
| Lack of industry modular coordination | S4.1.2 |
| **Incoherent specification** | |
| No impact assessment of material specification on onsite waste generation | S4.2 |
| Unclear/incomplete/incorrect/ unsuitable specification | S4.2.4 |
| Over-specification | S4.2.4 |
| Time constraints leading to off shelf specification | N/A |
| **Detailing inconsistencies** | |
| Complex detailing | S4.3.1 |
| Detailing errors | S4.3.3; S4.3.5 |
| No impact assessment of detailing on material wastage | S4.3.1; S4.3.2 |
| Designers’ restricted detailing responsibility | S4.1.3; S4.1.4 |
| Time constraints leading to off shelf details | N/A |
| **Limited use of modern methods of construction** | |
| Limited use of off-site construction techniques | S4.2.2 |
| Architects’ reluctance to design in prefabricated packages | S4.2.2 |

# Appendix 4.3.4

## Design waste causes versus DoW actions during Tender stage

**Appendix 4.3.4** Design waste causes versus DoW actions during Tender stage

| Waste Cause | DoW Framework Action |
|---|---|
| **Waste minimisation not entrenched in tender documentation** | |
| Waste minimisation not issued and enforced in document control procedures for tender and contact | S5.2.1; S5.2.2; S5.2.5 |
| Poorly defined waste minimisation responsibilities | S5.2.3 |
| Lack of waste minimisation tender's agreements | S5.2 |
| No waste reduction target setting and implementation guidance | S5.2.1; S5.2.4 |
| No financial costing of waste in bill of quantities | S5.1 |
| **Incomplete tender documentation** | |
| Detailing and specification under development during tender stage | S5.1.2; S5.1.3; S5.1.4 |
| Not fully coordinated design and detailing information | S5.1.1; S5.13; S5.1.4 |
| Incomplete information from design team | S5.1 |
| Incoherent information release schedule | S5 |
| Lack of waste minimisation design intent | S5.2; S5.3 |
| Lack of architect's waste minimisation recommendations in tender documentation and action | S5.2; S5.3 |

# Appendix 4.3.5

## Design waste causes versus DoW actions during Construction stage

**Appendix 4.3.5** Design waste causes versus DoW actions during Construction stage

| Waste Cause | DoW Framework Action |
|---|---|
| **Limited 'Mobilisation' timescale and material over-ordering** | |
| Insufficient mobilisation time | S6.1.1 |
| Missing/incomplete design information leading to material ordering assumptions and over-ordering | S6.1 |
| No thorough check of design information prior to construction | S6.2 |
| **Design changes and rework** | |
| Client-led | S6.3.2 |
| Architect-led | S6.3.2 |
| Contractor-led | S6.3.2 |
| Sub-contractors-led | S6.3.2 |
| **Incoherent design information** | |
| Incomplete design information | S5.1 |
| Inconsistencies between specification and drawings | S5.1 |
| Slow drawing revision and distribution | S5.1 |
| Design errors | S5.1 |
| Detailing flaws | S5.1 |

# APPENDIX 5

# LIST OF PUBLICATIONS

## LIST OF PUBLICATIONS

This research generated 16 published outputs, which are listed below.

### Books Chapters

Osmani, M. (2011) Construction Waste, in Letcher T.M. and Vallero D. A. (eds) Waste: *A Handbook for Waste Management*, Elsevier, 207-218.

### International Journal Papers

1. Osmani, M. (2013a) Design waste mapping: a project life cycle approach. *Waste and Resource Management* **166** (3), 114-127.

2. Osmani, M. (2012a) Construction waste minimization in the UK: current pressures for change and approaches, *Social and Behavioral Sciences* **40**, 37-45.

3. Osmani, M., Glass, J., Price A.D. (2008a) Architects perspectives on construction waste minimisation by design, *Waste Management* **28**(7), 1147-1158.

4. Osmani, M., Glass, J., Price A.D. (2007a) Architect and contractor attitudes towards waste minimisation, *Waste and Resource Management* **59**(2), pp.65-72.

Journal papers in progress:

A designing out waste framework. To be submitted to the *Journal of Cleaner Production.*

### International Conference Papers

1. Osmani, M. (2015) Waste management legislation implementation at construction project level: a case study from the United Kingdom. *Proceedings of the Third International Conference on Architecture and Civil Engineering (ACE 2015)*, 12-14 April 2015, Singapore.

2. Osmani, M. (2013b) Construction waste management: challenges and priority interventions. *Proceedings of the fourteenth Waste Management and Landfill Symposium*, 30 September- 4 October 2013, Sardinia, Italy.

3. Osmani, M. (2012b) Implementation of Site Waste Management Plans Regulations in the UK: limitations and missed opportunities. *Proceedings of the International Conference on Recycling and Reuse*, Istanbul, Turkey, 4-6 June 2012, pp.158-164.

4. Osmani, M., Glass, J., Price A.D. (2009) Taking the pulse of construction waste minimisation practices and challenges in the UK: a contractor's perspective. P*roceedings of the 5th International Conference on Environmental, Cultural, Economic and Social Sustainability*, 5-7 January 2009, Mauritius.

5. Osmani, M., Glass, J., Price A.D. (2008b) An investigation of design waste causes in construction. *Proceedings of the Proceedings of the Fourth International Conference on Waste Management and the Environment*, 2.-4 June 2008, Granada, Spain.

6. Osmani, M. (2008c) Sustainable construction waste management: challenges and opportunities. *Proceedings of the Eighteenth European Construction Institute Conference on Major Projects, Major Issues: Managing Mega Projects Successfully,* 24-25 April 2008, London.

7. Osmani, M. (2007b) Designing out waste in building projects: an integrated approach. *Proceedings of the First KTN Resource Efficiency Conference on Designing out Waste: Gaining the Advantage*, 15-17 February 2007, Reading, UK.

8. Osmani, M., Glass, J., Price A.D. (2007c) Rethinking waste management in construction. *Proceedings of the International Conference on Solid Waste Technology and Management*, 3-7 April 2007, Philadelphia, USA.

9. Osmani, M., Glass, J., Price A.D. (2007d) The potential for construction waste minimisation through design. P*roceedings of the Second International Conference on Sustainable Planning and Development,* 2007, 25-27 June 2007, Bologna, Italy.

**Contribution to British Standards**

1. Osmani, M (2014) *Draft Scope of BS 8895-2: Designing for material efficiency in building projects*, British Standards Institute (BSI), London.

2. Osmani, M (2012c) *Draft Scope of BS 8895-1 (Designing for material efficiency in building projects*, British Standards Institute (BSI)