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On-site Concrete Waste Minimisation in Iran

by

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Declaration

I hereby declare that following thesis has been composed by me, that the work which covers the experimental data has been carried out by me, and not been submitted in any form for another degree or diploma at the higher education level. Information obtained from the work of others has been acknowledged in the text and a list of references is given.

Amir Reza Babahaji Meibodi

Dedication

This thesis is dedicated to my parents Mr. & Mrs. Meibodi

my wife Mrs. Sadeghian

and my dazzling son, Sam who was born

during the final stages of my thesis.

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Abstract

Construction waste minimization and management plays an efficient role in achieving sustainability by providing appropriate consideration to the environment, community, and social conditions by delivering built assets. The construction industry has a significant effect on the environment in terms of resource consumption and waste production. Recent statistics published by the UK Government disclose that the construction and demolition sector generates approximately 32% of the total waste produced in the UK, which is three times more than the waste generated by all households combined. Concrete has been a leading construction material for more than a century. However, current and on-going studies in the field of construction waste minimization and management mostly focus on general waste management or examine one specific method of waste minimization. While only a limited number of studies have been conducted to examine on-site concrete waste minimization, the literature reveals that research in this context is required.

This research aimed to propose an on-site concrete waste minimisation framework (OCWMF) for construction projects, which could be potentially applicable and achievable in Iran. In this pursuit, six objectives were determined to guide the research, which are: to identify the common methods of OCWM in the UK as a successful pattern in WM; to rank OCWM methods in UK; to rank OCWM methods in Iran; to identify the differences between common methods of OCWM in the UK and Iran and explore the possible causes of these differences; and to investigate the causes of differences in the favoured methods in the UK and the favoured methods in Iran. Finally, the last objective was to propose a framework for Iran.

Both quantitative and qualitative strategies as well as a combination of qualitative and quantitative strategies were adopted for this research. Data was collected through face-to-face semi-structured interviews in the UK (N=5), a self-administered postal questionnaire survey in the UK (N=196 distributed, N=73 received), a self-administered postal questionnaire survey in Iran (N=196 distributed, N=110 received), and face-to-face semi-structured interviews in Iran (N=10). Interviewees were project managers, site superintendents, consultants, and engineers selected from the top 100 contractor companies and the top 100 consultant companies in the UK and in Iran. The questionnaire questions were developed based on the findings of the literature review and the semi-structured interviews in the UK. Then, to examine the outcomes of interviews in Iran, three case studies in Iran was observed. Finally, emanating from study results, an OCWMF was developed and refined using discussions (N=2), a questionnaire (N=6), and interviews (N=7).

Key findings that emerged from the study include: legislation and regulations in the UK are the main drivers for construction waste reduction; governmental incentives in reducing waste, use of pre- fabricated building components, and education and training are the most recommended OCWM methods in the UK in terms of overall worthiness or spending to create savings or minimize waste; governmental incentives to reduce waste, education and training, and purchase management are the most recommended methods in Iran; the main differences between proposed OCWM methods in Iran and in the UK are in the use of pre-fabricated concrete elements (PCEs) and ready-mix concrete; the cost of using PCEs is the main cause of differences in methods between the countries; and the consultants and contractors involved in the case study were not interested in using PCEs in their projects due to the high costs involved despite the significant reduction in waste when this method is used. In conclusion, the framework proposed various remedies that could potentially be used for improving OCWM in Iran.

The study has also made some recommendations for the industry, policy makers, and for further research. The content should be of interest to contractors, clients, and engineers.

Key words: Construction waste minimization, concrete waste, on-site concrete waste, pre-fabricated concrete elements, waste minimization, waste origins, UK, and Iran.

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List of Abbreviations

B

BEng	Bachelor of Engineering
BERR	Department for Business Enterprise and Regulatory Reform
BIM	Building Information Modelling
BIMs	Building Information Models
BRE	Building Research Establishment
BRMCA	British Ready-mixed Concrete Association

C

CCANZ	Cement & Concrete Association of New Zealand
C&D	Construction and Demolition
CD&E	Construction, Demolition, and Excavation
C&DW	Construction and Demolition Waste
CFC	Chlorofluorocarbon
CIRIA	Construction Industry Research and Information Association
CL	Clients
CPIM	Construction Process Improvement Methodology
CO	Contractor
CO2	Carbon Dioxide
CSF	Critical Success Factor
CSR	Corporate Social Responsibility
CWMF	Construction Waste Minimisation Framework

D

DE	Designers and Engineers
DEFRA	Department for Environment, Food and Rural Affairs
DRIVE	Define, Review, Identify, Verify, Execute

E

EMAS	Environmental Management and Audit Scheme
EPA	Environmental Protection Agency
EU	European Union
EuPC	European Plastic Converter

G

GDP	Gross Domestic Product
GPS	Global Positioning System

H

HMRC	Her Majesty's Revenue & Customs
HMSO	Her Majesty's Stationery Office

I

IBCC	Book of Construction Contractors of Iran
ICBQ	Iran's construction Bills of Quantity list

ICE	Institution of Civil Engineers
ISO	International Organization for Standardization
IT	Information Technology
L	
LAMDA	Look-Ask-Model-Discuss-Act
M	
MDF	Medium Density Fiberboard
MF	Manufacturer
MSc	Masters of Science
N	
NCDWC	National Construction and Demolition Waste Council
O	
OCR	Optical Character Recognition
OCWMM	On-site Concrete Waste Minimisation Method
OCWMF	On-site Concrete Waste Minimisation Framework
P	
PC	Personal Computer
PCE	Pre-fabricated Concrete Elements
PM	Policymakers
PWMF	Procurement Waste Minimisation Framework
R	
RAC	Recycled Aggregate Concrete
RFID	Radio Frequency Identification
RICS	Royal Institution of Charted Surveyors
S	
SMART	Specific, Measurable, Achievable, Realistic, and Timely
SME	Small or Medium Enterprise
SPSS	Statistical Package for Social Sciences
SSF	Selected Success Factor
SU	Supplier
SWMP	Site Waste Management Plan
T	
TMWM	Tehran Municipality Waste Management
TV	Television
U	
UK	United Kingdom
US	United States
V	
VAT	Value Added Tax

W

WGR	Waste Generation Rate
WMP	Waste Management Plan
WM	Waste Minimization
WRAP	Waste Resources Action Programme

1. Introduction

1.1. Context

In recent decades, construction waste has become a significant environmental problem in many large cities around the globe (Begum et al., 2006). The construction and demolition (C&D) sector is considered one of the major contributors to the total waste production due to the massive amount it produces (Kulathunga et al., 2006). Over one billion tonnes of construction and demolition waste (C&DW) is generated globally each year (Amnon, 2004). For instance, in Australia, the National Waste Minimization and Recycling Strategy has estimated that each year 14 million tonnes of solid waste is disposed to the landfill (ibid.). Teo et al (2001) reported that in Canada, construction waste is estimated to account for approximately 30% of solid waste. C&DW accounts for approximately 20% of overall landfill waste volume in the US and more than 50% in the UK. In Hong Kong, in 2001, the C&D sector produced more than 40% of the amount of total waste generated from all sources (Wong et al., 2004). The C&D sector in Tehran produced 50,000 tonnes of waste each day in 2010 alone (TMWM, 2011). In Tehran, average C&D waste generation is about 4.64 kg *per capita* per day based on reports from Tehran Municipality Waste Management (Saghafi et al., 2011). Although many waste management and recycling programmes were implemented in Europe between 1995 and 1998, the amount of waste generation increased by approximately 15% and the gross domestic product grew by 10% during the same period.

The situation for construction waste management in particular is alarming. In many countries, construction waste has already started to become unmanageable (Stenis, 2004). Most construction waste goes into landfills, increasing the burden on landfill loading and operation, but there are other options. Some materials can be recycled directly into the same product for re-use. Others can be reconstituted into other usable products. Additionally, waste minimization (WM) is regularly identified as a key performance indicator of sustainable performance in construction (BERR, 2008; Kibert, 2008). Advocacy of waste management of construction activities for environmental protection, and awareness of waste generated from C&D work have been promoted around the world (Shen & Tam, 2002). In recent years, growing awareness of waste management concerns from C&D waste has been responsible for the expansion of waste management in construction projects (Tam, 2008)

1.2. Background

Iran is a country of 78.5 million inhabitants, and the annual demographic growth is at 1.29% in the country (Iranian Centre for National Statistics, 2015). Construction sector in Iran is seeing a steady annual growth of 4.2%, which is expected to double in coming years, especially in 2016 where the sector is projected to reach a market size of US$ 154.4 billion (Iranian Ministry of Housing and Urban Development, 2015). According to many international experts and prominent economists, Iran is the next major construction market in the Middle East region.

Construction sector that has been considered in this research includes any companies or manufacturers that produce or provide construction materials and construction services for construction projects. According to Iran's Planning and Budgeting Organisation (PBO), construction projects in the country are divided by five main categories, including: buildings, road building and transportation, hydraulic structures, mining, and mechanical construction. About 60,000 companies provide materials, labour, machine and services for the five sorts of construction projects in Iran, employing around 4,000,000 designers, engineers, consultants, project managers, unskilled workers, tenders and contractors, construction material manufacturers and suppliers; contributing around 13% of employment to the national economy (Iranian Ministry of Housing and Urban Development, 2015).

Construction industry in Iran has links with 130 economic sectors, and thus plays an important role in the national economy. The annual turnover in the construction industry in Iran amounts to about US$40 billion, and it contributes to more than 20 percent of fixed capital formation each year, accounting for 20–50% of the total private investment in the country (IIM, 2014b).

Among the aforementioned five sorts of construction projects in Iran, this research focused on buildings. A growing young population and lifestyle changes in Iran are increasing housing demand, which causes more construction material consumption and, consequently, more waste material in the future (Ardakani and Madani, 2009). One of the important components of the total construction investment in Iran is residential buildings projects. According to the annual report of Iran Central Bank (2014), investment in housing has increased more than 75 times in the 24 years (1990-2014), and the average share of investment in housing in the national GDP in the same period has been 5.8%. Housing production has been almost entirely carried out by the private sector in Iran. The average share of the private sector in investment on housing has been 90 percent, and the state participation in housing market has been less than 10 percent (Iranian Ministry of Housing and Urban Development, 2015).

In 2013-14, the private sector's investment in the buildings of urban areas, after adjustment for 'construction services' and 'construction materials' price indices, rose 23.2 percent (at current prices). In the same period, private sector investment in the buildings of 'Tehran', 'other large cities', and 'small and medium-sized cities' grew by 8.7, 48.4, and 11.6 percent, respectively (Iran Central Bank, 2014).

Statistics from June 2014 to June 2015 put the number of total Iranian households at 16.2 million and the total number of dwelling units at 14.1 million, showing a significant demand for dwelling units (Iranian Centre for National Statistics, 2015). Each year, there is a need for about 750,000 additional units in the country, as young couples embark on married life. At present, 2000 units are being built every day although this needs to increase to 2740 units (Iranian Ministry of Housing and Urban Development, 2015).

Building are conventionally constructed with a reinforced concrete or steel structure in Iran, plastered and painted masonry walls and steel fenestration. In the conventional method of construction in Iran, floor finishes are terrazzo or ceramic tiles, while plumbing pipes and conduits for electric wiring are embedded in masonry walls (Saghafi and Hosseini, 2011). The rate of steel consumption between the years 2005 to 2009 in Iranian buildings was estimated to be 14,084,569 ton, and steel consumption rate growth was 7.21% in the same period. The rate of cement consumption between the years 2005 to 2009 was announced to be 8,248,829 ton, and its growth was 14.8% (Veise and Tahmasebi, 2009). In recent years, demands and interests for launching mass building projects, use of new technologies and fast-pace project execution, new construction materials, and technological advances has been booming in the country.

Generally, construction waste production in Iran is higher than the average in developed countries. For example, average construction and demolition waste production in the United States is 0.77 kg per capita per day (DSM, 2008), while construction and demolition waste production is 4.64 kg per capita per day in the city of Tehran in Iran (TMWM report, 2009).

In terms of eliminating waste from construction projects, it is worth noting that tipping and taxes tend to further weaken the reuse and recycling of C&D waste; once there is a lack of fulfilment of such regulation, control over the illegal disposal, and application of penalties. According to similar experiences in Iran and other developing countries, this context makes illegal disposal an attractive option from an economical point of view. Furthermore, these kinds of taxes directly affect real estate prices, especially in housing sector (Saghafi and Hosseini, 2011).

This research was concerned with minimising and eliminating construction waste from the works executed at construction projects in Iran. With this concern, a classification of construction wastes offered by Alwi et al. (2002) was adopted that categorises construction wastes into material, labour, and machinery wastes. This research focused only on material waste, in particular, on concrete waste generated from construction projects. Furthermore, following Cox and Clamp (2003), three major stages in construction projects were recognised, including design, tendering and contract, and construction (on-site or in situ). The focus of this research was on concrete waste generated from construction stage (on-site or in situ).

In the words of Ekanayake and Ofori, (2000), this research focused on any concrete material that is required to be transported away from the construction site or used in the construction site for the purpose other than the intended purpose of the project, because of material damage, excess, specification change or non-compliance with specifications, or because it is a by-product of construction processes and activities (on-site or in situ). In other words, the focus was on on-site concrete waste generated as "a consequence of the works executed at buildings or any construction project from the foundation upward" (Llatas, 2011, p. 1266). For this pursuit, a comprehensive literature review was conducted with a hierarchical approach. The review focuses on three main areas, including construction waste, construction waste minimization, and on-site concrete waste minimization, particularly in the UK and in Iran. Furthermore, a literature review about research methodologies was conducted to choose an appropriate research methodology for this study. Literature in English and in Farsi was included in the search. Printed books, journals, theses, reports, databases, and electronic publications were used in the review. The literature review led to understanding of gaps knowledge, enabled the research objectives to be established and refined, and identified tools and techniques (i.e., research methods) that could be employed in the research.

1.3. Research Justification

Although construction waste is physically visible on construction sites, the causes of its production are related to project life cycle (Osmani et al., 2008). Literature shows that the causes of the construction waste production are related to three main stages of projects: design, tender and contract, and construction.

- Causes of waste production related to the design stage, for instance: selection of poor quality materials and products or unclear specifications (Osmani et al., 2008; Poon et al., 2004a; Ekanayake & Ofori, 2000); detailing errors (Osmani et al., 2008, 2006; Ekanayake & Ofori, 2000); and poor dimensional coordination in design (Kulathunga et al., 2005; Poon et al., 2004a; Chen et al., 2002;).
- Causes of waste production related to the tender and contract stages, for instance: uncompleted contract documents at the beginning of construction stage (Osmani et al.,

2008; Kulathunga et al., 2005; Ekanayake & Ofori, 2000); contract type (e.g., in cost plus contracts, although the client has limited control over material wastages, they bear the full cost of material supply to the site); and tendering method.

- Causes of waste production related to construction (on-site) stage, for instance: non-compliance of the materials with specifications; insufficient protection during transportation and unloading; incorrect site storage; poor-quality purchase management and over ordering; poor craftsmanship; and offcuts (Osmani et al., 2008; Kulathunga et al., 2005; Ekanayake & Ofori, 2000)

Although the above classifications show different causes related to each stage of a project, the major part of waste generation is usually related to the on-site construction stage. Waste minimization in construction sites (on-site or in situ) includes a wide range of activities from design stage until handing over of the project and after. For instance, design details can be changed during the construction stage in various circumstances. Therefore, by focusing on on-site waste minimization, a wide range of stage of construction projects can be studied. Although post construction recycling is one method of reducing the amount of waste that ends up in landfills, on-site waste minimization methods such as prevention through lean construction processes and minimization of waste by pre-fabrication and the use of building information modelling are more effective techniques and could have a greater impact on decreasing the amount of waste sent to landfills (Maedows, 2011).

Various research approaches have been conducted in the field of construction waste minimization or construction management. However, the majority of these studies has been focused on construction waste minimization in general or examined one specific method for minimizing a particular material. For instance, Hao et al. (2008) and Tam (2008) focused on implementing general waste management plans, and Poon et al. (2001) focused on waste sorting methods and techniques. In addition, a few limited studies have focused on specific material such as concrete, which is one of the main construction materials globally. Therefore, lack of data about on-site concrete waste minimization methods is particularly noticeable.

Importance of concrete

Concrete has been a leading construction material for more than a century. It is estimated that the global production of concrete is approximately 2.5 tonnes *per capita* annually (Neville, 2003). Concrete also has been one of the main waste materials in construction projects (Kofoworola & Gheewala, 2009). Among different types of construction materials, concrete is collected in the most significant amounts from construction sites, demolition sites, general civil works, and renovation works, respectively. According to Noguchi and Fujimoto (2007), concrete is the second most extensively consumed material in the world after water. By using some concrete waste management methods such as recycling concrete, natural resource exploitation, and associated transportation costs, the amount of waste going to the landfill can be reduced (Woodward & Duffy, 2010). Some countries such as the Netherlands and Japan have achieved almost complete recovery of concrete waste, with up to 100% of waste being recycled (Tam, 2009). Some countries such as Ireland have certain targets to achieve. Each year, many buildings are demolished In Iran, mainly because their useful lifetime is finished, natural disasters (e.g., earthquake), low safety standards, and demand for more high-rise buildings. Several factors may reduce the lifetime of buildings in Iran, for instance: poor quality construction due to inadequate execution or supervision, poor maintenance, or inability to modify buildings due to changes in the environmental or user demands. Buildings currently being demolished in Iran were generally constructed in the 1960s or earlier. These buildings were constructed mostly with traditional masonry materials such as clay brick (Saghafi & Hosseini, 2011). However, according to TMWM 2012, in less than 15 years, Tehran will need to begin demolishing concrete structures, with more concrete waste production as a consequence. Furthermore, lack of published studies or even data about concrete waste during construction and demolition in Iran motivated the researcher to conduct the present research.

1.4. Aim and Objectives

This research aimed to propose an on-site concrete waste minimisation framework

(OCWMF) for construction projects, which could be potentially applicable and achievable in Iran by focusing on motivating the stakeholders of the projects to use one of the OCWM methods used in the UK which is currently missing or ignored in Iran.

In this pursuit, the following objectives were determined: to identify the most preferred on-site concrete waste minimization methods used both in the UK (using UK methods as examples of successful methods) and Iran; to explore any differences in the preferred methods both in the UK and Iran; and to scrutinise the causes of these differences, in order to develop a framework or possible recommendation to improve on-site concrete waste minimisation in Iran. Therefore, the first three objectives of the research were specified as such in Table 1.1. Next, objectives 4 and 5 were determined. Finally, objective 6 was to propose a framework (OCWMF) for Iran. Table 1.1 illustrates the research objectives, research approach for each objective, and the related rationale.

Table 1.1. Adopted research approaches for achieving the study objectives

Research Objective	Research Approach	Rationale
(1): To identify the common methods of on-site concrete waste minimization in the UK.	Qualitative	Most on-site concrete waste minimization methods were identified through the literature review and examination of previous studies. However, the purpose was to explore all existing methods, which were confirmed by the professionals in construction industry. Therefore, a purposeful sample and an approach based on individual interpretation rather than quantification was required.
(2): To rank the on-site concrete waste minimization methods in the UK. (3): To rank the on-site concrete waste minimization methods in Iran.	Quantitative	The purpose was to determine the most suitable and preferred methods in each country. Use of a quantitative approach was required to create valid and replicable results.
(4): To identify differences between common methods of on-site concrete waste minimization in the UK and in Iran and explore the possible causes of these differences.	Qualitative	The purpose was to compare the methods in the UK and Iran and to determine the reasons or causes for differences between common methods.
(5) To investigate the causes of differences between the best methods in the UK and best methods in Iran.	Quantitative Qualitative	The purpose was to determine the best way to conduct an in-depth study to confirm or refute the points mentioned by interviewees.
(6) To propose a framework for Iran	Quantitative Qualitative	The purpose was to determine the best way to propose the possible remedies for improving on-site concrete waste minimisation in Iran.

Source: Author.

The choice of the UK as reference context for this research was primarily emerged from a review of 87 papers published in the discipline of construction and demolition waste management between 2000 and 2009 in eight selected journals. This initial review was carried out in 2011 at the beginning of this research, showing that researchers from the UK, Hong Kong, Australia, and the US are the main contributors to OCWM research and literature (Yuan and Shen, 2011). Further search for good examples of empirical works on OCWM led to identify that the UK government has introduced legislation and regulation to force different sectors to reduce waste by zero by 2020 (WRAP, 2012). Exemplary, the UK Government's Waste Strategy 2007 seeks to potentially reduce construction waste to zero by 2015 (see section 2.3.2.3). Companies in the UK construction sector are required to follow the regulations and recommendations in the legislation to achieve this goal (WRAP, 2011). Moreover, this research had been done in a UK university, and the researcher had have access to the British professionals in construction projects as sources of primary data about successful on-site concrete waste minimisation (OCWM) methods used in the country. As such, there was a proper environment for doing interviews and questionnaire survey in the UK. In a nutshell, proper literature and a range of sources about successful OCWM methods were available in the UK, making the country a reference context for the present research.

It should be mentioned that this research did not determine to conduct a comparative study; it in fact intended to search for the OCWM methods, which have been used in the UK to date. This search informed a list of the UK OCWM methods against which the OCWM methods that are currently in use in Iran were cross-checked. This cross-checking exercise resulted in to find one of the most preferred OCWM method in the UK which is missing or ignored in Iran at present, with which improving on-site concrete waste minimisation in construction projects in the country could be achieved.

1.5. Research Methodology Overview

This research was conducted by selecting the most suitable methods and procedures to address the research objectives. The strategies of investigation for this research involved both quantitative and qualitative strategies. This adopted research approach helped to counteract the disadvantages of using a single research method (Saunders et al., 2007;

Creswell, 2003). The research implemented a sequential mixed methods procedure in order to gain knowledge from the participants. A qualitative method was first used to complete and check data in the literature review. Subsequently, a quantitative method was employed to examine methods raised from the qualitative study in the UK and Iran that were ranked by individual participants (see Table 1.1). The following sections summarise the data collection and data analysis methods that were used during this research.

As explained earlier, the research has six objectives. Table 1.2 illustrates the adopted research methods for data collection for each of the research objectives.

Table 1.2. Adopted research methodologies

Research Objective	Research Method
Objective 1	Semi-structured face-to-face interviews in the UK
Objective 2	Questionnaire survey in the UK
Objective 3	Questionnaire survey in Iran
Objective 4	Semi-structured, face-to-face interviews in Iran
Objective 5	Case study in Iran
Objective 6	Proposal and validation of a framework in Iran (pre-validation questionnaire and validation semi-structured, face-to-face interviews)

Source: Author.

1.5.1. Semi-structured Interviews in the UK

The literature review revealed a number of issues centred on the existing methods of on-site concrete waste minimization that warranted further investigation. Therefore, the aim and objective of this stage of data collection was to identify the existing methods for on-site concrete waste minimization in the UK in order to have updated information about current methods being used by construction companies. This data was also used to ensure the reliability and completeness of the questionnaire in the next phase of the research. Although most on-site concrete waste minimization methods were identified in literature review from recent studies, in order to be confident that the most updated information was obtained, semi-structured face-to-face interviews were conducted.

Purposive non-random sampling was employed to select interview participants. Five interviews were conducted with professionals in the construction industry that were senior managers or executives of companies with sufficient and reliable knowledge, experience, and success in the construction industry. Companies were chosen from lists of the 100 leading construction companies, 100 leading homebuilders, and 100 leading consulting firms in the UK. Data collection was done through note taking focused on capturing key points. It was expected that the selected top 100 construction organisations would be experienced in different practices and engaged in major issues in waste minimisation and management and would therefore gain better inputs for the questionnaire.

1.5.2. Questionnaire Survey in the UK

This stage aimed to rank the on-site concrete waste minimization methods in the UK and to identify favourite and preferred practices. After completing the literature review and conducting interviews in the UK, a list of possible on-site concrete waste minimization methods was prepared. This list was used to create a questionnaire that asked professionals in the C&D industry to rank the methods. Participants were asked to rate on-site concrete waste minimization methods in terms of:

a) Cost of implementation;

b) Difficulty of implementation;

c) Cost efficiency; and

d) Their overall value in terms of spending on the method to create savings or minimize waste.

To improve the questionnaire, fill in gaps, and determine the time required for completion, five pilot questionnaires were completed. A total number of 196 questionnaires were sent to participants that included consultants, contractors' project managers, and site superintendents. Participants were chosen from lists of the top 100 construction contractor companies and top 100 consultant companies in the UK. The probability sampling method was adopted for this part of the research, and the technique used was stratified random sampling. Questionnaires were sent to potential participants by mail, accompanied with a pre-paid, addressed envelope to return completed questionnaires to the researcher. The response rate was based on the total number of questionnaires sent and the total number of respondents. A total of 196 questionnaires were sent, and 73 participants responded to the survey. Therefore, the active response rate for the survey was 37.2%. Quantitative data analysis was used to examine the results.

1.5.3. Questionnaire Survey in Iran

This part of the research was conducted because of the lack of reliable published information about existing on-site concrete waste minimization methods in Iran. This part aimed to rank the on-site concrete waste minimization methods in Iran and to identify the most favoured methods. The same questionnaire administered in the UK was used in Iran with the same questions, sample size, and frame. Again, to check the suitability of the questionnaire for Iran's C&D industry, five pilot questionnaires were conducted. A total number of 196 questionnaires were sent to participants, which included consultants, contractors' project managers, and site superintendents. Participants were chosen from the top 100 top construction contractor companies and top 100 consultant companies in Iran. Questionnaires were sent to participants by mail, accompanied with the pre-paid, addressed envelope to return completed questionnaires to the researcher. However, other delivery and collection methods for the questionnaires were also used. The response rate, based on a total of 196 sent questionnaires and 110 returned questionnaires, was 56.1%.

1.5.4. Semi-structured Interviews in Iran

As described earlier, the objective of interviews was to identify the differences in common on-site concrete waste minimization methods in the UK and in Iran (determined by comparing questionnaire results in both countries) and explore the possible causes of these differences. Comparison of popular methods in the UK and Iran revealed that the main differences are in "Use of pre-fabricated elements" and "Use of ready-mix concrete" in Iran. Further explanation is provided in section 7.3.1. A qualitative approach, semi-structured face-to-face interviews, was used to collect data about differences in top ranked on-site concrete waste minimization methods in the UK and Iran as revealed by the survey results. The purposive heterogeneous sampling method was used to select participants (Saunders et al. 2009: 232). Ten interviews were conducted with professionals in the construction industry who were including senior managers and executives of companies who had recently been involved in at least one multiple-story, concrete structure building project, had more than 20 years of experience in the construction industry, and were graduates of a UK or US university or had proper, up-to-date knowledge about global waste management strategies so they could compare the methods. The companies from which interviewees were chosen were selected from lists of the 100 leading construction companies, 100 leading homebuilders, and 100 leading consulting firm in Iran. The same sample frame as for the questionnaire was used. During the interviews, participants were asked to express their points of view about possible reasons for differences between methods in the UK and Iran based on their understanding of and experiences with minimizing on-site concrete waste. The responses provided in-depth understanding about the possible causes of differences and through clarifying and coding the responses, possible causes were determined. It was clear that the majority of responses were focused on the cost of using pre-fabricated concrete elements. Therefore, the next stage of the study was to examine a case study, which included three different methods of concrete works (use of pre-fabricated concrete elements, use of ready-mix concrete, and traditional in situ concrete).

1.5.5. Case Study

This part of study aimed to investigate the reasons for differences in the OCWM methods used in the UK and the methods in Iran. Therefore, a case study approach was employed to examine costs, which was the main reason for differences between the methods in the UK and Iran, and concrete waste production of three different methods of making and pouring concrete in a construction project in Tehran. These three methods were: in situ concrete, ready-mix concrete, and pre-fabricated concrete elements. Before the case study, the researcher communicated with the contractor of the project by email and phone. The contractor and client had agreed on using the three methods of concrete work. The selected project was a seven-story building with a concrete frame structure in North Tehran, Iran. The contractor used three methods for casting concrete elements:

- In situ concrete (making and pouring) for floors 5 and 6;
- Ready-mix concrete for floors 3 and 4;
- Pre-fabricated concrete elements for floors 1 and 2.

Data collection methods were interviews accompanied by the collection of hard documentary data. Semi-structured interviews and audits of cost and waste were conducted.

1.5.6. Propose a Framework in Iran

An on-site concrete waste minimisation framework (OCWMF) was developed based on the findings of the literature review, the questionnaire surveys in the UK and Iran, interviews in Iran, and the case study in Iran. Applying general problem solving methodology to the findings of the research helped to place the findings into a logical sequence, which set the foundation for OCWMF development. The OCWMF diagnoses the barriers to using PCE in Iran, and attempts to provide recommendations for potential improvement in using PCE.

The OCWMF validation aimed to examine and refine the appropriateness of the proposed framework. A combination of qualitative and quantitative approaches was used to validate the framework in terms of its clarity, information flow, and appropriateness of content. The validation process involved three stages: pilot study discussion with two researchers in the field of construction management; completion of six pre-validation questionnaires; and seven semi-structured interviews for follow-up. The sample for the pre-validation questionnaire was drawn from respondents to the first questionnaire study in Iran. For validation interviews, five out of 10 interviewees from the first interviews in Iran participated plus two managers in top positions in Tehran Construction Waste Management Organisation.

Figure 1.1 illustrates a summary of the adopted research methods and outcomes of each stage of the study.

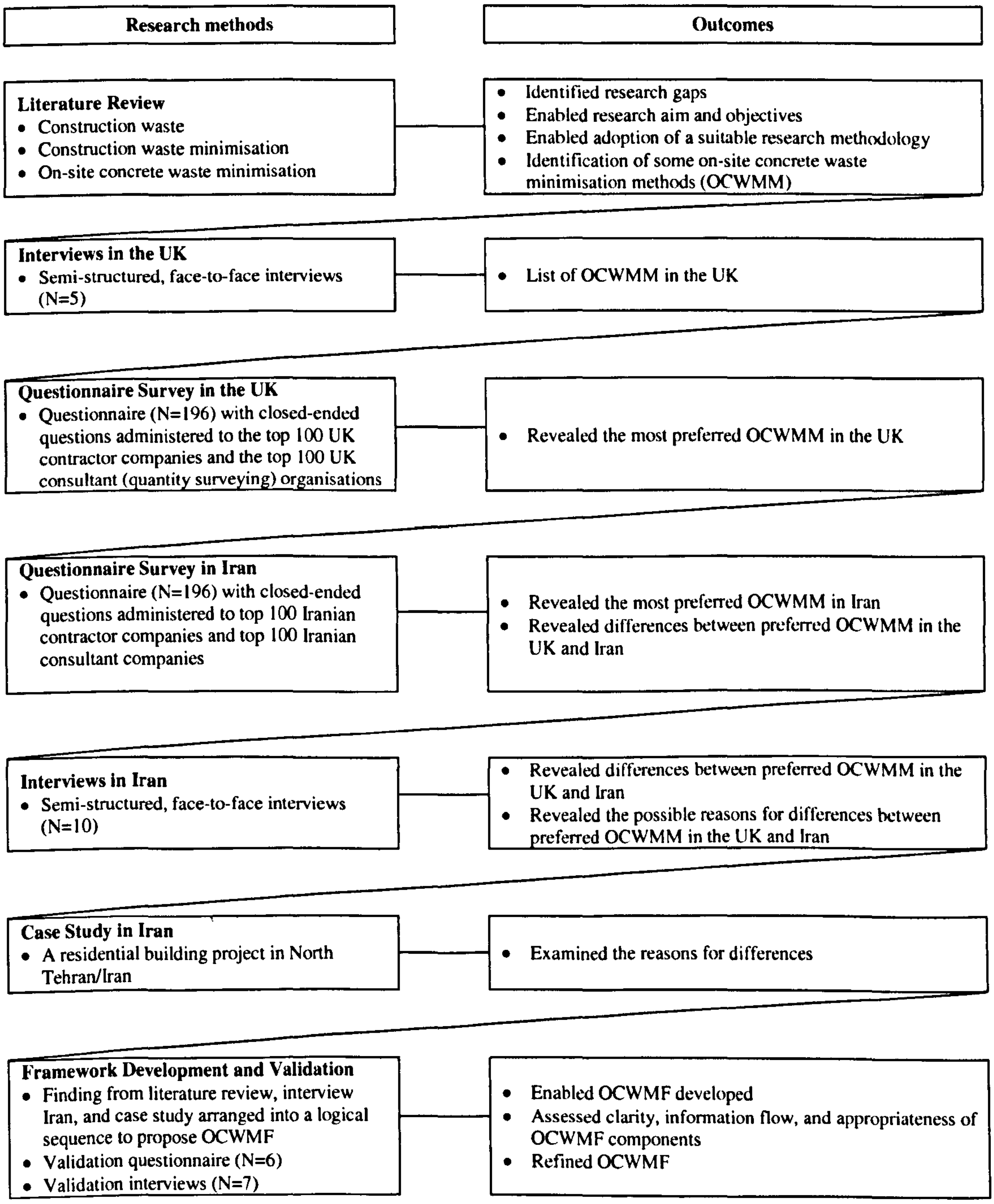


Fig. 1.1. Research methods and outcomes, Source: Author.

1.6. Contribution of the Research

This study investigated on-site concrete waste minimization methods in the UK and Iran by surveying professionals in the construction sector in both counties who were chosen from the top 100 contractors and consultant companies in both countries. Hence, the outcomes of research increased the available information and enhanced understanding of on-site concrete waste minimization methods. The specific contributions of this research in each stage of study are discussed in this section.

Interviews in the UK

A complete list of on-site concrete waste minimization methods in construction projects was produced.

Questionnaire survey in the UK

The outcomes of the questionnaire in the UK illustrated the cheapest methods for waste reduction and the most expensive methods; the easiest methods to implement and the most difficult ones; the most cost efficient methods and the least cost efficient methods; finally, the most recommended methods in the UK among current practices and the least recommended methods.

Questionnaire survey in Iran

The outcomes revealed the cheapest methods of waste reduction in Iran, and the most expensive ones; the easiest methods to implement and the most difficult methods; the most cost efficient and the least cost efficient methods; finally, the most recommended the least recommended methods in Iran among current practices.

Interviews in Iran

By focusing on the responses from questionnaire surveys, differences between OCWMM in the UK and Iran revealed. Interviews in Iran illustrated the causes regarding these differences.

The case study

The findings of the case study indicated that the use of pre-fabricated concrete elements has the highest cost and reduces on-site concrete waste the least compared to the other two main methods. In situ concrete is the least expensive and produces the most concrete waste. Although there is significant reduction in material waste when pre-fabricated elements are used, the consultants and contractors in the case study were not interested in using this method in their projects in Iran due to the high costs involved with pre-fabricated construction.

The OCWMF

The OCWMF proposes several recommendations that can potentially be used for improving on-site concrete waste minimisation by focusing on one of the most preferred OCWM methods in the UK, which is not currently used properly in Iran.

Furthermore, the proposed OCWMF could address some blind spots in the construction waste minimisation literature. Regarding that there is no clear evidence in the literature on OCWMF of previous models, developing the OCWMF contributed to address this shortcoming, serving as a heuristic instrument for mapping collective efforts of projects' stakeholders within a whole system of minimising concrete waste (on-site or in situ) which has been severely lacking prior to present research.

In addition, this research regarded that how broader contexts may affect the efforts of stakeholders or the acceptability of the proposed OCWMF by them, and how the OCWMF might get distorted in the process of implementation as it interacts with broader contexts. With this regard, the proposed OCWMF further addressed a lack in the construction waste minimisation literature.

Moreover, the OCWMF developed from the outcomes of this research has potential of a tool for implementing lean construction thinking at construction projects in Iran, and it can be considered as an addition to the existing lean construction tools.

1.7. Thesis Structure

This thesis includes nine chapters, which are outlined below.

Chapter 1 (Introduction) provides an overview of the thesis. The chapter begins by describing the context of the research and the literature review and then states the research justifications, aim, and objectives. Next, an overview of the research methodology and contributions of the research are explained. The chapter ends with an outline of the structure of the thesis.

Chapter 2 (Literature Review) is a critical review of the literature, undertaken to determine the context of the study. This chapter contains four main sections, including construction waste, construction waste minimization, on-site concrete waste minimization, particularly in the UK and in Iran, and critical remarks on the literature reviewed.

Chapter 3 (Methodology) illustrates the research methodology and starts with an overview of research strategies, types of research, research designs, and data collection methods. Subsequently, the chapter describes the adopted research strategy and data collection methods for the research such as questionnaire surveys, face-to-face semi-structured interviews, and case study. Moreover, sampling, administration of the research processes, and data analysis techniques are presented.

Chapter 4 (Survey in the UK) presents the interviews and questionnaire surveys conducted in the UK. The data collection, analysis, and results of the survey methods in the UK are explained in sequential order. The chapter aims to identify the common methods of on-site concrete waste minimization methods in the UK through interviews then determine the favoured methods through administration of questionnaires.

Chapter 5 (Survey in Iran) presents the interview and questionnaire surveys conducted in Iran. This chapter explains the process of data collection, analysis, and results of each method in Iran. The chapter aims to rank the on-site concrete waste minimization methods in Iran by conducting a questionnaire survey and identify differences between the favoured on-site concrete waste minimization methods in the UK and Iran. Then, the interviews conducted in Iran, which were conducted to determine the causes of these differences, are explained.

Chapter 6 (Case study in Iran) presents the process by which objective 5 (to investigate the reasons for differences between the best methods in the UK and the best methods in Iran) was achieved by examining the costs associated with the use of pre-fabricated concrete elements in Iran (a proposed cause of difference between preferred methods of on-site concrete waste minimization in the UK and in Iran).

Chapter 7 (Proposed Framework in Iran) presents the OCWMF design, development and validation process. The chapter discusses OCWMF development methodology and describes the framework's structure and components. This chapter also presents the OCWMF validation results emanating from the pre-validation questionnaire and semi-structured interviews in Iran.

Chapter 8 (Discussion) presents a discussion of the outcomes revealed during each stage of the research in Iran and the UK. This chapter also makes an attempt in post-rationalising the findings from this research.

Chapter 9 (Conclusions and Recommendations) summarises the research outcomes, highlights the conclusions and presents the key contributions of the research. The chapter also explains research limitations. The last section of this chapter provides recommendations for stakeholders of construction projects in Iran and suggestions for further research.

2. Literature Review

2.1. Introduction

This chapter presents the literature review about on-site concrete waste minimization methods in the UK and Iran. It explores previous research in three main areas, which are construction waste, construction waste minimization, and on-site concrete waste minimization, particularly in the UK and Iran. An additional aim of this chapter is to identify current issues of on-site concrete waste minimization methods in Iran. The chapter is divided into four sections: construction waste, construction waste minimization, on-site concrete waste minimization, and critical remarks on the literature reviewed.

The first section of the chapter (section 2.2) provides appropriate definitions of waste and statistics about waste generation. Then, the chapter provides a classification of general construction waste in the UK and reviews the causes of waste production in the construction sector in the UK. This is followed by a classification of general construction waste in Iran, quantification of the amounts produced, and common causes of construction waste production in the country.

The second section (section 2.3) reviews construction waste minimization, explains the importance of construction waste minimization, and illustrates the drivers of construction waste minimization. This is followed by a discussion about construction waste minimization methods in the UK and Iran, including legislation and regulations in both countries.

The third section (section 2.4) focuses on on-site concrete waste minimization and explores previous studies in construction waste management in order to illustrate the importance of 'concrete' waste, and 'on-site' concrete waste minimization. This section also reviews the causes of on-site concrete waste production in the UK and Iran and explains the current on-site concrete waste minimization methods in the UK and Iran.

The last section (section 2.5) talks about blind spots in the literature reviewed, and critically discusses reflective gaps in previous studies. This section also sketches out the ways in which the present research could address the shortcomings in the literature.

2.2. Construction waste

2.2.1. Definitions

Waste is usually defined as a material or object that is not required by its owner after use (NSCC, 2007). Waste is also identified as any material or article that the holder discards, intends to discard, or is required to discard (European Council, Directive 91/156/EEC, Article 1, Letter a). Construction waste is identified in various ways in the literature, for instance, construction waste comprises redundant material, which is produced directly or incidentally by construction and the construction industries. According to Ekanayake and Ofori, (2000), construction waste is identified as any material, including earth materials and waste from raised buildings or other structures, that is required to be transported away from the construction site or used in the construction site for the purpose of land filling, recycling, reuse, or compost, other than the intended purpose of the project, because of material damage, excess, specification change, or non-compliance with specifications or because it is a by-product of new construction or remodelling and repairing processes. According to Osmani et al., (2005), these definitions can be used for all construction waste materials regardless of whether or not they are intended for recovery operations or disposal. According to Alwi et al. (2002), construction waste can be divided into three major categories: material, labour, and machinery waste. However, the forthcoming debate is focused only on material waste.

2.2.2. Construction Waste in the UK

The reason this research was conducted in the UK is the UK Government's establishment of programmes such as Waste Strategy 2007, which seeks to potentially reduce construction waste to zero by 2015 and landfill waste to zero by 2020 (see section 2.3.2.3). Companies in the construction sector in the UK must following the regulations and recommendations in the legislation to achieve this goal (WRAP, 2011). Furthermore, research by Yuan and Shen (2011) has indicated that 87 papers were published in the discipline of construction and demolition waste management between 2000 and 2009 in eight selected journals, which illustrates that researchers from the UK, Hong Kong, Australia, and the US are the main contributors to construction and demolition waste management research. Therefore, proper literature and a range of sources are available for the present research. Construction waste is categorised as 'controlled waste'. Controlled waste is a type of waste subject to legislative control in its handling and/or its disposal (Controlled Waste Regulation UK, 2012). As a legal term, controlled waste applies exclusively to the UK, but many other countries follow this concept in their laws as well. Controlled waste includes domestic, commercial, and industrial waste and is subject to regulations because of its toxicity, hazardous nature, or capability to do harm to human health or the environment at the current time or in the future. Therefore, construction waste is subject to waste-related legislation and thus there is a 'duty of care' on the produce to ensure its safe storage, transportation, and subsequent recycling or disposal. According to the Government's Waste Strategy for England 2007, the construction industry is one of the biggest sources of waste in England. The construction industry uses over 400 million tonnes of solid material each year, which is the highest tonnage of resources in any sector. The construction, demolition, and excavation (CD&E) sector also generates more waste than any other sector in England and is the largest generator of hazardous waste, producing approximately 1.7 million tonnes annually. The sector accounts for 9% to 10% of the gross domestic product (GDP) index (Defra, 2009).

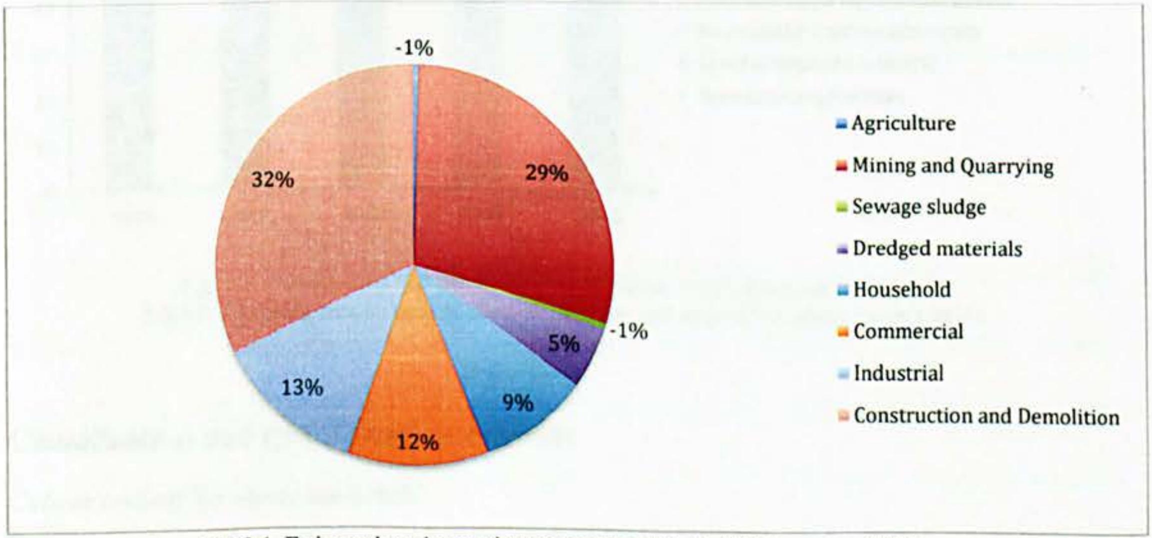


Fig.2.1. Estimated total annual waste produced in the UK by sector: 2004
Source: Defra, ODPM, Environment Agency, Water UK

Figure 2.1 illustrates the percentage of waste production of different industries in the UK in 2004. As seen, the construction industry produces the largest amount of waste of all industries. According to "Developing a Strategic Approach to Construction Waste" (available at: www.bre.co.uk), construction, demolition, and refurbishment account for approximately 100 million tonnes of waste in the UK each year. Approximately half of the waste from the demolition sector and parts of the construction sector is recycled. The over 400 million tonnes of resources that are consumed by the construction industry each year suggest that a greater scope for waste reduction, reuse, and recycling should exist. Due to the large amounts of waste generated by construction activities, this sector has become a priority for many organisations in terms of diverting waste from landfills, reducing the costs of waste management, and resource management (WRAP, 2007). Fig.2.2 illustrates construction and demolition waste in England from 1999 to 2008 in terms of whether it was recycled or non-recycled.

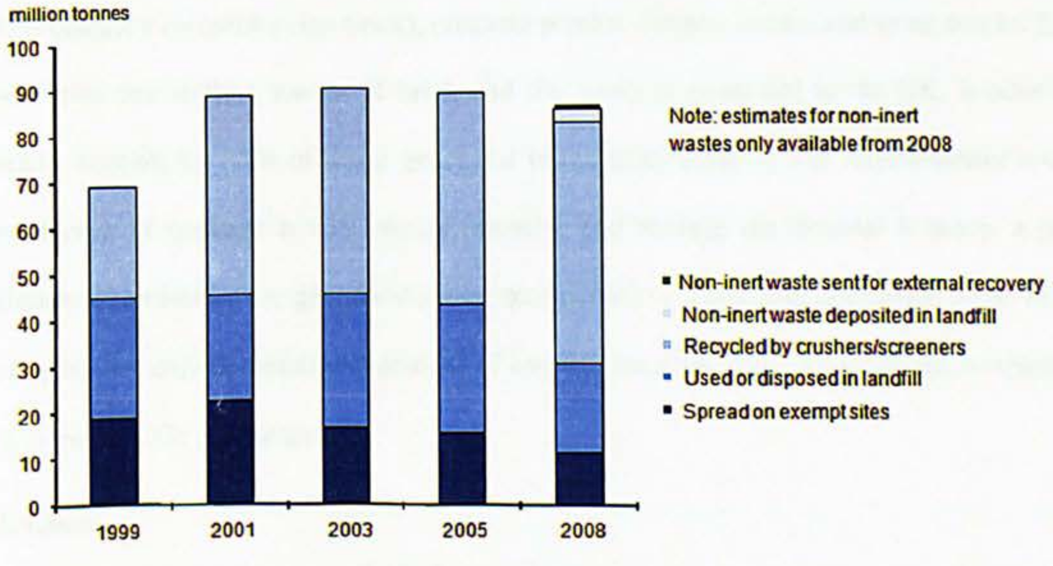


Fig. 2.2. Construction and demolition waste management, England 1999-2008
WRAP: Updating data on construction, demolition and excavation waste report (2008)

Classification and quantification of waste

Colour coding for waste materials

As part of the National Colour Coding Scheme for Construction Waste, the seven most common waste materials produced on construction sites have been colour coded. The industry-specific scheme was developed by the Institution of Civil Engineers (ICE), with the allocated colours for plastics and glass as indicated by WRAP given below:

Plasterboard	White
Inert	Grey
Mixed	Black
Wood	Green
Hazardous	Orange
Metal	Dark Blue
Packaging	Brown
Plastics	Purple
Glass	Light Blue

Note: In this classification, Inert materials include concrete, brick, asphalt, and stone.
(NSCC, 2007)

Classifications by WRAP

WRAP (2011) has classified construction waste materials into the following eight categories:

1. **Bricks and Blocks**

This category comprises clay bricks, concrete precast, aerated blocks, and stone blocks. Each year over one million tonnes of brick and tile waste is generated in the UK. Blocks and bricks account for 32% of waste generated in the SME building and refurbishment sector. Production of concrete is very energy intensive and because the material is heavy, a great amount of emissions are generated during transportation. Therefore, decreasing waste in this category not only decreases the amount of landfill, but also makes a significant contribution to reducing CO_2 emissions.

2. Glass

Currently, between 20% and 30% of flat glass produced in the UK has recycled content. The majority of construction glass waste is flat glass from windows. Glass waste is also produced from other sources such as fluorescent lighting, PC monitors, TV screens, and, increasingly, structural glass such as that used in contemporary office blocks. Domestic window replacement alone produces approximately 90,000 tonnes of glass waste per year.

3. Plasterboard and Gypsum

Plasterboard, other specialised board such as fire protection board, and plaster are manufactured from gypsum. Manufacturing of plasterboard consumes approximately 60% of the total gypsum in the UK. Annually, 2.5 million tonnes of plasterboard are used in the UK construction industry and approximately 300,000 tonnes of plasterboard waste is produced per year. Although the amount of plasterboard waste arising from demolition and refurbishment projects is difficult to quantify, it is estimated to be in the range of 500,000 to more than one million tonnes per year. Plaster and cement (5% gypsum) are also minor sources of gypsum waste in the construction industry. Between 10% and 35% of the plasterboard used during on-site during installation is often waste.

4. Wood

In the UK, approximately 50 million cubic meters of timber is consumed per year. The construction industry is the largest consumer, using up to 70% of softwood in the UK. Another 16% is used for packaging such as pallets and packing crates. Of total amount of the wood that enters the construction sites in the UK, 39% leaves as waste. It is estimated that construction and demolition sites produce approximately four million tonnes of waste wood annually, in forms that range from MDF board to tree branches. Usual sources of wood waste include pallets, crates, beams, window and doorframes, doors, shuttering, floorboards, fencing, and panels such as chipboard.

5. Insulation

Insulation materials include fiberglass, polystyrene, sheep's wool, spray foam, polyurethane, and fibreboard. Insulation is supplied in a variety of forms such as rolls of flexible material, blown foam, and rigid board. The amount of waste produced during installation depends on the type of insulation. Installation using blown and pre-shaped products produces little waste, while installation using insulation boards with set dimensions creates extra waste due to offcuts. An average of 7.5% waste is produced during insulation installation. However, the greatest amount of insulation waste comes from demolition and refurbishment projects. Insulation waste recycling is a difficult area to delivering high performance.

6. Plastics

The UK consumes over five million tonnes of plastic annually. The building and construction sector is a significant part of the plastics market and consumes approximately 23% of the total. Construction plastics are involved in pipework and are also used in building construction as insulation, window frames, and flooring. The European Plastics Converters (EuPC) trade association has classified the main applications of plastics for the construction and demolition sector as: pipework, insulation, wall covering and flooring, and window frames. The usual sources of plastic waste are packaging, pipework, insulation and interior fittings, wall and floor coverings, and window frames.

7. Flooring and Wall Coverings

Approximately 500,000 tonnes of carpet waste is generated annually in the UK. Carpet is estimated to account for approximately 2% of all waste that enters landfills. Of this amount, 93% is used carpet and the remaining 7% is post-industrial waste from manufacturing and installation operations. Waste from floor and wall coverings includes carpet, carpet tiles, vinyl, linoleum, laminate flooring, wood, ceramic tiles, and wall paper.

8. Packaging

Packaging accounts for approximately 10% to 20% of site waste by volume and can be up to 50%, particularly on new build projects. Another estimate is that an average of 34% of waste leaving a construction site is packaging. Key waste streams are wooden pallets, cardboard, and plastic film. The pallets used to deliver bricks, the plastic used to wrap blocks, and metal paint tins are the primary packaging waste materials. The majority of packaging waste is wooden pallets (26% of packaging waste by volume), cardboard (29% by volume), and plastic film (12% by volume). Table 2.1 presents key types of construction waste for traditional new build schemes and waste production amount of each construction material in the UK according to WRAP (2007).

Table 2.1. Key types of construction waste for traditional new build schemes

Material	**Average range %**
Packaging (wood pallets, cable drums, cases)	25 - 35
Plaster board	5 - 36
Rubble (broken bricks, blocks, and tiles)	25 - 40
Timber (excludes pallets)	15 - 25
Cement and plaster	10 - 17
Insulation (rock wool and fibreglass)	6 - 15
Metal	3 - 9
Dry concrete products	2 - 12
Plastic products (excludes packaging)	1 - 11
Ceramic material	1 - 8

The table above demonstrates that packaging, rubble, plasterboard, timber, cement/plaster, and insulation are consistently the main waste streams. Table 2.2 summarises the construction process that typically generates the key types of waste by material and product type and ranks them accordingly.

Table 2.2. Construction material waste production

3 = generally high, 2 = reasonably high, 1 = noticeable, blank = not relevant or negligible

	Application	**Building product/material waste streams**							
		Timber	Concrete	Plaster board	Panel prods	Sheet or roll prods	Bricks, blacks tiles	Cement mortar plaster	Bldg service s prods
Roofing	Rafters, joists etc	3							
	Battens	2							
	Tiling						3	1	
	Insulation				2	2			
Membranes	External walls					3			
	Block inner leaves						3		
	Brickwork						3	2	
	Cladding	2			1				
	Windows & Doors	1							
	Cavity wall insulation					3			
	Cement, mortars, render				1				
Flooring	Ground flooring	3	3			1			
	Ground floor insulation					3			
	Columns	3							
	Decking	2							
	Site peripherals								
	Hoardings	3							
Interior fit-out	Interior/party walls								
	Plasterboard			3				2	
	Plastering								
	Paint work etc								
	Interior windows								
	Plumbing equipment								
	Electrical equipment								2
	Heating equipment								2
	Lighting products								2
	Bathroom fittings								
	Ironmongery								
	Interior doorsets								
	Fitted kitchen	3							
	Wall 7 floor tiling						1		
	Floorcovering								
	Mouldings	3							

Source: WRAP, 2007, Current Practice and Future Potential in Modern Methods of Construction.

Common causes of construction waste production

Several studies have examined the causes of construction waste production. The literature shows that there are a variety of different classification schemes for the causes of waste generation in construction. For instance, there are classifications based on different project activities (e. g. Ekanayake and Ofori, 2000); project stakeholders (e. g. Keys et al., 2002); construction sector (e.g. Ilozor, 2009); and stage of production (e.g., Osmani et al., (2008). Table 2.3 represents the classification of construction waste according to WRAP and the common causes of waste production on construction sites.

Table 2.3. WRAP's waste material classification

	Category	Material	Causes
1	Bricks and Blocks	Concrete precast	
		Clay bricks	Damage during unloading and storage Damage during cutting
		Aerated blocks	
		Stone blocks	
2	Glass		Demolition projects Replacement of windows in refurbishment projects Waste during installation Breakages and over ordering
3	Plasterboard and Gypsum		Offcuts Damage during storage and handling Over ordering Damage during installation
4	Wood		
5	Insulation		Offcuts Demolition and refurbishment
6	Plastics	Pipework	Waste during installation
		Insulation	
		Wall covering, flooring	
		Window frames	
7	Flooring and wall coverings	Carpet	Used carpet Waste during installation Breakages Offcuts Over ordering
		Carpet tiles	
		Laminate flooring	
		Wood, ceramic tiles	
		Wall paper	
8	Packaging		Unwrapping

Source: Author, complied from literature

As mentioned in section 2.2.3, there are various classifications for construction waste as well as various causes for waste generation in construction projects. For instance, Tam et al. (2010) explained the main causes of wastage for each type of material. Table 2.4 illustrates the causes of waste for different each construction materials.

Table 2.4. Causes of material wastage

Construction material	Causes	Specifications
Stone slabs	Cutting	Lack of adjustment between sizes of different products; imperfections of the product; choices during design; lack of knowledge about construction during the design stage
	Shape	Imperfections of products; choices made in design about specifications of the product; method of transportation
	Quality	Choice of a low-quality stone slab during design; lack of influence of contractors; lack of knowledge about construction during the design stage
	Over ordering	Lack of possibilities to order small quantities
	Storage and handling on construction site	Unpacking supply
	Cracking during transportation	Unpacking supply
Concrete	Over ordering	Required quantity of products unknown due to imperfect planning
	Loss during transportation	Required quantity of products unknown due to imperfect planning
	Scraping off	Method to lay the foundations of a building
Mortar	Scraping out	Negligent practice
	Mortar in the tub	Negligent practice
	Atmospheric influence	Negligent practice
	Specifications of the mortar	Short processing time
	Mess	Negligent practice; quantities of supply too high
Roof tiles	Sawing different from the design of roof	Attention not paid to sizes of the products used in design; designer not familiar with possibilities of different products; information about products received late; types and sizes of different products do not fit
	Cracking during transportation	Negligent handling by the supplier
Reinforcement	Cutting	Use of steel bars with sizes that do not fit
Formwork	Cutting	Use of timber boards with sizes that do not fit
Brick/block	Cutting	Use of sizes that do not fit
	Damage during transportation	Unpacking supply

Source: (Shen et al. 2002)

According to Cox and Clamp (2003), design, tendering and contract, and construction are the three major stages in construction projects. Hence, for the purpose of this research (as discussed in section 2.2.3) causes of waste production related to the construction (on-site) stage are studied. Table 2.5 represents the causes of waste generation during the on-site construction stage according to Osmani et al. (2008) and Gamage (2011).

Table 2.5. Causes of waste during on-site construction

Cause of waste		References
Procurement	Ordering errors (e.g., ordering items not in compliance with specification)	Ekanayake and Ofori (2000); Kulathunga et al. (2005); Osmani et al. (2008)
	Over allowances (e.g. difficulties in ordering small quantities)	Ekanayake and Ofori (2000); Kulathunga et al.(2005)
	Supplier errors	Osmani et al. (2008)
	Shipping errors	Osmani et al. (2008)
Transportation	Damage during transportation	Ekanayake and Ofori (2000); Kulathunga et al. (2005); Osmani et al. (2008)
	Insufficient protection during unloading	Osmani et al. (2008)
	Inefficient methods of unloading	Osmani et al. (2008)
	Difficulties for delivery vehicles to access the construction sites	Osmani et al. (2008)
Material storage	Inappropriate on-site storage space leading to damage or deterioration	Ekanayake and Ofori (2000); Kulathunga et al.(2005); Osmani et al. (2006;2008)
	Materials stored far away from the point of application	Osmani et al. (2008)
	Inadequate storage methods	Osmani et al. (2008)
Material handling	Material supplied in loose form	Kulathunga et al. (2005); Ekanayake and Ofori (2000); Osmani et al. (2008)
	Inappropriate on-site transportation methods from storage to the point of application	Ekanayake and Ofori (2000): Osmani et al. (2008)
	Inadequate material handling	Osmani et al. (2008)
	Unpacked supply	Osmani et al. (2008)
On-site management and planning	Inadequate planning for required quantities	Ekanayake and Ofori (2000);Kulathunga et al. (2005); Osmani et al. (2008)
	Delays in passing information on types and sizes of materials and components to be used	Ekanayake and Ofori (2000); Osmani et al. (2006; 2008)
	Lack of on-site material control	Kulathunga et al. (2005); Osmani et al. (2008)
	Lack of an on-site waste management plan	Osmani et al. (2008)
	Lack of supervision	Osmani et al. (2008)
	Inadequate project information after work has commenced	Osmani et al. (2008)
Site operation	Accidents due to negligence	Ekanayake and Ofori (2000); Kulathunga et al. (2005);
	Equipment malfunction	Ekanayake and Ofori (2000); Kulathunga et al. (2005); Osmani et al. (2008)
	Poor craftsmanship	Kulathunga et al. (2005); Osmani et al. (2008)
	Use of incorrect materials resulting in their disposal	Ekanayake and Ofori (2000); Kulathunga et al.(2005); Osmani et al. (2008)
	Poor work ethic (unfriendly attitudes of project team and labour)	Ekanayake and Ofori (2000); Kulathunga et al.(2005); Osmani et al. (2008)
	Poor communication between designer and builder or within organisations	Ekanayake and Ofori (2000); Kulathunga et al. (2005)
	Damage to completed work caused by succeeding trades	Ekanayake and Ofori (2000); Kulathunga et al. (2005)
	Unused materials and products	Osmani et al. (2006; 2008)
	Time pressure	Osmani et al. (2008)
Residual	Waste from application process (i.e., over preparation of mortar)	Kulathunga et al. (2005); Osmani et al. (2006; 2008)
	Offcuts from cutting materials to length	Osmani et al. (2008)
	Waste from cutting uneconomical shapes (conversion waste)	Osmani et al. (2006; 2008)
	Inadequate or incorrect packaging	Osmani et al. (2008)
Other	Weather	Osmani et al. (2008)
	Vandalism	Osmani et al. (2008)
	Theft	Osmani et al. (2008)

Source: Gamage, 2011; Osmani et al., 2008

2.2.3. Construction Waste in Iran

Generally, construction and demolition waste production in Iran is higher than the average in developed countries. For example, average construction and demolition waste production in the United States is 0.77 kg *per capita* per day (DSM, 2008), while construction and demolition waste production is 4.64 kg *per capita* per day in the city of Tehran in Iran (TMWM report, 2009). Although this is a very important issue, detailed quantitative data about construction and demolition waste production in Iran are still very limited (Saghafi and Hosseini, 2011). However, in recent decades, limited research has been conducted in this area (e.g., Mahmoudi and Nikghadam, 2009; Ardakani, 2003). Construction and demolition waste is usually divided into two groups according to the source of generation.

1. Construction waste is generated as a consequence of the works executed at buildings or any construction project from the foundation upward (Llatas, 2011).
2. Demolition waste is generated as a result of dismantling at demolition works or when restoring and repairing buildings and facilities. All of the building demolished is considered waste (Wang et al., 2010). Although construction waste at disposal sites produces physical and chemical damage to the environment, there are still a large amount of undeveloped land outside cities in Iran that can be used as construction sites and demolition waste disposal for many years. Improper attention has been paid to this important issue (Saghafi and Hosseini, 2011). Furthermore, the growing young population and lifestyle changes are increasing housing demand, which causes more construction material consumption and, consequently, more waste material in the future (Ardakani and Madani, 2009).

Quantification

Tehran is the capital of political and economic activities in Iran and its growth requires deliberation about sustainable development. However, rapid population growth has resulted in unsustainable expansion of the construction and building industry (Reza et al, 2011). The construction industry in Tehran produced 50,000 tonnes of waste each day in 2010 (TMWM, 2011). Approximately 60% of construction waste comes from demolition and construction works and 40% from excavations. According to the 2009 Tehran Municipality Waste Management Annual Report, daily construction and demolition waste generation in Tehran equals 46,655 m^3, including soil generated from excavations. The average weight of construction and demolition waste is approximately 863 kg per cubic meter. Steel consumption by construction sector in Iran was estimated at approximately 14,084,569 tonnes from 2005 to 2009. Steel consumption in the construction industry increased from 2005 to 2009 by 7.21%. Cement consumption during the same period was approximately 8,248,829 tonnes with a growth rate of 14.8% (Veise and Tahmasebi, 2009). Although there is lack of data about construction waste materials in Iran and their classification, the results of a recent study by the Building & Housing Research Centre of Iran quantify the amounts of demolition waste for typical residential buildings in Tehran. The study investigated 8 buildings, which are numbered from one to ten. This information is presented in Table 2.6 (Saghafi and Hosseini, 2011).

Table 2.6. Demolition waste for typical residential buildings in Tehran

Building number	Structure	Area (m^2)	Weight (tonnes)	Volume (m^3)	Weight (tonne/m^3)
1	Steel	635	851.04	416	1.34
2	Steel	390	557.08	283	1.43
3	Concrete	800	1188	581.31	1.49
4	Mixed	400	645	360	1.61
5	Mixed	290	421.77	240	1.45
6	Mixed	435	465.95	236.51	1.39
7	Mixed	433	696	341	1.61
8	Masonry	290	438.08	232.47	1.51

Tehran as the capital city of Iran and the leading city in construction an building project and construction methods and techniques which includes the approximately 17% of Iran's population (official population clock, 17/03/2015 available from: http://www.amar.org.ir) About 30% of Iran's public-sector workforce and 45% of large industrial firms are located in the city and almost half of these workers are employed by the government (Cordesman, 2008). Approximately, 30% of total building projects in Iran have been placed in Tehran (Saghafi and Hosseini, 2011). Having said that, still one of the limitations for this study would be to present the most of data about Tehran, which was due to lack of reliable studies, and publications about all other cities in Iran in the field of construction waste.

Common causes of waste production in Iran

Common causes of construction waste production in Iran are ordering errors such as over ordering, non-compliance of materials with building specifications, damage during transportation and handling, improper storage, lack of on-site material control and improper inventory management, poor craftsmanship, offcuts, weather, vandalism, and theft (Saghafi and Hosseini, 2011; Reza et al., 2010; Siamardi, 2009; Damghani et al., 2007). These causes are similar to the causes of waste production in the UK, but there are differences in the volume of the waste material. The volume of waste produced in Iran has increased due to the following reasons:

Lack of motivation for recovery or recycling

There are abundant natural resources for construction materials in Iran with sufficient quality and quantity to meet the demand for building materials at moderate costs. Therefore, motivation to obtain these materials through recycling is low (Ardakani, 2003). For instance, large areas in Iran are covered by alluvial soil, which is the main resource for sand and gravel, thus creating reduced motivation to process concrete waste in order to obtain gravel (Saghafi and Hosseini, 2011).

Improper demolition

Approximately 1.3 to 1.61 tonnes of waste per square meter of construction is generated during demolition in Tehran (Ardakani, 2003). Each year, many buildings are demolished In Iran, and most are constructed with traditional masonry materials such as clay brick (Saghafi and Hosseini, 2011). Buildings demolished in the current decade in Iran were generally constructed in the 1960s or earlier. Only a few limited materials such as bricks, metal, and doors and windows are being partially recycled, with the rest being crushed with sledgehammers and sent to a landfill (Saghafi and Hosseini, 2011).

2.3. Construction Waste Minimization

2.3.1. Importance of Construction Waste Minimization

There are various reasons why attention is currently being paid to waste minimization methods. Sustainability has been one of the main concepts in business and the environment in recent years. Waste minimization is one of the key factors of sustainability in construction. On one hand, by minimising construction waste, environmental pollution can be reduced in terms of the energy consumed during processing, delivery, and using materials in a project, consequently reducing CO_2 emissions. On the other hand, waste minimization can also increase profitability of a project. A well-defined waste management strategy that includes effective recovery and recycling of resources can improve a company's reputation and give it an edge when tendering for new projects (NSCC, 2007). According to NSCC (2007), the key reasons for rethinking waste policy include:

Accomplishing environmental responsibilities

Managing waste efficiently allows environmental responsibilities to be met. Cutting the amount of waste to landfill and reducing the quantities of raw materials used contributes to corporate social responsibility (CSR) agendas and enables promotion of a respectable environmental image.

Increasing profitability

Reducing the amount spent on waste can have a significant effect on the cost of projects as the true cost of waste, including the cost of materials purchase, transport, and landfill taxes, is usually higher than it seems to be.

Improving site conditions

Reducing the amount of waste on-site leads to cleaner and safer sites and improves health and safety issues.

Meeting legal obligations

2.3.2. Drivers of Construction Waste Minimization

According to Ekanayake and Ofori, (2000) the effects of construction waste can be classified into two levels: the project level and the national level. At the project level, construction waste impacts contractors' profits, performance, productivity, and reputation (Ekanayake and Ofori, 2000). At the national level, construction waste causes national and even global environmental problems. Recent literature has illustrated that construction waste management drivers can be mainly categorized into economical drivers, industrial drivers, environmental drivers, and, finally, government policy and regulatory drivers (Osmani et al., 2006, Jaillon et al., 2009).

Environmental drivers

The importance of environment pollution problems such as water and air pollution and fire hazards (Esin and Cosgun, 2007) means that construction waste management has been allocated as a top priority. In addition, construction waste is difficult to recycle due to a high degree of heterogeneity and high levels of contamination (Brooks et al., 1994; Bossink and Brouwers, 1996). It is also more difficult to dispose of due to the possibility that it contains hazardous substances such as asbestos, adhesives, chlorofluorocarbon (CFC), treated timber, emulsions, solvent-based concrete additives, or resins (ICE, 2004). Limited landfill sites, especially in large cities, for construction waste disposal are becoming a serious problem (Sve, 2009; Chan and Fong, 2002). For instance, according to Harman and Benjamin, (2003), the UK government predicted that landfill capacity would be reached by 2017. Therefore, due to higher production of waste, the construction industry should take responsibility for environmental issues such as pollution, disposal of waste, and health and safety. Thus, the construction industry must minimize waste generation in order to minimize or reduce negative impacts to the environment.

Economic drivers

Cost reduction is one of the drivers for construction waste minimization (Yahya and Boussabaine, 2006). Several factors such as extra overhead costs, delays, extra work for cleaning, and lower productivity can decrease a project's profitability (Ekanayake and Ofori, 2000). In addition, costs associated the waste disposal such as transportation and landfill taxes are also an additional cost for projects (WRAP, 2010a; RICS, 2006). For instance, a study conducted by WRAP (2009) illustrated that on projects in the UK with a floor area of 75,000 square feet, an effective and efficient approach to waste management can typically save up to £110,000. According to CIRIA, (2006), the cost of construction waste (apart from governmental costs such as the Landfill Tax) includes: the cost of purchasing materials that are waste; the cost of storage; the cost of transport and disposal of waste; the cost of time spent managing and handling waste; and the loss of profits by not saving waste materials.

Government policy and regulatory drivers

Recent literature has shown there is a growing concern among several governments to introduce various policies and regulations and further reinforce their existing policies on waste management (e.g. EU members, Australia, Hong Kong, New Zealand). The UK government has also introduced legislation, including regulations, policies, and good practice guidance, to support the industry in minimising construction waste.

***Regulations*:** These include Landfill Tax and Site Waste Management Plans (SWMP) regulations on waste management practices, which came into force in 2008 and made this mandatory for all construction projects in England costing over £300,000 (DEFRA, 2008).

Policies: The UK Government also introduced a number of policies such as Waste Strategy 2007 and Sustainable Construction Strategy 2008. Waste Strategy 2007 is aimed at achieving the potential objective of zero net construction waste by 2015 and zero waste to landfill by 2020. The Sustainable Construction Strategy 2008, which is a joint strategy between industry and the Government, is intended to promote leadership and behavioural change as well as provide substantial benefits to both the construction industry and the wider economy (BERR, 2008).

Good practice guidance: Various organizations in the UK have been founded to support the construction industry handle waste management, including the Waste and Resources Action

Programme (WRAP) and the Construction Industry Research and Information Association (CIRIA) as well as the environmental agencies Constructing Excellence and Envirowise. These organizations offer a variety of support such as free help lines, free publications, various workshops, technical and procedural support, and best practice examples and guidance.

Industrial drivers

Construction industry stakeholders, including clients, contractors, consultants, manufacturers, material suppliers, and research and development institutions, are becoming more sensitive about waste management topics. Consequently, the construction industry itself has requested more intensive waste management strategies.

Increasing client demand for waste management: Clients are increasingly requesting enhanced environmental performance (Osmani et al., 2006).

Institutional pressure and guidance: Institutions linked to waste management (see 2.3.2.3) put pressure on and influence the construction industry by improving awareness of sustainable waste management in order to enhance companies' improvements, for instance, in their CSR agendas (Osmani et al., 2006).

Proactive engagement: There are a number of clients and contractor organisations leading the way for achieving sustainable waste management practices (WRAP, 2010c). However, according to the literature, comprehensive data about the exact proportions, causes, and amount of waste related to construction is still rather limited and does not completely support long-term assessment of how waste can be prevented or managed more effectively in the future and, instead, the lack of information creates delays. An alternative approach is to identify what target the industry should be aiming for and then establish or reinforce the required mechanisms to achieve this objective and monitor progress towards it. Accordingly, an approach to development of this strategy could include the following steps (NSCC, 2007):

1- Taking a forward look at construction, along with an assessment of threats and opportunities in relation to waste and resource efficiency.

2- Developing long-term goals for improvement and, where possible, relating these to baseline data.

3- Modelling the way to achieve these goals (short- or medium-term actions)

4- Identifying required information and activities to support development and implementation of the strategy.

2.3.3. Waste Hierarchy

The waste hierarchy is a useful framework to illustrate the priority of waste management options based on environmental impact (DEFRA, 2007b). EU policy explains that waste management strategies should first aim to prevent waste production. Where this is not possible, waste materials should be reused, then recycled or recovered, or used as a source of energy, with the final option disposal by a safe process (EU, 2008).

Fig.2.3. Waste hierarchy
Diagram sourced from www.sepa.org.uk

Although waste prevention is a top priority position in the waste hierarchy, relatively less attention has been paid to it. Instead, until recently, most research was focused on the recycling of construction waste (Poon, 2007). However, many studies agree that prevention is the most efficient method for minimising waste (e.g., Osmani et al., 2008; Esin and Cosgun, 2007; Formoso et al., 2002). The next section of this chapter explains options of the waste hierarchy and how solutions relate to the specific construction waste issues

2.3.4. Construction Waste Minimization Methods

Construction waste minimization methods in the UK

According to WRAP (2011), there are common methods that can be applied to minimize or reduce the construction waste. These are presented in the following sections:

1. **Brick and Blocks:** There are several options for minimising brick and block include: careful storage to reduce the amount of damaged material; a dedicated storage area and training in handling; proper design (consideration of waste during design in order to minimize the need for cutting bricks and blocks); reclaiming (bricks have a lifetime of more than 200 years and can be reused in new buildings or paving); recycling (inert waste can be crushed and turned into aggregate; used on-site as general fill or as the sub-base for roads; or sent off-site to recycling companies for processing); reprocessing clean waste material by brick and block companies; using chipped bricks in landscaping or brick dust as a surface for tennis courts or athletics tracks; and just-in-time ordering.

2. **Glass:** Glass waste can be minimized by just-in-time ordering (reduces the risk of breakages in handling and storage and over ordering); careful storage (designating secure storage on-site); and recycling.

3. **Plasterboard and Gypsum:** Plasterboard and gypsum waste can be reduced by proper design (detailing dimensions in the plan in accordance with the measurements of the plasterboard panels used can considerably reduce offcuts); off-site cutting (waste can be managed better in the manufacturer's environment and cutting plasterboard to size off-site decreases waste from offcuts and damage during handling); careful storage and handling (proper storage areas prevent water damage and accidental damage by on-site and minimize handling, reducing damage from dropping and collisions); just-in-time ordering (this can reduce over ordering and damage during handling); reuse of offcuts; and recycling.

4. **Wood:** Wood waste can be minimized by reuse of pallets (and repairing broken pallets rather than disposing of them as waste); careful handling and storing (designated,

protected storage areas can minimize accidental damage); off-site pre-fabrication (using pre-fabricated timber frames, walls and flooring can minimize wood waste by up to 40% due to waste reduction in offcuts on-site and over ordering); proper design (designing dimensions in accordance with panel sizes and careful positioning of windows and doors can reduce wastage from offcuts); recycling (wood waste can be recycled into other products such as landscaping pellets and mulch and chipboard to create new kitchen units); and recovery (by sorting into separate skips, both treated and untreated wastes can be recovered in later years).

5. Insulation: Insulation waste can be minimized by proper selection of insulation materials (the type of insulation directly effects the installation waste generated; for instance, rigid insulation is estimated to generate 10% to 15% waste, flexible insulation 8% waste, and blown insulation 5% waste); proper design (for instance, in rigid insulation, proper design helps to reduce the amount of waste generated from offcuts); use of pre-formed materials; just-in-time ordering (reduces over ordering and minimize handling waste); careful storage and handling; reuse of offcuts; and recycling.

6. Plastics: Plastic waste can be minimized by just-in-time ordering (reduces over ordering and damage during storage and handling); proper design (for instance. in plastic pipe networks, waste can be reduced by designs that use as few fittings as possible); reuse (if carefully stored, offcuts can be reused); and careful storage and handling.

7. Flooring and Wall Coverings: Waste can be minimized during fitting by proper design (designing dimensions in accordance with board measurements can reduce wastage from offcuts); proper material selection (for instance, using pre-fabricated bathroom pods); just-in-time ordering; reuse (unused tiles or offcuts can be stored for further reuse); proper storage (designating a protected secure storage can decrease waste caused by water and accidental damage); and recycling.

8. **Packaging:** The amount of packaging waste generated on-site can be minimized by selecting responsible suppliers; ordering in bulk where appropriate; choosing proper

materials (that can be delivered in minimal or reusable packaging where possible); reuse; and recycling.

Table 2.7 summarises construction material waste minimization advice by WRAP (2011).

Table 2.7. Construction material waste minimization methods

	Category	Waste minimization advise
1	Bricks and blocks (including pre-fabricated concrete)	Proper storage Reuse Recycling Proper design Just-in-time ordering
2	Glass	Just-in-time ordering Careful storage Recycling
3	Plasterboard and gypsum	Proper design Off-site cutting Careful storage and handling Just-in-time ordering Reuse Recycling
4	Wood	Reuse Careful storage and handling Off-site pre-fabrication Proper design Recycling Recovery
5	Insulation	Proper material selection Proper design Use of pre-formed materials Just-in-time ordering Careful storage and handling Reuse Recycling
6	Plastics	Just-in-time ordering Proper design Reuse Careful storage and handling
7	Flooring and wall coverings	Proper design Proper material selection Just-in-time ordering Reuse Proper Storage Recycling
8	Packaging	Selecting responsible suppliers Ordering in bulk Choosing proper materials Reuse Recycling

Source: Extracted from WRAP (2011)

Construction waste minimization methods in Iran

As mentioned earlier, a growing young population and lifestyle changes in Iran are increasing housing demand, which causes more construction material consumption and, consequently, more waste material in the future (Ardakani and Madani, 2009). Therefore, minimization of construction and demolition waste has become a sensitive topic among experts in the construction sector (Lam et al. 2010). The construction sector as an industry produces enormous amounts of waste materials. Thus, recycling, reuse, and other waste management strategies need to be implemented as waste is a critical problem for the environment in Iran and enormous amounts of resources and capital are sent to the landfill (Kharaazi and Ganjian, 2010). However, the Iranian construction industry does not pay appropriate attention to construction waste minimization methods. Proper storage and handling, reuse, recycling, just-in-time ordering, and proper material and supplier selection, were discovered during the review as the most common methods of waste minimization in Iran. Labour is inexpensive in Iran, as it is a developing country, and offers opportunities to develop manual deconstruction and on-site reuse and recycling (Saghafi and Teshnizi, 2011).

Reuse: Only some types of waste material such as bricks or some steel products can be partially reused. They usually need to be separate manually to be reused.

Recycling: As mentioned earlier, only a few materials from construction projects such as bricks, metal, doors, and windows are being partially recycled in Iran at the moment. A typical two-story residential building in Tehran was analysed as a case study to assess the maximum potential recycling rate with current technologies and the current recycling rate. The results indicate that the amount of waste recycling in comparison with the highest potential rate of recycling with available technologies can be improved by 68.81%.

Table 2.8. Recovery information for construction waste materials in Tehran (case study)

Material		Potential recovery	Current recovery
Metal	Structural steel	Recycle/Reuse	Recycle
	Bar	Recycle	Partly recycled
	Window	Recycle/Reuse	Recycle/Reuse
	Aluminium (doors and windows)	Reuse	Recycle/Reuse
Concrete	Lean concrete	Recycle	Landfill
	Foundation	Recycle	Landfill
Brick	Clay brick wall	Reuse	Partly reused/Recycled
	Façade brick	Reuse	Partly recycled
	Clay brick roofing	Reuse	Landfill
Wood	Door	Reuse	Reuse
Glass	Window	Recycle/Reuse	Partly reused
Stone	Foundation isolation	Recycle/Reuse	Reuse
	Finishing	Recycle	Landfill
Flooring	Ceramic	Landfill	Landfill
	Tile	Landfill	Landfill
	Terrazzo	Landfill	Landfill
Finishing	Plaster	Landfill	Landfill
	Cement coat	Landfill	Landfill

Source: Extracted from Saghafi and Hosseini (2011)

Furthermore, the total amount of potential recovery for construction waste is 634.61 tonnes but current recovery is only 156.10 tonnes. The current total amount of waste is 539.4 tonnes but could potentially be 60.89 tonnes. Therefore, potential recovery could be 91.25% of waste while at the present it is only 22.44% (Saghafi and Hosseini, 2011).

2.3.5. Legislation and Regulations

Legislation and regulations in the UK

The UK Government has published legislation with the aim of decreasing or limiting construction waste, for instance:

UK Landfill Tax

According to HMRC (2014a), the UK Landfill Tax depends onto the amount of waste disposal. It aims to encourage waste generators to reduce the production of waste, to recover more waste by reuse, recycling, or composting, and to use more environmentally friendly methods of waste disposal. The UK Landfill Tax was introduced in 1996 and was the UK's first environmental tax. The Landfill Tax is seen as a key mechanism in supporting the UK to achieve its targets to reduce waste production. Furthermore, by increasing the cost of sending waste to landfills, other advanced technologies for waste treatment with higher gate fees are becoming more financially attractive. The amount of tax charged is calculated by weight of the material disposed of in a landfill, with two rates for active and inactive waste.

- Inactive or inert waste includes most materials used in buildings and excavation material for foundations, including most forms of concrete, brick, glass, soil, clay, and gravel. This category is subject to a lower rate.
- Active waste includes all other forms of waste such as wood, ductwork, piping.

Table 2.9 illustrates the UK Landfill Tax rates for active and inactive waste, which are subject to standard and lower rate taxes, respectively.

Table 2.9. UK Landfill Tax on active and inactive waste

Date of change	Standard rate (£ per tonne)	Lower rate (£ per tonne)
1 April 2009	40	2.50
1 April 2010	48	2.50
1 April 2011	56	2.50
1 April 2012	64	2.50
1 April 2013	72	2.50
1 April 2014	80	2.50

Source: HMRC, 2014b

Site Waste Management Plans (SWMPs)

New regulations in the UK came into force on 6 April 2008 require an SWMP conforming to regulations to be prepared for any project on a construction site with an estimated cost greater than £300,000, excluding VAT must, before construction work starts. An SWMP records the amount and type of waste generated on a construction site and outlines the methods used for reusing, recycling, or disposal. The regulations aim to firstly increase the amount of recovery, reuse, and recycling of construction waste and to improve materials' resource efficiency, and secondly to prevent illegal waste activity by requiring appropriate waste disposal in accordance with the waste duty of care provisions (Site Waste Management Plans Regulations, 2008). The Site Waste Management Plans Regulations 2008 are available at www.legislation.co.uk. This website is managed by The National Archives on behalf of the Government. Publishing all UK legislation is a core part of the remit of Her Majesty's Stationery Office (HMSO), which is part of The National Archives and the Office of the Queen's Printer for Scotland. The Considerate Constructors Scheme (1997) in the United Kingdom encourages all contractors to implement a strict waste minimization strategy, and the Code for Sustainable Homes (United Kingdom Government Department for Communities and Local Government, 2006) makes on-site construction waste minimization, sorting, and recycling compulsory (Solis-Guzman et al., 2009).

Legislations and regulations in Iran

Tehran is the capital city of Iran and is home to an urban population of more 8.2 million, with more than 14 million residents in metropolitan area in 2012. Tehran is the largest city in

Western Asia with a metropolitan area of 1274 km^2 (TMWM, 2012). As discussed earlier, due to lack of published information about all Iran's cities, some brief information about Tehran as a capital city of Iran and an example has been provided below. The Municipality of Tehran is responsible for solid waste management for the city. Tehran Waste Management Organisation is a branch of the Municipality of Tehran and was established and began work in early 1980s. Municipal Infraction Prevention was the original name of the organisation. Currently, construction waste material is mainly sent to the landfill. There are two permanent centres and some temporary centres for landfilled waste in Tehran. Waste from excavation is currently sent to sand and gravel production plants to produce aggregate, with a small part used for embankment. A majority of the waste from construction and demolition is manually divided to reuse, with a small part sent for recycling. Due to the importance of waste management and sustainability, Tehran Waste Management Organization is trying to implement and apply more legislation and regulations. In 2012, more than 1,000 contractors and sub-contractors worked for Tehran Construction Waste Management organization (TMWM, 2012).

History of Construction Waste Management Organisation of Tehran

- In early 1987 some municipality units were introduced to prevent the illegal construction waste landfill in 20 districts of Tehran.
- In 1988 these units were companied together and named Construction Waste Landfill Exclusion Headquarter.
- In 2009 the organization called Construction Waste Management Organisation, which was a branch of Waste Management Organisation.

Waste related legislation and regulations

Waste Management Organisation of Tehran, in 1995 with the help of Global Bank and German consultants, started to establish the "solid waste management Plan and strategy". Therefore in 1998 the first proposal for "Waste Regulation and legislation" was introduced. The first proposal was sent to the Iranian Parliament (fifth parliament) for approval, which was rejected. The parliament and government on 2004 finally approved the proposal after several improvements (WMO, 2013). Construction waste at the moment send to the landfill sites by the permission of municipality (WMO), because Environment organization of Iran has not enough execution power to stop unlimited landfilling, and there is no clear definitions and limits for landfilling in Iran. Currently some limited recycling companies started to collect waste materials from construction sites. The products of these companies mainly include pavement blocks and stones, concrete slabs, etc. However several construction companies has started to use adopted waste management policies and strategies to improve their reputations, partially to improve their profitability, or reduce environmental impacts. Although in governmental projects it has been started to ask about sustainability and waste management strategies of the companies in order to choose the best contractor in bidding stage, (as a great number of building projects in Iran are private projects) enough attention has not been paid to waste minimization practices. However a number of current methods for minimizing on-site concrete waste have been illustrated in section (2.4.7).

Iran Landfill Tax

According to TMWM (2013a), Iran's Landfill Tax is based on the amount of waste disposed measured in cubic meters. The tax was established to reduce the production of waste and encourage recovery instead of disposal. For calculation of the tax, waste in Iran is divided into five sub-groups:

1- Regular waste: includes domestic waste and construction waste.
2- Hospital waste.
3- Special waste (dangerous waste): includes infected, toxic, and flammable waste.
4- Agricultural waste.
5- Industrial waste: includes all manufacturing waste, mining waste, oil and gas refinery waste, and exploration and excavation waste.

Landfill taxes in Iran are normally paid by the construction waste transportation contractors (CWTCs) who transport the waste from construction sites to the landfill sites. Therefore there is not any especial tax for the project contractor for the site's waste. The transportation contractors add these taxes to their service. Also there is not any penalty charge for the waste production of the project contractor at the moment in Iran, and the only contractors who are controlled by the WMO are the CWTCs. The WMO gives the landfill permission to the CWTCs at the start of their service and charges them for landfill tax. (WMO, 2011). According to Iran's law, transport and dumping (landfilling) of waste without permission is liable to a penalty charge ranging from 500,000 to 1,000,000 Rials for regular waste (including construction waste) for the first time, with the fine doubled for subsequent offenses (TMWM, 2013a). Iran's national Radio and Television organization is required by law to cooperate with waste management organizations to provide required and useful information to the public. Due to the growing population of Tehran and the increase in construction and building projects, construction waste has become an important issue for areas such as air pollution. Therefore, the Tehran Waste Management Organization conducts important activities in order to control construction waste, including (TMWM, 2013b):

- Issuing permits for excavation, demolition, waste transportation, and controlled dumping.
- Using IT technologies such as GPS, RFID, and OCR cameras for waste transport vehicles.
- Recycling construction waste at relevant facilities and programmes.
- Monitoring and controlling waste management contractors.

2.4. On-Site Concrete Waste Minimization

2.4.1. Previous Studies in Construction Waste Management

The analysis of research on this topic helps to identify subjects that were investigated previously, consequently avoiding duplication of other researchers' efforts (Yuan and Shen, 2011). According to Yuan and Shen, (2011) published papers on construction and demolition waste management between 2000 and 2009 can mainly be grouped into the following six categories: (1) waste generation, (2) waste reduction, (3) waste reuse, (4) waste recycling, (5) waste management in general, and (6) human factors in waste management. Osmani et al. (2008 further extracted topics from the construction waste management literature published after 2000 and divided approaches into the groups outlined in Table 2.10.

Table 2.10. Approaches to waste management

Research approach group	Example
Construction waste quantification and source evaluation	Ekanayake and Ofori, 2000; Poon et al., 2004a,b; Kulatunga et al., 2005; Solis-Guzman et al., 2009; Liatas, 2011;
On-site construction waste sorting methods and techniques	Poon et al., 2001; Wang et al., 2010; Lu et al., 2011;
Development of waste data collection models, including flows of waste and waste management mapping to help the handling of on-site waste and eco-costing of construction waste	Treloar et al., 2003; Shen et al., 2004; Yahya and Boussabaine, 2006; Hao et al., 2010
Development of on-site waste auditing and assessment tools	McGrath, 2001; Chen et al., 2002
Impact of legislation on waste management practices	Eikelboom et al., 2001; Tam et al., 2007c; Hao et al., 2008
Improvements of on-site waste management practices	Chadrankanthi et al., 2002; Hao et al., 2008; Tam, 2008
Reuse and recycling in construction	Lawson et al., 2001; Emmanuel, 2004
Benefits and factors of waste management	Coventry et al., 2001; Begum et al., 2007
Waste management manuals, including guides for designers	Greenwood (2003); WRAP (2010d)
Attitudes towards waste	Lingard et al. (2000); Teo and Loosemore, (2001); Sanders and Wynn (2004); Kulatunga et al. (2006); Begum et al. (2009)
General construction waste management tips	Esin & Cosgun, 2006; Lu et al., 2011;
Comparative waste management studies	Chen et al. (2002); Ilozor (2009)
Specific waste management methods (i.e. pre-fabrication or ready mixed concrete)	Cosgun & Esin, 2005; Woodward & Duffy, 2010;
Construction waste reduction by design	Keys et al. (2000); Osmani et al. (2006: 2008)

Source: Gamage, 2011; Osmani et al., 2008; further literature

As seen in Table 10, almost all studies were focused on construction waste material in general or construction waste in different stages of a project (such as the design or procurement stages) or investigated a specific method of waste minimization. There are few studies that focused on one specific material. Research in this field in Iran is very limited as well. However, as discussed in the next section (section 2.5), concrete is one of the main concerns in Iranian construction industry in terms of waste minimization. To provide another point of view, the aims of research conducted after 2005 were studies and divided into the three categories in Table 2.11. These three categories are: studies on concrete, studies on on-site waste minimization, and studies on specific applications of waste management.

Table 2.11. Recent research in the on-site construction waste management field

Field	Author	Aims	Results
Concrete	Tam, 2010	The aims of the research were to recommend measures to improve the current concrete recycling situation in Australia based on lessons learned from Japan by examining the existing standards for the use of recycled concrete.	Defining details about the classification of recycled products such as recycled aggregate; Inclusion of concrete recycling management evaluation in tender appraisal; Continuous efforts to improve concrete recycling management in organizations; providing in-house training on concrete recycling; effective communication on concrete recycling issues among all parties; exhaustive control of concrete waste volume generated on-site from the government; government financial support for companies; high landfill charge for disposing waste
	Tam, 2009	This paper investigates concrete recycling implementation in construction and studies of the existing methods in Japan, Hong Kong, and Australia.	It was found that "increasing overall business competitiveness and strategic business opportunities" was considered as the major benefit for concrete recycling by Hong Kong and Japanese respondents, while "rising concrete recycling awareness such as selecting suitable resources, techniques and training and compliance with regulations" was considered the major benefit by Australian respondents.
	De Silva, 2008	The aim of this research was mainly to identify the pre-cast contribution to the construction waste minimization in the Sri Lankan construction industry through a comparison of material waste arising from pre-cast, ready-mixed, and site-mixed concrete.	The study found that mean wastages of cement, sand, and metal in pre-cast elements amounted to 5.34%, 13.86%, and 7.62%, respectively, showing lower values compared with the material wastages in the other two technologies (in situ concrete elements – site mix, and in situ concrete elements – ready mix).
	Shen et al., 2008	This paper shows the benefits of replacing in situ concrete with pre-cast slabs for temporary works to improve sustainable construction performance.	The case study results shows about 43.93% of the cost of using cast in situ concrete can be saved by reusing precast slabs for temporary works. Furthermore, by using pre-cast concrete slabs, operation time can be reduced substantially compared to cast in situ concrete.
	Cosgun & Esin, 2005	In this study, the application levels of the methods of environmental management in regards to the ready mixed concrete production in Turkey were determined.	It was determined that there are differences between plants in their environmental applications of ready mixed concrete production in Turkey, and, despite the strides taken in this area, the desired levels have not been achieved. Therefore, inspections must be increased in order to strengthen the enforcement of the rules and regulations of the environmental laws in Turkey.

Cont.

Field	Author	Aims	Results
On-site management	Lu et al., 2011	The study investigated waste generation rates (WGRs) by conducting on-site waste sorting and weighing in four on-going construction projects in Shenzhen, located in South China.	The results revealed that WGRs ranged from 3.275 to 8.791 kg/m^2 and that miscellaneous waste, timber for formwork and false work, and concrete were the three largest components amongst the generated waste.
	Wang et al., 2010	This research aimed to identify the critical success factors (CSFs) for on-site sorting of construction waste in China.	This study identified six CSFs among the nine selected success factors (SSFs) for on-site sorting of construction waste through a series of analytic procedures. They are CSF1: Manpower, CSF2: Market for recycled materials, CSF3: Waste sortability, CSF4: Better management, CSF5: Site space, and CSF6: Equipment for sorting of construction waste. These CSFs clearly indicate that cost consideration, management capacity, and feasibility of on-site sorting are the major determinants of effective on-site sorting of construction waste in China. Moreover, on-site sorting cannot be successfully implemented without sufficient support of the local government and the contractor.
	Begum et al., 2009	This paper provided insights on how contractor attitudes and behaviours affect waste management in the construction industry of Malaysia.	The important and significant factors that affect contractor attitudes toward waste management include contractor size, source reduction, reuse and recycling measures, frequency of waste collection, staff participation in training programs, and waste disposal method. Factors such as construction-related education among employees, contractor experience in construction works, source- reduction measures, reuse of materials, waste disposal behaviours, and attitudes toward waste management are the most significant factors affecting contractor behaviour regarding waste management.
	Begum, 2006	This study provided an idea of the amount of waste generation, sources and composition as well as reuse and recycling of materials on construction sites, taking into account the economic dimension.	Waste minimization is common in project sites, where an average 73% of waste material is reused and recycled. The net benefit of reusing and recycling of waste materials is estimated at 2.5% of the total project budget.
	Esin & Cosgun, 2006	The aim of this study was to provide suggestions regarding the prevention and reduction of waste generated due to modifications done for various purposes in residences in Turkey.	Result illustrates that pollution caused by construction waste negatively affects the environment and leads to economic losses in Turkey. Thus to prevent the generation of construction waste and to make it easier to reuse building materials and components some suggestions have been given.
	Tam et al., 2005	This paper investigated the generation of construction waste on-site and its relationship with prevailing sub-contracting arrangements and project types in Hong Kong.	By using the findings of this research, four methods are proposed to mitigate the generation of waste by reshaping the current practices of construction projects. These methods are: (i) development of a cost- effective approach, (ii) integrated waste minimization at the tender stage, (iii) provision and motivation of waste reduction training, and (iv) a waste control system as a part of site management functions.
Specific application for waste management	Tam et al., 2012	This paper examines the existing implementation of waste management systems in the Hong Kong construction industry.	Use of pre- fabricated building components and non-timber hoarding are the recommended methods to improve the existing implementation of waste management systems.
	Yuan et al. 2012	This study research proposed a model that can serve as a decision support tool for projecting C&D waste reduction in line with the waste management situation of a given construction project and, more importantly, as a platform for simulating effects of various management strategies on C&D waste reduction.	Results of the case study not only build confidence in the model so that it can be used for quantitative analysis, but also assessed and compared the effect of three designed policy scenarios on C&D waste reduction. One major contribution of this study is the development of a dynamic model for evaluating C&D waste reduction strategies under various scenarios so that best management strategies could be identified before being implemented in practice.
	Lu & Yuan, 2011	The aim of this paper was to develop a framework that helps readers understand the C&D waste management research archived in selected journals.	It is found that C&D generation, reduction, and recycling are the three major topics in the discipline of C&D waste management. Future research is recommended to (a) investigate C&D waste issues in wider scopes including design, maintenance, and demolition; (b) develop a unified measurement for waste generation so that waste management performance can be compared across various economies; and (c) enhance effectiveness of waste management approaches (e.g. waste charging scheme) based on new waste management concepts (e.g. extended producer responsibility).

Cont.

Field	Author	Aims	Results
Specific application for waste management	Yuan et al. 2011	This paper highlighted the dynamics and interrelationships of construction and demolition (C&D) waste management practices and analysed the costs and benefits of this process using a system dynamics approach.	The findings reveal that net benefits from conducting C&D waste management will occur, but a higher landfill charge will lead to a higher net benefit as well as earlier realization of the net benefit. In addition, the general public will suffer under a higher landfill charge from a higher environmental costs caused by illegal dumping.
	Ortiz, 2010	The main objective of this paper was to evaluate environmental impacts of construction wastes in terms of the LIFE 98 ENV/E/351 project.	Results show that in terms of global warming potential, the most environmentally friendly treatment for construction waste is recycling.
	Tam, 2008	The aim of this study was to investigate the effectiveness of the existing implementation of the waste management plan (WMP) method in the Hong Kong construction industry	The result showed that on-site reuse of materials and reduction of waste are the main benefits gained from the implementation of the WMP method. However, low financial incentive and increases in overhead cost were considered the major difficulties in implementation. The use of pre-fabricated building components is considered the most effective measure to encourage the implementation of the WMP method.

As seen in Table 2.11, the first five studies are common in focusing in concrete waste management. However, these studies focus on one or two specific approaches or methods for concrete waste minimization, and do not cover all the existing methods that can be used in minimising concrete waste (on-site or in situ).

The first five studies presented in Table 2.11 also show that the adoption of specific concrete waste management approaches or methods is context-dependent. For instance, Tam (2009) studied existing concrete recycling methods in Japan, Hong Kong and Australia, and found different motivations and benefits for concrete recycling in Hong Kong and Japanese compared to Australia. In a further study, Tam (2010) aimed to recommend measures for improving the current concrete recycling situation in Australia based on lessons learned from Japan, and identified difference in the existing standards for the use of recycled concrete in the two countries (see Table 2.11).

These studies undertaken in Japan, Hong Kong, Australia (Tam, 2009, 2010) show that each country has its own rules, regulations and standards that highly determine the adoption of specific approaches or methods for minimising concrete waste. This suggests further concrete waste management studies in context-specific way. Also, the studies by De Silva (2008) and Shen et al. (2008) presented in Table 2.11 reveal how different motivations and benefits determine the adoption of concrete waste management approaches or methods in a specific context. De Silva (2008) compared material waste arising from pre-cast, ready-mixed and site-mixed concrete, and investigated motivation and benefits for using pre-cast in the Sri Lankan construction industry. The study conducted by Shen et al. (2008) discovered the benefits of replacing in situ concrete with pre-cast slabs for temporary works in China. Furthermore, a study by Cosgun and Esin (2005) presented in Table 2.11 showed the importance of the enforcement of the rules and regulations in a specific context. They determined that there are differences between plants in their environmental applications of ready mixed concrete production in Turkey, and recommended more inspections in order to strengthen the enforcement of the environmental laws in the country. It can be learned from the first five studies presented in Table 2.11 that it is essential considering why a particular concrete waste management approach or method is adopted in a specific context, and how the adopted approach or method works in the context.

The next six studies presented in Table 2.11 are common in focusing on on-site waste management in general. These studies also address one or two specific approaches or methods for minimising waste on-site, and do not investigate all the existing methods that can be used for this purpose, or cover all construction materials used on-site or in situ. These studies were conducted in different countries, including South China (Lu et al., 2011), China (Wang et al., 2010), Malaysia (Begum et al., 2009; Begum, 2006), Turkey (Esin and Cosgun, 2006) and Hong Kong (Tam et al., 2005), further showing who the particular circumstances and conditions of each country determine the adoption of specific on-site waste management approaches or methods by the country, and how the adopted approach or method works in each country.

Nonetheless, because the on-site waste management studies presented in Table 2.11 do not investigate all the existing on-site waste management approaches or methods, nor cover all construction materials, there is a lack of published works in this area that suggest further contribution to the existing knowledge in the area.

The last six studies are common in introducing or examining specific application for waste management. Some of these studies were carried out in case- or context-specific way. For example, Tam et al. (2012) examined the current implementation of waste management systems in Hong Kong. As another example, Tam (2008) investigated the effectiveness of the existing implementation of the waste management plan (WMP) method in the Hong Kong construction industry.

Some of the last six studies presented in Table 2.11 made attempts to draw general conclusions from the findings of the studies. For instance, Yuan et al. (2012) proposed a decision support tool for projecting C&D waste reduction in line with the waste management situation of a given construction project, that can serve as a platform for simulating effects of various C&D waste management strategies. They concluded that the results of this case study not only confirm that the proposed tool can be used for quantitative analysis, but also it can serve as a dynamic model for evaluating C&D waste reduction strategies under various scenarios so that best management strategies could be identified before being implemented in practice (Yuan et al., 2012). Such kind of drawing general conclusion from findings is true for the studies conducted by Yuan et al. (2011) and Ortiz (2010) presented in Table 2.11. Nevertheless, it seems that more conceptual and empirical works are needed to draw robust conclusions about generalisation of the findings from these studies to other cases of construction waste management in various contexts.

After all, data and reliable published studies on construction waste minimisation in Iran are rare, by reviewing the literature, the aim of the present research (on-site concrete waste minimisation methods) was determined to attempt to fill existing knowledge gaps.

2.4.2. Importance of Concrete Waste

Concrete has been a leading construction material for more than a century (Tu et al., 2006). It is estimated that the global production of concrete is at an annual rate of approximately 2.5 tonnes per capita (Neville, 2003). Concrete has also been one of the main waste materials in construction projects (Kofoworola and Gheewala, 2009). The large amount of concrete used on construction sites and in stocks compared with other construction materials raises environmental concerns about issues such as CO_2 emissions during cement and concrete production and transport and the amount of concrete waste generated. Moreover, concrete has conventionally been considered difficult to recycle (Noguchi and Kitagaki, 2010). According to Li (2002), concrete waste comprises the major proportion of total construction waste in Hong Kong. Among different types of construction materials, concrete is the most significant material collected from construction sites, demolition sites, general civil works, and renovation works. Table 2.12 illustrates the percentage of material collected from construction sites.

Table 2.12. Composition of construction waste collected in South East New Territories Landfill (Hong Kong)

Waste Type	**Percentage**			
	Construction sites	Demolition sites	General civil works	Renovation works
Metal	4	5	10	5
Wood	5	7	0	5
Plastic	2	3	0	5
Paper	2	2	0	1
Concrete	75	70	40	70
Rock/Rubble	2	1	5	0
Sand/Soil	5	0	40	0
Glass/Tile	3	2	0	10
Other	2	10	5	4
Total	100	100	100	100

Source: (Li, 2002).

According to Noguchi and Fujimoto, (2007) concrete is the second most extensively consumed material in the world after water. For instance, the amount of concrete produced in 2000 in Japan was approximately 500 million tonnes, which accounts for almost 50% of resource consumption in construction industry and 25% of total input resources in Japan. Cement and concrete production, execution and demolition of concrete structures, and the recycling and disposal of concrete waste raise numerous environmental concerns (Noguchi and Fujimoto, 2007). According to Begum et al. (2006), the estimated amounts of construction waste generated on-site in a construction project case study in Malaysia are presented in Table 2.13.

Table 2.13. Estimated construction waste generation and composition on-site

Construction waste material	Amount of waste generated (tonnes)
Soil and sand	7290
Brick and blocks	315
Concrete and aggregate	17820
Wood	1350
Metal products	225
Roofing materials	54
Plastic materials	13.5
Packaging products	0.9
Total	27068.4

According to a study by Solís-Guzmán et al. (2009), based on 100 residential projects constructed during 2004in Spain, concrete waste accounts for approximately 23.4% of total construction waste by volume in new construction projects, apart from excavated earth. Research conducted by Lu et al. (2011) revealed that the waste generation rate in construction projects in South China ranged from 3.275 to 8.791 kg/m2, and miscellaneous waste, timber, and concrete were the three largest components of the generated waste. By using concrete waste management methods such as recycling concrete, natural resource exploitation, and associated transportation costs, the amount of waste going to landfill can be reduced (Woodward and Duffy, 2010). However, this has little impact on reducing greenhouse gas emissions as most emissions occur when cement is made (WBCSD, 2014). Cement cannot yet be recycled. Some countries such as the Netherlands and Japan have achieved almost complete recovery of concrete waste, with up to 100% of waste being reused or recycled (Tam, 2009). Some countries such as Ireland have set specific targets. Ireland exceeded its target of recycling 50% of concrete waste by 2001; however, the major part of the waste recycled was inert soil and stones. A further target of recycling 85% of concrete waste by 2013 has been established (NCDWC, 2013). Each year, many buildings are demolished in Iran, mainly due to finishing their useful lifetime, natural disasters (e.g. earthquakes), low safety standards, and demand for more high-rise buildings. Several factors may reduce the lifetime of buildings in Iran, for instance, poor quality buildings due to inadequate execution or supervision, poor maintenance, and inability to modify buildings to environmental changes and users' demands. Buildings being demolished in the present decade in Iran were generally constructed in the 1960s or earlier. These buildings are mostly constructed with traditional masonry materials such as clay brick (Saghafi and Hosseini, 2011). However, according to the TMWM (2012), in less than 15 years, Tehran will begin demolishing concrete structure buildings, consequently producing more concrete waste. Furthermore, reduction or minimization of concrete waste has various advantages. For instance, according to Dong et al., (2008) recycled aggregate concrete (RAC) meets the 3Rs strategies of waste minimization (reduce, reuse, and recycle). The study describes RAC as a successful method to solve the problem of waste concrete. Dong et al. (2008) stated that RAC can reduce not only the amount of waste sent to the landfill and construction resource consumption, but also construction costs.

Benefits achieved in concrete recycling include (Tam et al., 2010):

- Decreasing the need for new landfills.
- Saving natural materials.
- Decreasing cost of projects by using recycled materials,
- Locating recycling machines on-site to save transportation costs between site and recycling plant.
- Stimulating continuous improvement in concrete recycling.
- Increasing concrete recycling knowledge such as selecting suitable resources, techniques and training, and fulfilling with regulations
- Increasing overall business competitiveness and strategic business opportunities.
- Improving management and employees' communication on concrete recycling information and commitment.

2.4.3. Importance of On-site Concrete Waste Minimization

There are two main methods of construction waste minimization: source reduction techniques and improvement of on-site waste minimization strategies (McDonald and Smithers, 1998). Additionally, the literature review revealed that causes of waste production are generally associated with three main stages in construction projects: design, tender and contract, and construction (on-site). Waste minimization strategies should be applied to these three stages. However, waste minimization on construction sites (on-site or in situ) includes a wide range of efforts, which cover the design stage through handing over of the project. For instance, design details can be changed in the construction stage in many circumstances. A report from the Environmental Protection Agency (EPA) estimated that more than 135 million tonnes of waste from construction sites is brought to landfills every year, making construction waste the single largest source in the waste stream (Maedows, 2011). Until recently, most discussions on construction waste management have focused on recovery, reuse, recycling, or diversion of waste post-construction instead of reducing waste on the front end through better management, procurement, and construction practices. Although post-construction recycling is one method of reducing the amount of waste that ends up in landfills, on-site waste minimization methods such as prevention through lean construction processes, pre-fabrication, and the use of building information modelling are more effective techniques and could have a greater impact on decreasing the amount of waste sent to landfills (Maedows, 2011). Several researchers have studied construction waste minimization methods and emphasized the use of advanced technologies in construction such as pre-fabricated concrete (e.g. Shen and Tam, 2002; Poon et al., 2001a,b; Chen et al., 2000; Poon, 2000). Waste prevention is another classic waste minimization strategy. Waste prevention includes: the use of efficient purchase and ordering materials (purchase management), efficient timing and delivery of materials, efficient material storage, minimising material losses, maximising material reuse, preventing undoing and redoing, and using pre-fabrication. These methods were widely inspected in previous studies (e.g., Shen and Tam, 2002; Faniran and Caban, 1998; McDonald, 1998; Chun et al., 1997; Poon, 1997; Graham and Smithers, 1996). For instance, Shen et al. (2009) focused on examining on-site concrete waste production of existing temporary works by a case study in Hong Kong and demonstrated cost savings and environmental performance improvements from replacing in situ concrete with pre-fabricated slabs for temporary works. These results illustrate that by replacing in situ concrete with pre-fabricated slabs reused once, twice, or three times, cost reductions of about 43.93%, 64.01%, and 70.70%, respectively, could be achieved. Moreover, by using pre-fabricated concrete slabs, operation time can be decreased substantially compared to cast in situ concrete work methods.

2.4.4. Causes of On-Site Concrete Waste Production in the UK

There are common causes for on-site concrete waste generation globally. For instance, conventional cast in situ reinforced concrete is the preferable method for high-rise buildings in South China. Although concrete is the main construction material, mixing concrete on-site is banned because of the noise produced and other environmental issues. Therefore, concrete is usually ready-mixed and transported to sites with trucks by sub-contractors using just-in-time delivery and then pumped into formwork. According to Lu et al. (2011), the greatest amount of concrete waste on studied sites was caused by poorly constructed formwork. If the formwork is installed inaccurately or broken, there is bulging or leakage, and re-pouring generates waste. There is also some concrete waste from the spike hammer for facilitating the concrete pour for the next floor above. Furthermore, excessive ordering of ready-mixed concrete can cause unexpected waste generation (Lu, et al. 2011). According to Tam et al. (2006), over ordering, damage during transportation, loss during installation, poor workmanship, and change of design are some of the major causes of concrete waste. Concrete waste cannot be completely removed from demolition sites and remains at site mixed with earth and sand. In addition, subsurface structures such as foundations might remain unexcavated and thus are not counted as waste in statistics (Hashimoto et al., 2009).

2.4.5. Causes of On-site Concrete Waste Production in Iran

Because new methods and technologies are not often used on construction sites in Iran (Siamardi, 2009), some common causes for concrete waste are:

- Use of on-site concrete
- Waste of ready-mix concrete caused by issues such as over ordering or concrete that remains in the pump car or pump pipe

- Poor quality workmanship at the site level
- Lack of training about waste reduction
- Errors in calculating the quantity of concrete needed because of improper planning or poor communication
- Concrete wastage during transportation, i.e., sometimes long a time is required for concrete transportation from the manufacturer to the site due to issues such as traffic congestion and the concrete cannot be used for construction activities
- Difficult waste handling processes that, in some cases, demand significant labour hours
- Poor formwork that causes wastage of concrete.

Other causes of on-site concrete waste were identified as follows:

- Damage by mishandling, weather and inadequate storage
- Vandalism and rework
- Lack of recycling facilities within the studied region.

Despite the fact that pre-fabrication can minimize on-site concrete waste generated by major construction trades and achieve a 100% reduction in waste in the plastering trade alone (Tam et al., 2004), there is still unwillingness to use pre-fabrication in some countries.

The following factors were identified that influence on on-site concrete waste minimisation:

- Role of the contractor's site manager or superintendent
- Lack of partnership amongst the supply chain
- Casual attitude to works undertaken by some sub-contractor
- Lack of proper market for recycling and reused materials
- Lack of interest for recycling due to various reasons
- Design and form of the building.

2.4.6. Current Methods of On-site Concrete Waste Minimization in the UK

Recent studies have illustrated different methods for minimizing Concrete Waste in construction sites such as reuse and recycling, improvements in on-site waste management

(Osmani, 2012), use of environmental management systems, on-site C&D waste sorting (Weisheng and Hongping, 2010), use of pre-fabricated building components (Tam, et al. 2010; De Silva and Vithana, 2008; WRAP, 2007; Poon et al., 2004a), on-site reuse of materials, on-site waste conservation, and use of information technology on-site (Tam, 2008). Moreover, education and training, green building and design techniques, green procurement practices, green roof technologies, lean construction, pre-fabrication, and waste management are also considered major methods for the promotion of sustainable construction (Bakhtiar et al., 2008). According to Tam et al. (2006), concrete waste during in situ concreting can be reduced by 43.4% by using ready mixed concrete. By using pre-fabricated concrete elements instead of in situ concrete, a 73.51% reduction of concrete waste could be achieved. Table 2.14 summarises some recent methods for concrete waste minimization in construction projects.

Table 2.14. Concrete waste minimization methods

Methods	Study
Use of pre-fabricated building components	(Tam, et al. 2010; Bakhtiar et al, 2008; De Silva and Vithana, 2008; Poon, 2007; WRAP, 2007; Tam, 2006; Poon et al., 2004a)
Waste prevention in on-site transport (includes use of volumetric trucks to handle exact quantities needed)	(Esin and Cosgun, 2007; Poon, 2007)
On-site waste conservation	(Saghafi and Teshnizi, 2011; Tam, 2008)
On-site reuse	(Osmani, 2012; Tam, 2008; Esin and Cosgun, 2007; Poon, 2007)
Central area for cutting and storage	(Weisheng and Hongping, 2010)
On-site waste recycling operation	(Osmani, 2012; Saghafi and Teshnizi, 2011; Esin and Cosgun, 2007; Poon, 2007)
Identification of available recycling facilities	(Osmani, 2012; Kofoworola and Gheewala, 2009; Esin and Cosgun, 2007; Poon, 2007)
Use of information technology on-site (e.g. BIM to avoid mistakes and misfit designs)	(Tam, 2008)
Implementation of environmental management systems	(Bakhtiar et al, 2008; Poon, 2007)
Education and training	(Bakhtiar et al, 2008)
Governmental incentives for implementing wastes reduction practices	(Osmani, 2012; Weisheng and Hongping, 2010)

Source: Author (extracted from the reviewed literature)

Building information modelling (BIM) is an engineering software to process the generation and management of digital representations of physical and functional characteristics of building. Building information models (BIMs) are files that are used to support decision-making about a building.

2.4.7. Current Methods of On-site Concrete Waste Minimization in Iran

Unfortunately, at the moment, new technology for concrete is rarely used in Iran, with the exception of some special projects. For instance, in Iran, only 8.64% of total cement used is ready-mixed concrete, and only 2.16% is used for pre-fabricated concrete elements. However, in Japan, the percentages for ready-mixed concrete and pre-fabricated elements are 73.2% and 13.2%, respectively. In the US, the same percentages are 55.7% and 11%. In Turkey and Russia, 62% and 52% of total cement is for ready-mixed concrete, respectively, and 12.4% and 19.3% is for pre-fabricated concrete elements for construction, respectively. Furthermore, approximately 75% of ready-mixed concrete producers do not hold Iran's standard certificate. Some of the methods used to reduce concrete waste are (Siamardi, 2009):

- Proper estimation of the amount of required concrete.
- Use of measured trucks to adjust the daily concrete requirements.
- Designing suitable places for pouring over-ordered concrete, for instance, making precast concrete blocks, or pavement.
- Recycling, for instance, recycled aggregate accounts for approximately 5% of the total aggregate market in Iran.

There are very few studies about existing methods for minimizing concrete waste on construction sites in Iran. However, some of the most common methods for minimization are: recycling, on-site reuse of materials (partially for earth filling, embankments for unloading areas, or landscapes), and very limited education and training classes. However, there is limited published information about on-site concrete waste minimization methods in Iran and more study is required in this field.

2.5. Critical remarks on the literature reviewed

From different research approaches, attempts have been made to work out towards construction waste minimisation. In the literature reviewed in this chapter, the focus of what is considered the issue of construction waste production, as well as the challenge(s) against minimising construction waste are different. However, all the studies reviewed in the literature are talking about is that there is no 'one' adequate diagnosis of construction waste problem, 'one' adequate problem framing, and 'one' best way to minimising construction waste.

That is to say, the scholars whose work have been reviewed in this chapter are relying on their own academic knowledge and professional skills in understanding the problem pertaining to construction waste production, as well as working out in the specific circumstances and conditions of their own case studies to manage the problem.

Nevertheless, these attempts have yielded a variety of solutions for construction waste minimisation that feature some common threads: they are mainly concerned with problem solving through efforts of construction waste minimisation or construction management focussing on one specific method or a particular material. However, the embedding of the efforts within broader contexts has been barely addressed in the literature reviewed. This argues that the efforts for construction waste minimisation interact with broader contexts in real world that are not only affected by, but also affect the contexts.

Nonetheless, the literature reviewed has paid little attention to the interactions between theses efforts and the broader contexts in which the efforts are understood to work. This argument, in turn, suggests empirical and conceptual work for context-specific understanding and management of the issue of construction waste production as was done within this PhD research.

Further, there are considerable reflective gaps first and foremost with regard to the importance of collective roles that different stakeholders could play to influence substantial efforts for minimising waste from construction projects. This means that the literature get lost pointing to these gaps in articulating a framework within which collaborative efforts of the construction project stakeholders in using a specific method for minimising a particular waste could be elaborated.

The argument and suggestion above do not imply a need to further broadening of focus, but hint at a shift in perspective on minimising construction waste. From a fresh perspective, it can be explored that how broader contexts could stimulate and/or hinder various stakeholders in minimising construction waste. In doing so, one can investigate how the stakeholders see their own conditions, make their own knowledge and experience in relation to construction waste management, and offer their own roles in minimising the waste. Within a broader context, it can also be explored that how diverse are perceptions, expectations, and strategies of the stakeholders, leading to a complex understanding of the issue of construction waste production.

The studies reviewed in this chapter do not adequately reflect the above-mentioned diversity, nor integrate distributed efforts of diverse stakeholders within a whole system for minimising construction waste, not put forward convincing elements of a collaboration framework that could potentially motivate the stakeholders to work together towards this end.

In line with the research aim, an attempt was made within this PhD thesis to address these shortcomings in the literature in a context- and case-specific manner. In doing so, the focus was on particular material such as concrete, which is one of the main construction materials globally on the one hand, and a few limited studies have focused on concrete waste minimisation on the other hand. In this way, this research then pointed to the lack of data about on-site concrete waste minimisation methods as presented in the next chapters, and concluded in the last chapter in detail.

2.6. Summary

This chapter aimed to explore the existing methods of on-site concrete waste minimization in the UK and Iran. It provided an account of construction waste, construction waste minimization, and on-site concrete waste minimization methods in the UK and Iran. The chapter also presented the origins and causes of waste generation in the construction industry in the UK and Iran. The literature review illustrated that the origins and causes of construction waste generation can be classified into different categories.

In the next section of this chapter, the importance and necessity of construction waste minimization and drivers of construction waste minimization were discussed and existing methods of construction waste minimization in the UK and Iran explained and summarized. Environmental, economic, government policy and regulatory, and industrial drivers of waste reduction were then discussed. In addition, a brief review of government legislation and regulations in these two countries was presented.

As Yuan and Shen, (2011) stated, in order to reach the objectives of research, the first step is the analysis of research topics. Such analysis helps to identify the topics that have been previously investigated in order to avoid duplication of other researchers' efforts and spot existing gaps in knowledge. Therefore, in the next section, previous studies in construction waste management area were reviewed. Then, the next part of this chapter explained why on-site concrete waste minimization is the main topic for the present research. Therefore, discussion regarding the importance of on-site concrete waste minimization was provided. The next section discussed on-site concrete waste minimization methods in the UK and Iran. The causes and some common solutions for minimization of on-site concrete waste were presented and it was revealed that there is very limited literature about concrete waste minimization in Iran. There have been almost no published studies in this field that have investigated on-site concrete waste minimization methods in Iran.

In contrast, different concrete waste minimization approaches have been implemented in other countries. These methods include a broad range of initiatives such as reuse and recycling operations, improvements to on-site waste management practices, implementation of environmental management systems, on-site C&D waste sorting, use of pre-fabricated building components, on-site reuse of materials, on-site waste conservation, and use of information technology on-site. This variety of approaches emphasizes the necessity of comparing the favourite approaches in different countries to determine why they are so widely used.

In order to complete such a comparison and examine the differences in adapted approaches, the author selected the UK and Iran as the target countries.

Why was the UK selected?: As explained in Chapter 1, the UK was selected as reference context for this research following a review of 87 papers published in the discipline of construction and demolition waste management between 2000 and 2009 in eight selected journals. This initial review was carried out in 2011 at the beginning of this research, showing that researchers from the UK, Hong Kong, Australia, and the US are the main contributors to OCWM research and literature (Yuan and Shen, 2011). Further search for good examples of empirical works on OCWM led to identify that the UK government has introduced legislation and regulation to force different sectors to reduce waste by zero by 2020 (WRAP, 2012). Exemplary, the UK Government's Waste Strategy 2007 seeks to potentially reduce construction waste to zero by 2015 (see section 2.3.2.3). Companies in the UK construction sector are required to follow the regulations and recommendations in the legislation to achieve this goal (WRAP, 2011).

Moreover, this research had been done in a UK university, and the researcher had have access to the British professionals in construction projects as sources of primary data about successful on-site concrete waste minimisation (OCWM) methods used in the country. As such, there was a proper environment for doing interviews and questionnaire survey in the UK. In a nutshell, proper literature and a range of sources about successful OCWM methods were available in the UK, making the country a reference context for the present research.

Why was Iran selected?: Construction and demolition waste production in Iran is higher than the average for developed countries. For example, average construction and demolition waste production in the United States is 0.77 kg per capita per day. Furthermore, detailed quantitative data about construction and demolition waste production in Iran are still very limited so results of this research can be very useful to improve waste management activities in Iran.

It should be mentioned that this research did not determine to conduct a comparative study; it in fact intended to search for the OCWM methods, which have been used in the UK to date. This search informed a list of the UK OCWM methods against which the OCWM methods that are currently in use in Iran were cross-checked. This cross-checking exercise resulted in to find one of the most preferred OCWM method in the UK which is missing or ignored in Iran at present, with which improving on-site concrete waste minimisation in construction projects in the country could be achieved.

This chapter went to talk about blind spots in the literature reviewed, and critically discuss reflective gaps in previous studies. Further, the ways in which the present research could address the shortcomings in the literature were sketched out.

After all above-mentioned reviews, the following objectives were determined for this research. These are discussed in detail in the next chapter (Methodology):

Objective (1): To identify the common methods of on-site concrete waste minimization in the UK.

Objective (2): To rank on-site concrete waste minimization methods in UK.

Objective (3): To rank on-site concrete waste minimization methods in Iran.

Objective (4): To identify the differences between common methods of on-site concrete waste minimization in the UK and Iran and explore the possible causes of these differences.

Objective (5): To investigate the causes of differences between the best methods in the UK and the best methods in Iran.

Objective (6): To propose a framework in Iran

3. Research Methodology

3.1. Introduction

This chapter explains the research methods and the way in which the research was conducted to achieve the aim and best address the objectives. The adopted research methods for the study, the research structure and the research design are outlined in this chapter. In addition, data collection methods involving questionnaire surveys, semi-structured interviews, and case study observation are explained. This chapter is divided into ten sections.

In addition to the introduction, the first four sections consider the literature on research strategies, types of research, research design, and data collection methods. Each of these sections prepares the context to create a proper research methodology for the study. Subsequently, the next section illustrates the adopted research methods for the study. The chapter then provides details of the methods and techniques adopted for data collection as well as the rationale behind their choice. These techniques and methods include interviews in the UK, a questionnaire survey in the UK, a questionnaire survey in Iran, interviews in Iran, a case study in Iran, and framework development and validation. In each section, their aims, design and development, sampling methods, and administration processes are explained. The chapter also discusses the validity and reliability of the research and ethical considerations.

3.2. Research Philosophy

The word 'research' refers to a careful and systematic process of inquiry to discover answers to problems of interest (Tan, 2002). Particularly, a research study's tendency is to investigate problem(s) systematically and thoroughly aiming to describe, predict, explain or interpret phenomena. Thus, research is known as a systematic enquiry that contributes to knowledge besides worthy research should be systematic, organized, critical, analytical, and able to communicate findings effectively (Sekaran, 2013). Subsequently, a 'scientific modes of inquiry' is vital for discovering answers to problems of interest. Nevertheless 'scientific modes of inquiry' refers to the fact that there is more than one-way of doing science (Tan, 2002) and therefore this links to the debate of methodology (i.e. the science of finding out) (Babbie, 2007). Although, the words 'methods' and 'methodology' are seen as related concepts, the meanings of those words are different. 'Methods' of research are the actual techniques or procedures used to collect and analyze data related to the research question or hypothesis (Blaikie, 2007). This includes techniques or procedures such as engaging people in conversation, getting participants to complete questionnaires, document surveys getting surveys, and observing behavior. However, the word 'methodology' is described as a particular procedure or set of procedures (Creswell, 2012). Also, it is the analysis of how research should or does proceed (Blaikie, 2007). Specifically, establishment of methodology addresses three questions (Creswell, 2013):

- What knowledge claims the researcher is making?
- What strategies of inquiry would inform the procedures?
- What methods of data collection and analysis would be used?

Thus, methodology does not simply refer to a set of methods; rather it refers to the general philosophies of science and detailed research methods (Saunders et al., 2007). Methodology is contained of methods, the technical practices used to identify research questions, gather and analyze data and represent findings, and the sets of conceptual and philosophical assumptions that justify the adoption of particular methods (Payne and Payne, 2004). According to the concept of the 'research onion', methodology comprises philosophy, strategies, approaches, methods choices, time prospects, data gathering and analysis techniques and procedures (Saunders et al., 2007).

Easterby-Smith et al. (2002) stated that there are at least three reasons for understanding the philosophical issues of a research:

- It helps to clarify research designs.
- Knowledge of philosophy helps the researcher to identify, which design would work and which would not.

- Knowledge of philosophy helps the researcher to identify and even create designs that may be outside the researchers past experience.

Furthermore, research philosophies guide the researcher to consider research constraints of different subjects or knowledge structures (Easterby-Smith et al., 2002). The above-mentioned reasons emphasize the importance of knowledge of philosophical views in order to address different issues in research. In reviewing research methods' literature, there are two main philosophical perspective traditions: positivism and interpretivism. These traditions are based on different stances of ontology, epistemology, and axiology. The root definition of ontology is "the science or study of being" (Blaikie, 2007) and it refers to nature of reality (Tan, 2002; Creswell, 2007). Epistemology is "the theory or science of the method or ground of knowledge" (Blaikie, 2007) that is how the researcher knows reality (Tan, 2002; Creswell, 2007). Axiology refers to the role of values in the research. This includes values, ethics, and belief systems of a philosophy; also includes assumptions about the value, which the researcher attaches to the knowledge (Creswell, 2007). Moreover, axiology is a brand of philosophy that studies judgments about value (Saunders et al., 2007).

In the debate on reality, positivists (objectivists) argue that reality exists independent of the mind and they tend to stress objective knowledge, empirical regularities and deductive tests (Tan, 2002). It is also assumed that investigation is value free; thus, the researcher remains detached, neutral and objective (Darke et al., 1998). Vice versa, interpretivists (or subjectivists) believe reality depends on the perspective of a person or the subject. More specifically, this approach is based on an ontology in which reality is subjective: a social product constructed and interpreted by humans as social actors according to their beliefs and value systems (Darke et al., 1998). Thus, interpretivism suggests that the research is value-laden (Healy and Perry, 2000; Silverman, 1998). Furthermore, interpretivism (subjectivism) believes that there is no concept of 'the truth'. Instead, it believes in the concept of 'multiple truths'. Therefore, subjectivists tend to use the interpretive, qualitative or idiographic approach to science (Tan, 2002). Also, subjectivism rejects the notion of value free research and is not concerned with the repeatability of an explanation (Darke et al., 1998). Having outlined the two main philosophical traditions underpinning research, it is notable that there is literature evident for other philosophical perspectives as well: for instance, realism, functionalist, and pragmatism indicated in the idea of the research onion (Saunders et al., 2007). Although the positivist and interpretivist approaches have been traditionally considered as comprising irreconcilable differences, Lee (1991) has suggested that it is possible to combine positivist and interpretivist approaches together and provide different views of the same phenomena. The comprehensiveness of real world situations means one philosophical stance is unlikely to present a comprehensive view of a certain issue. Additionally, different philosophical stances provide different aspects of the real world. For instance, Mingers (1997) exampled that the adaptation of a specific philosophical tradition is like viewing the world through "a particular instrument such as a telescope, an X-ray machine or an electron microscope"(p.9). While each of these instruments reveals certain features, it is blind to other features. Therefore, Mingers (1997) believed that it is wrong to accept completely the assumptions of one paradigm. Thus, these arguments support multiple views of reality (multi - paradigm research). Additionally, the literature distinguishes the philosophical stance of 'pragmatism' (Tashakkori and Teddlie, 2009; Saunders et al., 2007; Creswell, 2007; Patton, 2003; Murphy, 1990). Pragmatism is a worldview, which arises out of actions, situations and consequences rather than antecedent conditions (Creswell, 2009). Pragmatists focus on the outcome of the research and a concern with applications – 'what works'- and solutions to problems (Patton, 2003). Thus, pragmatists believe that the important aspect of research is the problem being studied and the questions being asked about particular problems rather than merely a focus on methods (Saunders et al., 2007; Creswell, 2009). According to Cherryholmes (1992) and Murphy (1990) basic directions to pragmatism are as follows:

- "No commitment to any one system of philosophy and reality;
- Individual researchers have a freedom of choice. They are 'free' to choose the methods, techniques, and procedures of research that best meet their needs and purposes;

- Pragmatists do not see the world as an absolute unity. In a similar way, mixed methods researchers look at many approaches to collecting and analysing data rather than subscribing to only one way (e.g. qualitative or quantitative);
- Truth is what works at the time; it is not based in a dualism between reality independent of the mind or within the mind;
- Pragmatist research looks to the 'what' and 'how' to research based on its intended consequences-where they want to go with it;
- Pragmatists agree that research always occurs in social, historical, political and other contexts; and
- Pragmatists believed in an external world independent of mind as well as those logged in the mind and the need to stop asking questions about the reality and laws of nature." (Creswell, 2007, p.23)

Therefore, pragmatism applies to mixed methods research in that inquiries draw liberally from both quantitative and qualitative assumptions (Creswell, 2007; Saunders et al., 2007). However, as the philosophical underpinning for mixed methods studies, Tashakkori and Teddlie (2009) and Patton (2003) in order to drive knowledge about the problem, conveyed the importance for focusing on the research problem and then using a pluralistic approach. A summary of pragmatist perspective research has been provided by Creswell (2007) as: "In practice, the individual using this (pragmatism) worldview use multiple methods of data collection to best answer the research question, will employ both quantitative and qualitative sources of data collection, will focus on the practical implication of the research, and will emphasize the importance of conducting research that best addresses the research problem" (p.23).

The choice of research methods in management and social sciences embodies the researcher's assumptions (i.e. philosophical perspective) about the nature of the social world, the nature of the knowledge to be obtained, and the methods of gaining knowledge (Creswell and Clerk, 2007; Saunders et al., 2007). These philosophical assumptions are too important, as they direct the researcher to select the most appropriate research methods for the context. The two main philosophical perspectives (positivism and interpretivism) are traditionally and respectively, connected with quantitative and qualitative research methods whilst multi-paradigm research and pragmatism perspectives emphasize the possibility of using multi or mixed methods in research. Therefore, this study could be placed in the pragmatism knowledge claim position (Tashakkori and Teddlie, 2009; Creswell, 2007). In pragmatism, knowledge claims arise out of actions, situations and consequences rather than antecedent conditions (Creswell, 2013) and concerns with application 'what works' and solutions to the problems (Patton, 2003).

The major entities that this research was looking at were the OCWM methods used in construction projects in the UK and Iran. In doing so, this research tried to identify those OCWM methods, which have been successfully used in the UK, and could be potentially applicable and achievable in Iran. The aim was to propose an on-site concrete waste minimisation framework (OCWMF) for construction projects in Iran by focusing on motivating the stakeholders of the projects to use one of the UK OCWM methods, which is currently missing or ignored in Iran.

As OCWM currently is an undeveloped issue in construction sector in Iran, all stakeholders in a project have been targeted. Therefore it has been attempted to identify all possible recommendations for minimizing the on-site concrete waste by proposing to all actors from governmental organisations in Iran, contractors, quantity surveyors, clients, supplier, and precast manufacturers. Although this could seems very general, the aim was to cover as much recommendations as possible in order to decrease the amount of concrete waste.

3.3. Research Strategies

Bryman (2012) indicates two ways of doing scientific research. One way is deductive thinking about the problem being studied which uses general observation to reach conclusions for a specific case. The other is inductive way in which specific observation(s) of a particular case is used to reach general conclusion. A combination of both deductive and inductive thinking may be used for discovering answers to the problem of interest (Bryman, 2012). In practice, strategies are employed for doing scientific research. Research strategies link the researcher to specific approaches or methods for data collection and data analysis (Denzin and Lincoln, 2011). Research strategies can be classified as quantitative approaches, qualitative approaches, or combination of both as explained as follows.

3.3.1. Quantitative Approach

Generally, a quantitative approach is used to address questions such as how much and how many. Therefore, the results are instantaneous and cross-sectional (e.g., number of firms in an industry; market price of an item). The purpose of quantitative research is usually to prove a theory instead of to develop a theory (Gill and Johnson, 2002). It is an experimental approach with numerical data (Punch, 2005) and typically involves data collection and analysis using statistical procedures (Creswell, 2013). The most common methods for data collection in quantitative approaches are experiments and surveys (Robson, 2011; Saunders et al., 2007; Blaikie, 2000).

3.3.2. Qualitative Approach

A qualitative approach investigates people's opinions, understandings, and beliefs about a topic as individuals or as part of a group. Analysis of such data is generally more difficult than with quantitative data. For instance, a qualitative approach may involve transcribing interviews and analysing the content of conversations. According to Creswell (2011) there are five approaches to qualitative research: narrative research, phenomenology, grounded theory, ethnography and case study. In this research, both quantitative and qualitative methodologies were adopted according to the characteristics and applications of each (Creswell, 2013; Bryman, 2012). Table 3.1 illustrates the fundamental characteristics and applications of qualitative and quantitative methodologies.

Table 3.1. Characteristics and applications of quantitative and qualitative methodologies

Research methodology	Characteristics	Applications
Quantitative	Emphasizes quantification in data collection and analysis. Implements the practices and norms of natural scientific models. Entails a deductive approach. Can be generalized or replicated. Usually requires highly structured methods in the data collection stage.	To test theories. To explain causes and effects and relationships of particular phenomena
Qualitative	Emphasizes words and individual interpretations in data collection and analysis. Rejects the practices and norms of natural scientific models. Entails an inductive approach. Data typically collected in participants' setting from purposeful samples. Typically uses open-ended data. Flexible structure.	To generate theories. To build particular or general themes. Allows consideration of alternative explanations about a situation

Source: Creswell, 2013, Bryman, 2012; Saunders et al. 2009; Axinn and Pearce, 2006; White, 2000

3.3.3. Mixed approach

General strategies to mix quantitative and qualitative approaches can be classified as below (Creswell, 2013):

- Sequential mixed strategy: The researcher explains and expands the findings of one approach (qualitative or quantitative) based on the other approach. This may begin with a qualitative method for exploratory purposes, followed by a quantitative method; or it may begin with a quantitative method to test a theory or concept, followed by a qualitative method to develop the theory in more detail.
- Concurrent mixed strategy: Quantitative and qualitative data are combined for comprehensive data analysis. In this strategy, quantitative and qualitative data are collected at the same time.
- Transformative mixed strategy: This normally includes advancing an advocacy issue in the beginning and then using either a sequential or concurrent structure.

Another classification, proposed by Hammersley (In: Bryman and Teevan, 2005), is as below:

- Triangulation approach: A quantitative approach is used to corroborate a qualitative approach or vice versa.
- Facilitation approach: A qualitative or quantitative approach is to help conduct another approach.

- Complementarity approach: Both qualitative and quantitative methods are adopted to cover different aspects of the research.

The triangulation approach uses two or more research techniques and is a combination of qualitative and quantitative approaches, thereby reducing the disadvantages of each approach and increasing the advantages (Bryman 2012; Tashakkori and Teddlie, 2009; Creswell and Clark, 2007; Morgan, 2006; Stewart and Cash, 2006; Yin, 2003; Gill and Johnson, 2002).

3.4. Type of Research

Types of research according to its purpose are illustrated below:

- *Instrumental* – this approach is used to create or construct research instruments for physical measuring equipment, tests or data collection (e.g., questionnaires; rating scales).
- *Descriptive* – this type of study is conducted to scientifically identify and record the elements of a phenomenon, process or system. This approach can be used as a survey or as a case study and is normally used to enable the subject matter to be classified.
- *Exploratory* – exploratory research tests or explores the aspects of a theory.
- *Explanatory* – explanatory research is generally conducted to explain a specific issue or phenomenon, or to answer a particular question. This research can be a follow-on approach from exploratory research that has produced hypotheses for testing.
- *Interpretive* – when empirical testing cannot be conducted, an interpretive approach can be used to fit findings, or to experience a theoretical framework or model.

Another classification of research divides approaches by what is being investigated: product, process or both. Research in construction usually involves all three of these categories. Research into structural integrity is often product oriented.

3.5. Research Design

Research design is a plan that illustrates the process from the research question to conclusions (Tan, 2002). Choosing suitable methods for data collection and data analysis are the two most important stages of all research. Research design describes the way in which data will be collected and analysed to answer the research questions: therefore, research design provides a framework for conducting research (Bryman and Bell, 2003). Research design includes guidelines to link the elements of a study's adopted methodology, and relates the theory to the research strategy and the research strategy to the data collection methods (Denzin and Lincoln, 2011). Research design is defined differently by various authors. Table 3.2 provides deferent type of research designs according to different authors.

Table 3.2. Different type of research design

Bryman (2012)	Five research design types: experimental, cross sectional, longitudinal, case study and comparative study.
Saunders et al. (2007)	Experiment, survey, case study, action research, grounded theory, ethnography, archival analysis under the spectrum of research, deductive and inductive research approaches.
Tan (2002)	Six common research design types: Case studies, surveys, experiments, correlational research, causal-comparative research and historical research.
Yin (2009)	Five research design types: Experiment, survey, archival analysis, history and case study.

Source: Bryman (2012); Yin (2009); Saunders et al. (2007); Tan (2002).

Choice of research strategy and design are guided by research question(s), objectives, the extent of existing knowledge, the amount of time and other resources available, and philosophical foundations (Saunders et al. 2007). A summary of different research designs that have been discussed in the literature is provided in Table 3.3.1. (Bryman, 2012; Gamage, 2011; Yin, 2009; and Tan 2002)

Table 3.3.1. Research design types

Research Design	Explanation	Form of Research Question	Generally Suitable for:
Experimental design	Used for causal research, but number of variables is small and controllable	How and why?	Exploratory, Explanatory
Survey design	Cross sectional design: Entails the collection of data on more than one case and at a single point in time; quantifiable data in connection with two or more variables	Who, what, where, how many, and how much?	Descriptive, Exploratory, Correlation and Interpretative
	Longitudinal design: Sample is usually surveyed on at least more than one occasion		
Case study design	A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between a phenomenon and its context are not evident	How, why, and what?	Exploratory, Explanatory and Descriptive
Other designs	Comparative: Seeks to explain differences between two or more groups	Why and how?	Explanatory - differences
	Grounded theory: Seeks to empirically collect data to build a general theory that fits the data	Why and how?	Explanatory, Exploratory
	Ethnography: Seeks to study a particular cultural group or phenomenon	What and why?	Exploratory, Descriptive
	Archival analysis: Seeks to understand or draw lessons about past to present and future.	How, what and why?	Exploratory, Explanatory

Source: Bryman, 2012; Gamage, 2011; Yin, 2009; and Tan 2002

Exploratory: defining questions and hypotheses for a further study; Descriptive: giving a complete description of phenomenon within its context; Explanatory: explaining what causes/produces effects. Table 3.3.2 illustrates the typical form of research strategies related to each research designs in Table 3.3.1.

Table 3.3.2. Typical form of research strategies

Research Design	Research Strategy (typical forms)	
	Quantitative	Qualitative
Experimental design	Most research using an experimental design employs quantitative comparisons between experimental and control groups with regard to the dependent variable	No typical form. However, qualitative data on a qua-experimental research
Cross sectional survey design	Survey research or structured observation on a sample at a single point in time. Content analysis on a sample of documents	Qualitative interviews or focus groups at a single point in time. Qualitative content analysis of a set of documents relating to a single period
Longitudinal survey design	Survey research on a sample on more than one occasion, as in panel and cohort studies. Content analysis of documents relating to different time periods	Ethnographic research over a long period, quantitative interviewing on more than one occasion, or qualitative content analysis of documents relating to different time periods
Case study design	Survey research on a single case with a view to revealing important features about its nature	Intensive study by ethnography or qualitative interview of a single case
Comparative	Survey research in which there is a direct comparison between two or more cases, as in cross-cultural research	Ethnographic or qualitative interview research on two or more cases
Grounded theory	N/A	Involves observation techniques, in-depth in person or focus group interviews
Ethnography	N/A	Involves multiple forms: observation, documents, people, events, artefacts or fieldwork, unstructured interviewing.
Archival analysis	Document surveys	Examines contents and historical data in the form of accumulated documents or archives

Source: Bryman, 2012; Gamage, 2011; Yin, 2009; and Tan 2002

Two research strategies in construction and management studies, which are used in this research, are survey and case study.

Survey:

Surveys are popular strategies in management research and are conducted using data collection methods such as questionnaires (Saunders et al., 2007).

***Case study*:**

Case study is an empirical investigation of an existing phenomenon within its real-life context, particularly when the boundaries between phenomenon and context are not obvious (Yin, 2009). This method is often used in explanatory and exploratory research (Gerring, 2007; Saunders et al., 2007).

Table 3.4 shows the research designs weaknesses and the data collection methods related to each one (Blaxter et al., 2010; Fink, 2010; Yin, 2009; Gerring, 2007; Saunders et al., 2007).

Table 3.4. Research design methods and weaknesses

Research design	**Data collection methods**	**Weaknesses**
Survey	• Questionnaires • Structured or semi-structured interviews • Structured observations methods	• Surveys do not illustrate causality, especially opinion surveys • Progress could be delayed due to dependency on others' responses for information • There are problems with issues of truthfulness and accuracy due to difficulties in first-hand checking and the understanding of respondents
Case study	• Observation, • Interviews, • Questionnaires, • Reports and archival records	• Complexity of a case can make analysis difficult • Difficulties in assessing where the context begins and ends • Difficulties in generalising findings

Source: extracted from literature

3.6. Data Collection Methods

According to Blaikie (2000), Table 3.5 illustrates the data collection methods for each type of data.

Table 3.5. Data collection methods for each type of data

Type of data	Methods to produce data
Quantitative	Structured observation Questionnaire (self-administered) Structured interview Content analysis of documents
Qualitative	Observation (unstructured participant) Interviews (semi-structured and unstructured) Oral/life histories Focus group interviews Content analysis of documents

Source: extracted from Blaikie (2000)

The data collection method adopted is directly related to the required scope and depth of study. The choice is between narrow and deep study, a broad but shallow study, or a middle position as indicated in Fig. 3.1.

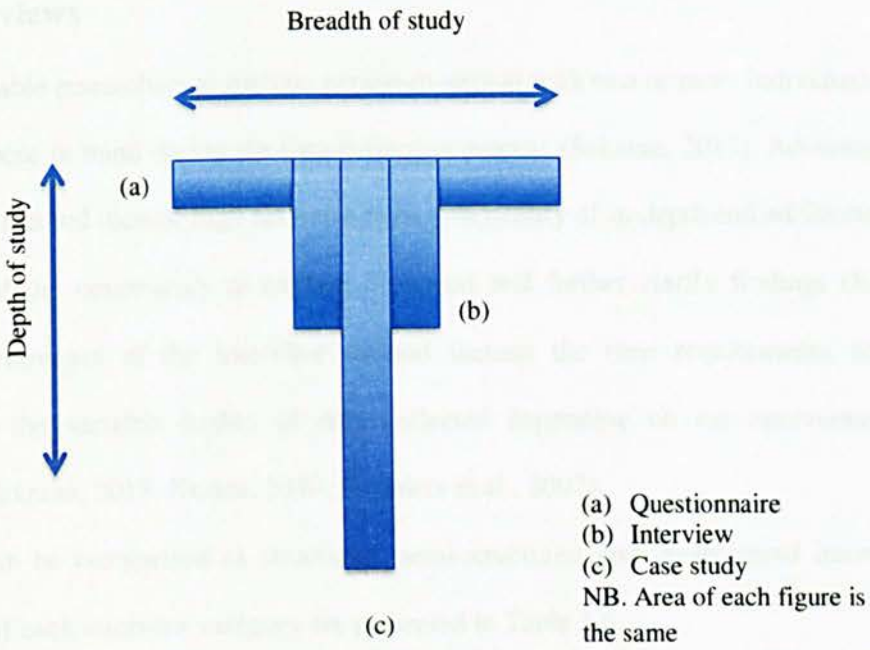


Fig. 3.1. Breadth vs. depth in studies (Source: Fowler, 1984)

3.6.1. Questionnaires

Questionnaire is a popular type of survey and includes a set of questions used to collect data. Questions take two primary forms – open or closed (Fowler, 1984). Questionnaires are appropriate in descriptive or explanatory research (Saunders et al., 2007). Questionnaires can be self-administered and conducted in person, over the phone, or online (Bernard, 2012). Questionnaires are also categorized by the method of administration such as mailed, collective administration, and administration in public places (Saunders et al., 2007). Questionnaires can ensure anonymity and are usually inexpensive (Sekaran, 2013; Kumar, 2010). However, the method has some weaknesses, including limited application, high labour intensity for respondents and the researcher, low response rates (e.g., mailed questionnaires usually have a 25-35% useable response rate), self-selecting bias, lack of opportunities to clarify issues, limited opportunities for spontaneous responses and the possibility respondents will consult others when providing responses (Kumar, 2010; Saunders et al., 2007).

3.6.2. Interviews

Interviews enable researchers to interact person-to-person with two or more individuals with a certain purpose in mind during the data collection process (Sekaran, 2013). Advantages of the interview method include high response rates, practicality of in-depth and additional data collection and the opportunity to explain questions and further clarify findings (Kumar, 2010). Disadvantages of the interview method include the time requirements, relative expense and the variable quality of data collected depending on the interviewer and interaction (Sekaran, 2013; Kumar, 2010; Saunders et al., 2007).

Interviews can be categorised as structured, semi-structured and unstructured interviews. Advantages of each interview category are presented in Table 3.6.

Table 3.6. Advantage of different categories of interviews

Category	Advantages
Structured interview	• High levels of reliability and repeatability (David and Sutton, 2004). • Provides uniform information, allowing comparisons to be made (Kumar, 2010). • Findings allow the researcher to describe or quantify certain phenomena, identify a specific problem, evolve a theory about the factors that influence the problem, and find answers to research questions (Sekaran, 2013).
Semi-structured interview	• More formal than an unstructured interview (Naoum, 2006). • At least some questions are common between interviewees for further analysis. • Maximum flexibility for opportunities to improve the data. • Interviewer can formulate questions while conducting the interview.
Unstructured interview	• Allows investigation of several that might be central to the broad problem area. • Respondents can help the researcher determine variables or issues that may need further investigation (Sekaran, 2013).

Source: Complied from literature

Interviews can also be categorised by the method of administration, into face-to-face, telephone or computer based. The advantages and disadvantage of each method are presented in Table 3.7.

Table 3.7. Strength and weaknesses of different interview administration methods

	Strength	Weaknesses
Face-to-face	Can establish rapport Enables clarification of questions, clears doubts, and allows for creation of new questions Can capture nonverbal cues Possible to use visual aids to clarify issues	Consumes personal time Expensive when wide geographic region is covered Interviewers need to be trained Can introduce interviewer bias
Telephone	Decreased cost and travel Ability to reach geographically dispersed respondents Increased interviewer safety Decreased space requirements Ability to take notes unobtrusively Permits more anonymity Allows respondents to feel relaxed and able to disclose sensitive information	Limited telephone coverage Absence of visual or nonverbal cues Risk of unilateral termination of the interview without warning or explanation Lower response rates Short interview duration compared to face-to-face interviews
Computer based	Easy to conduct Can reach globally or a wide geographical area Enhanced accuracy of collected data due to software use Helps sequence interview questions	Requires computer literacy Respondents must have access to the facility Entails heavy initial investment

Source: Sekaran, 2013; Novick, 2008

The face-to-face interview is the best method for collecting in-depth data because people are unusually honest when their opinions are asked firstly within a proper structured context, secondly, when the respondent knows the purpose of the interview, thirdly, when the questions are properly worded, and, finally, when complete anonymity is guaranteed with respect to the interviewee's responses (Bugher et al., 1999). In this research face-to-face interview method was adopted.

3.6.3. Observations

Kumar, (2010) explained that observation is a purposeful, methodical and selective way of observing and listening to an interaction or phenomenon as it implemented. Observation can be conducted to understand 'what is going on' in a process (Saunders et al. 2007). Observation can be categorised as: participant observation – (the researcher participates in the activities of those whom he is studying (Sekaran, 2013; Saunders et al., 2007) and non-participant observation – the researcher is not involved in the activities of the group and remains a passive observer (Sekaran, 2013; Kumar, 2010). Advantages of this method include the presence of the researcher in the situation and ability to observe the circumstances and activities. Disadvantages include possible change of the observed sample's behaviour due to their awareness of being observed, and bias in process or interpretation due to the observer's personality (Kumar, 2010; Saunders et al., 2007).

3.6.4. Analysis of Documents

Possible document sources for the document analysis method are: governmental and semi-governmental publications, previous research, personal records and archives, and mass media. Some disadvantages of this method are validity and reliability concerns, personal bias and the availability of data and documents (Tan, 2002).

Four types of data analysis methods are used in construction and demolition waste management research as follows: (Yuan and Shen, 2011):

1- Descriptive analysis: this method analyses data by calculating the percentages, mean values and standard deviations, and conducting statistical tests (e.g., Teo and Loosemore, 2001).

2- Simulation/modelling: this method analyses data by various mathematical modelling techniques (e.g., Hao et al., 2008).

3- Statistical analysis: this method use statistical analysis techniques such as the regression analysis (e.g., Begum et al., 2009).

4- Cost-benefit analysis: this method illustrates the costs and benefits of practices (e.g., Begum et al., 2006).

3.7. Adopted Research Strategy

The use of qualitative and quantitative techniques together is usually very powerful to achieve insights and results, to make suggestions or inferences, and to draw conclusions. The use of quantitative and qualitative methods together exploits the strengths of both and covers the weakness of one approach with the other one (Creswell, 2013). Also According to Yuan and Shen (2011), most published papers about construction and demolition waste management between 2000 and 2009 adopted one of four types of research methods:

1- Survey: questionnaires or conducting face-to-face interviews with industry specialists (e.g., Begum et al., 2007).

2- Case study: studying one or more construction projects (e.g., Roussat et al., 2009).

3- Review: to provide insights and critical analyses of the literature on a specific topic (e.g., Tam and Tam, 2006) or to illustrate the construction and demolition waste management practices in a city or country (e.g., Fatta et al., 2003).

4- Experiment: mainly conducted to study construction and demolition waste recycling (e.g., Correia et al., 2009).

Therefore this research employed qualitative and quantitative approaches, and a combination of both (similar to the approach that Creswell and Clark, 2010 used) using a qualitative literature review, semi-structured interviews, quantitative questionnaire surveys and a single case study observation. Further explanations about the research methodology steps are presented in section 3.6.1. This section explains how the research questions and objectives, the adopted methodology, the strategies to answer the research questions and properly address the objectives, the application of different research approaches such as the role of the researcher in the process were developed.

3.7.1. Developing the Research Objectives

This study was conducted to investigate the on-site concrete waste minimisation methods used in the UK, which could be potentially applicable in Iran. Each objective was produced to clarify the purpose and direction of the research (Saunders et al. 2009). The above-mentioned objectives also were tested against SMART test requirements to check if they were Specific, Measurable, Achievable, Realistic and Timely (Maylor & Blackmon in: Saunders et al., 2009). Table 3.8 explains requirements for each concept of the test.

Table 3.8. SMART test concepts and requirements

SMART test concept	Requirements to be met
Specific	The objectives must precisely indicate what is intended to be achieved by the research.
Measurable	The objectives must be appropriately measurable to conclude if they have been achieved or not.
Achievable	The objectives must be achievable according to existing constraints or restrictions.
Realistic	The objectives must fit with the researcher's abilities.
Timely	The objectives must fit with the research time frame.

Source: Saunders et al. 2009.

Based on the explanations of strategies in section 3.2, a mixed strategy was used in this research to cover different aspects and get the benefits of both the qualitative and quantitative methods. Also, because the findings of each objective were required to develop the consequent step and achieve other objectives, a sequential approach was adopted. Table 3.9 illustrates the adopted approach for each of the research objectives and the rationale for the choice.

Table 3.9. Adopted research approaches for achieving the research objectives

Research Objective	Data format	Data collection method	Rationale
(1): To identify the common methods of on-site concrete waste minimization in the UK.	Qualitative	Semi-structured face-to-face interview	Most on-site concrete waste minimization methods were identified through the literature review. However, the purpose was to explore all existing methods, which were confirmed by the professionals in construction industry. Therefore, a purposeful sample and an approach based on individual interpretation rather than quantification was chosen. Also according to Tables 3.6 and 3.7 Semi-structured face-to-face interview was adopted.
(2): To rank on-site concrete waste minimization methods in UK. (3): To rank on-site concrete waste minimization methods in Iran.	Quantitative	Questionnaire	The purpose was to determine the most suitable and preferred methods in each country. Use of a quantitative approach was required for valid and replicable results. Also according to Tables 3.1 and 3.5, questionnaire survey was adopted.
(4 To identify differences between common methods of on-site concrete waste minimization in the UK and in Iran and explore the possible causes of these differences.	Qualitative	Semi-structured face-to-face interview	To compare the methods in the UK and Iran, and to determine the reasons or causes for differences between common methods. Also according to Tables 3.6 and 3.7 Semi-structured face-to-face interview was adopted
(5) To investigate the causes of differences between the best methods in the UK and in Iran.	Quantitative Qualitative	Observation, Interviews, Reports and archival records	The best way to conduct an in-depth study to confirm or refuse the points, which interviewees for objective 4 had mentioned was to conduct a case study.
(6) To develop and validate OCWMF for Iran	Quantitative Qualitative	Validation questionnaire Validation interviews	The purpose was to determine the best way to propose the possible remedies for improving on-site concrete waste minimisation in Iran.

Source: Author

3.7.2. Research Structure

Since a sequential mixed method was selected, it was essential that a proper research structure be determined. The structure needed to properly clarify the research steps and procedures and illustrate how the outcomes of each step would be used in the next steps. To achieve these requirements, the research structure was formed as in Figure 3.2.

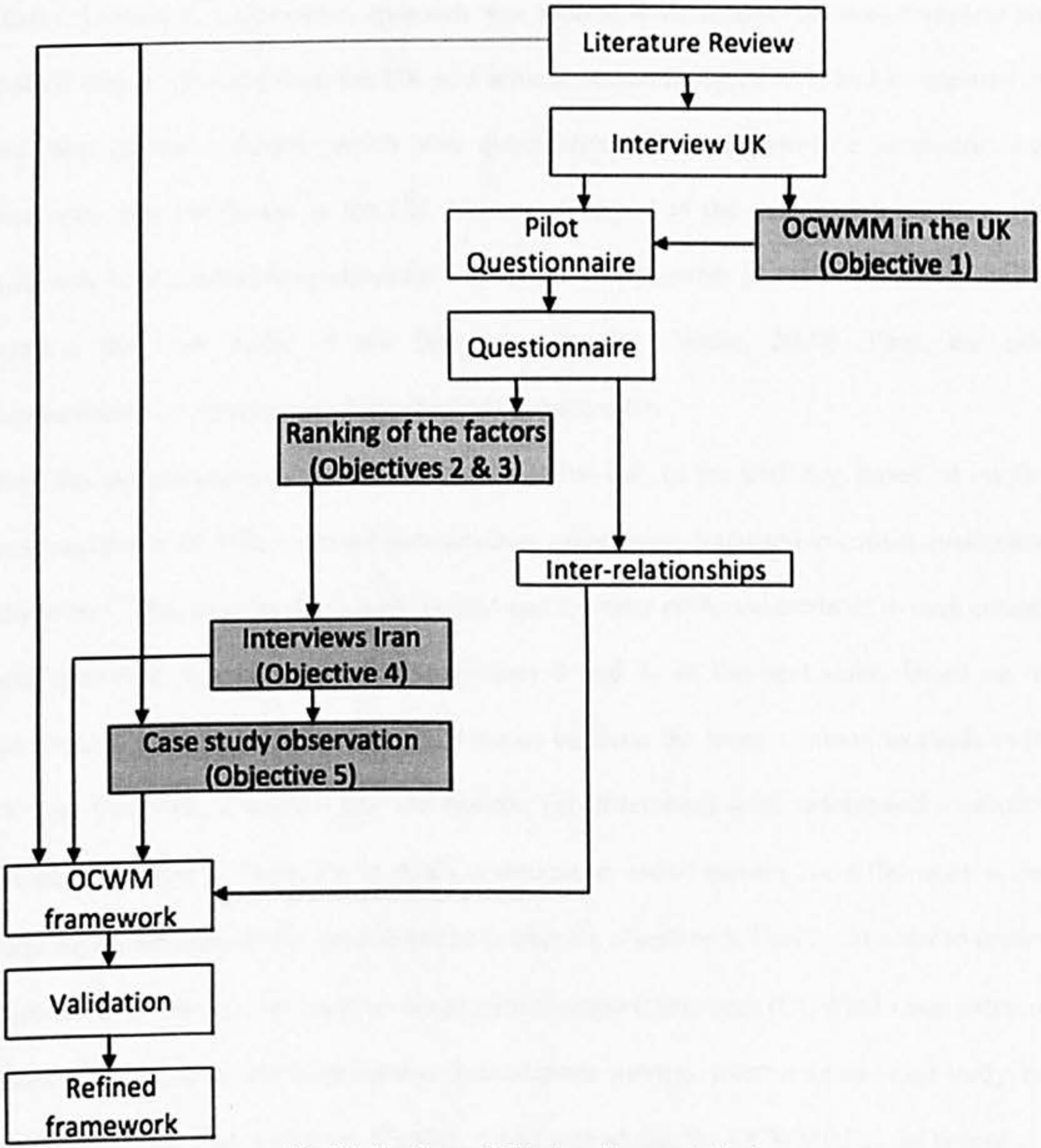


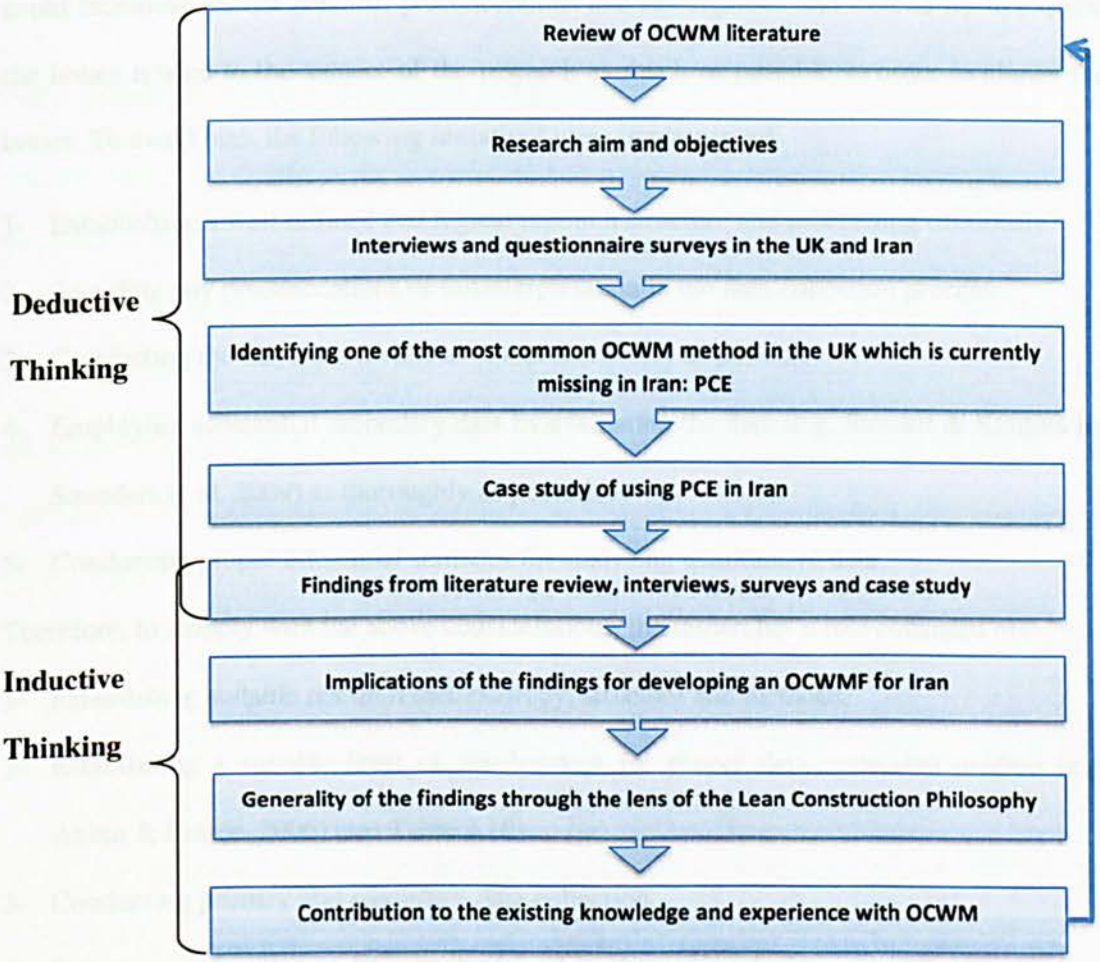
Fig. 3.2. The Research Structure (Source: Author)

The research began with an exploratory stage to collect data with qualitative methods so a follow-up quantitative approach could be developed (Creswell & Clark, 2010). The research began with a qualitative approach to produce a relatively in-depth understanding about the subjects. The qualitative approach could then improve and correct the author's initial assumptions about the research question and its objectives (Willig & Maidenhead, 2008). The extracted data from the literature review was global in nature and was selected from different sources and then compiled (e.g. Osmani, 2012; Saghafi and Teshnizi, 2011;

Weisheng et al, 2010; Kofoworola and Gheewala, 2009; Bakhtiar, 2008; De Silva and Vithana, 2008; Esin and Cosgun, 2007; Poon, 2007; Tam, 2007; WRAP, 2007; Poon et al., 2004b). Therefore, a qualitative approach was applied to determine the most complete and updated data as possible from the UK and achieve research objective 1, and to improve the next step of the research, which was quantitative. Thus, face-to-face semi-structured interviews were conducted in the UK. Next, with regard to the quantitative phase, a pilot study was conducted to help eliminate uncertainties or possible issues in the survey and to examine the time frame of the final questionnaire (White, 2000). Thus, the pilot questionnaire was improved to form the final questionnaire.

Then, the questionnaire survey was conducted in the UK. In the next step, based on the first questionnaire in the UK, a second questionnaire survey was conducted to collect quantitative data in Iran. The listed methods were ranked and the most preferred methods in each country were identified to achieve research objectives 2 and 3. At the next stage, based on the outcomes of the questionnaires, the differences between the most common methods in the UK and Iran were discussed and the reasons for differences were determined to achieve research objective 4. Then, for in-depth investigation about reasons for differences, a case study was conducted in Iran to achieve the research's objective 5. Finally, in order to achieve objective 6, an on-site construction waste minimisation framework (OCWMF) was extracted from the outcomes of literature review, questionnaire surveys, interviews and case study, and the OCWMF was then validated. Further, it was argued that the OCWMF has the potential to serve as a tool for implementing lean construction thinking at construction projects in Iran. As such, generality of the findings arising from this research was discussed in Chapter 8 in detail, embedding the outcomes of the research within the so-called lean construction philosophy. In doing so, it was seen that the premise underlying the OCWMF is in line with the ideal of the lean construction philosophy that is to minimise waste and maximise value of construction project by systematically applying a method to the project delivery system that fulfils the ideal above in a cost-effective and timely manners (Lehman and Reiser, 2000). Finally, contribution of this research to the existing knowledge was discussed.

As a short hand, the present research employed a sequential mixed approach as illustrated in Figure 3.3.



OCWMF = On-site Concrete Waste Minimisation Framework; PCE = Pre-fabricated Concrete Elements

Fig. 3.3. The sequential mixed approach to the present research (Source: Author)

Further explanations about each of the steps illustrated in Figure 3.3 are provided in the following sections. Meanwhile, a critical concern was determining adequate timing for the required actions for achieving the objectives. The research involved several time-consuming steps such as the case study via observations, questionnaire survey and interviews; therefore proper time schedules were established for the different steps. This scheduling was implemented according to the overall time frame of the research.

3.7.3.Role of the researcher

The researcher has approximately 10 years of field experience, including participation in several infrastructure projects. This allowed time to be saved and reduced the time spent for understanding project and organization level issues such as contractual relationships, and construction activities and methods. As Saunders et al. (2009) noted, the researcher should avoid including his/her personal preconceptions and assumptions and instead try to explore the issues related to the subject of the research as much as possible in order to clarify the issues. To avoid bias, the following initiatives were implemented:

1- Establishing a well-defined and logical research structure and proceeding cautiously.
2- Avoiding any preconceptions or misinterpretation in the data collection process.
3- Conducting the literature review as comprehensively as possible.
4- Employing substantial secondary data by evaluating the data (e.g. Stewart & Kamins In: Saunders et al. 2009) as thoroughly as possible.
5- Conducting proper inferential statistics for analysing quantitative data.

Therefore, to comply with the above considerations, the researcher's role consisted of:

1- Establishing suitable research methodology, structure and methods.
2- Establishing a suitable level of involvement for proper data collection method (e.g. Axinn & Pearce, 2006) (see Table 3.10).
3- Conducting primary and secondary data collection.
4- Selecting proper data analysis methods and conducting analysis.

Table 3.10. Level of researcher involvement in data collection

Data Collection Method	Necessity of Involvement	Level of Involvement
Survey	Usually	Low
Semi-structure Interviews	Always	High
Historical/Archival Document Review	Out of researcher's control	Low

Source: Axinn & Pearce, 2006.

Furthermore, because of confidentiality issues and difficulty accessing some sources such as senior managers or executives, access to required data is sometimes an easy task in management research (White, 2000). In this regard, the researcher's experience, communication skills, and contacts in the construction industry in Iran helped him to collect the required data through case study, questionnaire survey and interviews, particularly in Iran.

3.8. Adopted Data Collection Methods

As previously mentioned, both quantitative and qualitative methods and a sequential-step structure were adopted to achieve the research objectives. The quantitative and qualitative data (both primary and secondary) were collected independently because the research involved sequential, independent objectives, which were achieved through separate qualitative or quantitative approaches in different stages (see Creswell and Clark, 2010). Saunders et al. (2009) specified three important considerations for selecting the appropriate primary data collection method:

- No data collection method is inherently inferior or superior. What gives distinction to a method is whether it enables the researcher to properly answer the research questions or achieve the research objectives.
- Methods are not mutually exclusive and can be used together or as a part of each other.
- Although some methods are typically associated with particular methodology, allocating one method to a particular methodology is improperly naive and the choice of method should be based on its application.

Based on the above-mentioned issues, the proper data collection methods for achieving the research objectives were initially determined according to firstly, type of data and the desired outcomes, secondly, application of the methods, thirdly, characteristics of the methods, fourthly, timing and other resources criteria, and, finally, required level of researcher's involvement in the process. Applications and characteristics considered when using different methods in this research are presented in Table 3.11.

Table 3.11. Applications and characteristics of data collection methods

Data Collection Method	Application	Characteristics
Interview	To answer 'how', and 'why' questions	Deductive approach Can be used to collect qualitative data Planning and literature searching critically required Great control of the research process such as sample selection and the context required Difficult to establish external validity
Survey	To answer 'who', 'what', 'where', 'how much' and 'how many' questions To suggest possible reasons for particular relationships To produce models of relationships To describe or explain some aspects of a population	Deductive approach Appropriate for collecting quantitative data Allows the collection of a large amount of data from a sizeable population in a very economical way Outcomes can properly represent the whole population
Case study	To answer 'what', 'how', and 'why' questions For an empirical investigation of a particular phenomenon To obtain an in-depth understanding of the context of research To conduct an extensive study of a single situation.	Deductive and inductive approach Little control must be implemented in the process Proper compatibility within complex situations or when many different issues are involved. Ability to employ a variety of different data collection techniques Economical Looks at a real situation Capability to see the whole situation and inter-relations.

Sources: Saunders et al. 2009; White, 2000.

The secondary data included project reports, quantity bills and project meeting records and were used for the case study. The main reasons for using such data were that they were permanent, contextual data and saved time (Saunders et al. 2009). The data collection methods used to achieve each of the research objectives are illustrated in the next Six sections 3.7.1, 3.7.2, 3.7.3, 3.7.4, 3.7.5 and 3.7.6.

3.8.1. Interviews in the UK (Research objective 1)

Identification of the common methods of on-site concrete waste minimization in the UK was the first objective of the research. A list of on-site concrete waste minimization methods was produced by conducting a comprehensive literature review. To prepare a proper all-inclusive list of methods for use in the next stage of research (quantitative data collection), semi-structured face-to-face interviews were conducted. As King, (2004) noted, when exploratory work is required before quantitative research can be conducted, or when quantitative research has been conducted and qualitative data are required for validation or to illuminate the findings, interviews are the most appropriate method. Although to achieve objective 1 complementary methods (see section 3.2.3) were integrated, for collecting quantitative data semi-structured face-to-face interviews were conducted in accord to Table 3.9. Therefore practical recommendations and initiatives identified to eliminate the common methods of on-site concrete waste minimisation, which were recognized through literature review. The survey method was adopted for a few semi-structured interviews (Saunders et al. 2009). The reason for adopting this data collection method was to conduct a relatively in-depth exploration to identify professional opinions and collect comprehensive data as well as to provide opportunity to compare the responses, as Bryman, (2009) suggests. Therefore, by conducting semi-structured interviews, it was possible to comply with all of the above-mentioned considerations. The following considerations were made when conducting the interviews (Saunders, Lewis, and Thornhill, 2009):

- Informing the participants about the questions and the subjects of the interview before the sessions;
- Asking clear and open-ended questions;
- Recording by note taking.

Appendix (1) provides a list of the related documents used in interviews in the UK.

Interviews' aims

The aim of the interviews was to identify the common methods for on-site concrete waste minimisation in the UK in order to have most updated information about current methods used by construction companies. The aim was to compile a complete list of existing, on-site concrete waste minimization methods to improve the questionnaire. Although most of the methods were identified in the literature review, face-to-face interviews were implemented to increase confidence that the most complete, recent and updated data were acquired. Such interviews added depth to the study (Saunders et al, 2009) and revealed the most reliable, viable, and doable current methods. Moreover, the results of this stage were allocated in the questionnaire in the next stage of research.

Interview template

The interview template contained three sections:

- Section 1) Background information of interviewees (6 questions);
- Section 2) Existing policies and legislation of on-site concrete waste minimization (3 questions);
- Section 3) Existing methods of on-site concrete waste minimisation and recommendations regarding these (2 questions).

Questions in Section three were open-ended. Questions in Sections 2 and 3 were directly related to the findings of the literature review. The final version of the two-page interview template was finalized with a pilot study and subsequent revision.

Interview sampling methods

Having said the purpose of the present interviews was to have very initial judgment from the professionals of construction projects on the outcomes from literature review. With this purpose, the specific goal of the interviews was to complete the list of the OCWM methods already used in the UK, which was extracted by the researcher during the literature review.

According to Bryman (2012) and Van Tulder (2008), the sample sizes for the interviews with the purpose of complementing the literature review vary considerably depending on the resources available. For this research, limited resources, particularly time and budget, were available to conducting the interviews. That is, there was only one interviewer (the researcher) and large number of qualified professionals for the interviews. With this regard, conducting one-to-one interviews with all these qualified individuals was realised as very demanding exercise due to the lots of time needed, the budget needed, as well as difficulty of taking notes from the large number of interviewees, and then sorting the notes for further exercise of analysis.

To deal with the above-mentioned limitations, purposive non-random sampling method was employed to select interview participants. According to White (2000) and Saunders et al. (2009), purposive sampling is used when there is a specific reason for selecting a certain participant in a study in order to retrieve the relevant data to meet the research objectives. In practice, it was attempted to identify the potential interviewees by their background searched through their companies' web sites. In doing so, senior managers or executives of companies with sufficient and reliable knowledge, experience and success in the construction projects were identified. The companies were chosen from a list of the 100 leading construction companies, 100 leading homebuilders and 100 leading consulting firms in the UK.

Then, the profiles of the all identified individuals were checked to determine whether they met a set of criteria. By the criteria set, the potential interviewees should be the individuals who had recently been involved in at least one multiple-story, concrete structure building project, had more than 20 years of experience in the construction industry, and had proper, up-to-date knowledge about construction waste management strategies, so they could give judgment to the outcomes from literature review, and to complete the list of the current OCWM methods in the UK extracted through the literature review. By removing the individuals who did not completely meet the mentioned criteria, 15 candidates were selected. After corresponding with the 15 potential interviewees, five individuals agreed to participate in interviews.

As Van Tulder (2008) and Bryman (2012) suggested, the following advantages of face-to-face interviews were taken through the interview process in order to reduce the bias about small number of interviewees:

- Interviewer could make sure that right person has been selected as interviewee;
- Interviewer could answer interviewees' questions, and clarify any ambiguity that might arise during the interview;
- Interviewer could make sure that interviewee properly understood the questions, as well as answered the questions that have been formulated in advance; and
- Face-to-face interview provided opportunity for probing and prompting.

During the interviews, the participants were asked to express their understanding of and experiences with approaches to minimising concrete on-site waste, and give their judgment to the outcomes from literature review. The interviewees generously shared their knowledge and experience with the researcher, and provided in-depth understanding about possible and existing OCWM methods. Data was recorded through note taking, with a focus on capturing key points addressing the most common OCWM methods in the UK and Iran.

After all above-mentioned considerations, including the resources available to conducting the interviews, criteria set to identify the potential interviewees, sampling method used to select the interviewees, availability of interviewees, and administration of the interview process, the researcher realised that the outcomes from the five interviews fulfilled the goal of the interviews that was to identify as many OCWM methods as possible.

As such, the interviews resulted in to determine the most complete and updated data as possible from the UK, and helped to achieve research objectives 1, aiming to complement the literature review. While most of the OCWM methods in use in the UK had already been extracted by the researcher prior to the interviews, the outcomes from the interviews led to complete the initial list of the OCWM methods identified through the literature review. Besides completing the literature review, the outcomes from the interviews yielded to improve the further step of the research, in which the OCWM methods raised from the literature review and the interviews were ranked by the participants in a questionnaire survey conducted in the UK.

Interview process

To enhance clarity of the questions, check the time required for answering the questions, and conduct a practice session prior to actual interviews, two pilot interviews were conducted with construction managers who were graduates of the Department of Civil and Building Engineering. To allow the interviewees to prepare for the interview and collect relevant data, the interview schedule, a participant information sheet and a consent form were sent to the interviewees (Fowler, 2008). The schedule included aim and objectives, an agenda and questions. The participant information sheet included contact information for the researcher, a brief explanation of the research, sampling methods and ethical considerations. The consent form was signed by the researcher and each interviewee. All documents were approved by the Kingston University Ethical Committee. Samples of interview documents are available in appendix 2. The interviews were designed to last 45 minutes. Five interviews were conducted over approximately five weeks during November and December 2012. Figure 3.4 presents the interview process.

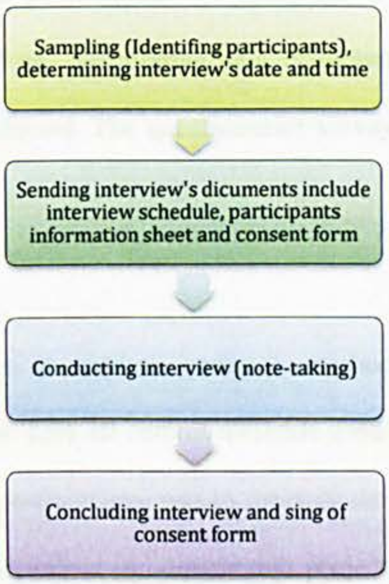


Fig.3.4. Interview process

Data analysis methods

For research objective 1, the first aim was to compile a list of common on-site waste minimisation methods in the UK through qualitative data collection methods. The emphasis was on deductive methodology through conceptualization (Saunders et al., 2009). According to Tesch (In: Saunders et al. 2009), this consideration involves the following three analysis methods:

- Comprehending the meaning of data;
- Discovering regularities;
- Reflection.

These techniques were used for data unification and recognition, developing the categories and drawing and verifying conclusions (Saunders et al. 2009). Moreover, because this stage of research was designed to identify as much on-site concrete waste minimization methods as possible, every additional method added to the list of methods for the next stage of the research, which was questionnaire survey.

3.8.2. Questionnaire for the UK (Research objectives 2)

It was determined that objectives 2 and 3 would be achieved through subjective assessments based on judgments from the professionals of construction projects. The aim here was quantification of data. Therefore, quantitative data collection methods were applied and questionnaire survey was conducted. The questionnaire survey in the UK was conducted to achieve the objective 2.

Questionnaire's aims

The questionnaire was aimed to explore common methods of on-site concrete waste minimisation in the UK, and to rank all current methods used in construction projects in the country. The purpose of the questionnaires was to measure the importance of each method in terms of price and their effectiveness in construction projects. This aspect of the research was conducted because of a lack of reliable published information. Quantities and percentages were calculated from responses. An additional aim was to collect possible comments and recommendations from professionals of construction projects (contractors, engineers, and consultants).

Questionnaire design and development

According to Saunders et al. (2009) and White (2000), general considerations applied in design of the questions were:

1- Using simple and easy to understand questions and constructing a logical order of the questions.
2- Creating compatibility between the outcomes of questions and the adopted data analysis techniques.
3- Including a cover letter with the questionnaire that provided a brief introduction to the research and the researcher's contact information.

Some issues that were considered for designing the questionnaire according to Saunders et al., (2007) point were:

- Respondents' characteristics;
- Importance of choosing a specific person as respondent;
- Importance of proper storage of respondents' answers (no contamination or distortion);
- Sample size;
- Proper types of questions to collect required data;
- Proper number of questions to collect required data;
- Time availability and requirements to collect data;
- Financial implications of data collection and entry;
- Ease of data entry.

In addition to general considerations, the format and administration of the questions was determined based on the following points:

1- For research objective 2, closed questions were prepared to collect appropriate and easy to compare responses.

2- For research objective 2, a method based on a five-point numeric rating scale was adopted to obtain experts' opinions about the level of agreements or to discover how strongly respondents held their views. The odd-numbered response scale permitted genuine 'centrality' to be accurately represented. In the questionnaire, the opportunity for respondents to note their own items not appearing on the list, as "Other, please note" was included. In this scale, number 1 represents the lowest level of importance and number 5 represents the highest level. This range of the scores creates a proper scale for respondents to express the importance of different methods.

The questionnaire was disseminated to top UK construction contractors and consultants (similar to Osmani et al., 2007). The final questionnaire includes eight multiple-choice questions. The results of the questionnaire are presented in the Chapter 4 of the thesis.

The Questionnaire contains two sections:

- Section 1) Interviewees' background information (4 questions);
- Section 2) Existing methods of on-site concrete waste minimisation and any recommendations (4 questions).

The questionnaire form is available in Appendix (2).

Population criteria

The elements or units from which data were collected through questionnaire survey were the points of view on the OCWM methods expressed by the professionals of construction projects in the UK. In other words, the universe of individuals from which the points of view on the OCWM methods were collected through the present questionnaire survey included consultants, general contractors' project managers and site superintendents who had recently been involved in the works executed at multi-story concrete structure buildings, with sufficient and reliable knowledge, experience and success in the construction projects. Therefore, the questionnaire survey population consisted of the aggregation of these professionals. Participants in the questionnaire survey were chosen from the top 100 construction contractor companies and the top 100 consultant companies in the UK. This variety of participants was used to obtain different opinions of stakeholders involved in the construction industry in the UK and create the same population as participants in the survey in Iran. Moreover, such a population helped to deliver the best possible knowledge to achieve the most appropriate research objectives (White, 2000). The specific population criteria (Eisenhardt and Graebner, 2007), as in Iran, were: (1) holding a managerial or directory position and (2) having been involved in multi-story concrete structure development projects. These criteria were determined to minimise sample frame bias (White, 2000) and researcher tendency bias (Burton-Jones, 2009). However, the population of construction contractors and consultants in the UK and Iran may not be equal as the population size was determined according to the population in Iran. Therefore, this could create bias. However this could lead to a minor bias as both sampling methods in the UK and Iran were probability approaches.

Sample frame and sample size

To create a valid sample that represents the population as described earlier, a primary list of qualified individuals was compiled. This list was used as the research sample frame to choose a representative sample (Saunders et al. 2009).

A list was created using the following directories:

- Top 100 leading construction contractors companies in the UK;
- Top 100 consulting companies in the UK;
- Lists of on-going concrete structure developments in the UK.

In the next step, all the individuals from the primary list were checked to determine whether they met the population criteria. By removing individuals who did not completely meet the population criteria, the final list of the sample frame was produced. Thereupon, a list of 198 qualified individuals was compiled.

Table 3.12. Numbers of individuals in the research sample frame

Contractor's project managers	Site superintendents	Project consultants	Engineers	Total
48	51	50	49	198

Source: Author

After identifying population size for the present questionnaire survey, following Miaoulis and Michener (1976), three criteria were then specified to determine the appropriate sample size: the level of precision, the level of confidence, and the degree of variability in the points of view of the qualified participants on the OCWM methods in question. For this research, the level of precision was determined at ±5%, that is, the range in which the true value of the population was estimated to be (Salant & Dillman, 1994; Dillman, 2000, 2007). Furthermore, it was desirable to have as number as participants that allow the researcher to be 95% confident about the estimates from the data within ±5% of the survey population. Moreover, the researcher had no idea about the diversity of opinions among the potential participants prior to conducting the survey, and therefore followed a suggestion offered by Dillman (2000, 2007) in taking a conservative 50/50 split approach to determining sample size for the questionnaire survey. Although the population size 198 were primarily identified, in order to be in the safe side more than 200 individuals were considered as qualified for the present questionnaire survey.

Table 3.13 published by Dillman (2000, 2007) and Salant and Dillman, (1994) informs the sample size for combination of the three criteria above, including precision, confidence levels, and variability.

Table 3.13. Sample sizes needed for population sizes regarding three criteria of precision, confidence level and variability

Population Size	**Sample size for the 95% confidence level**					
	± 3% sampling error		**± 5% sampling error**		**± 10% sampling error**	
	50/50 split	**80/20 split**	**50/50 split**	**80/20 split**	**50/50 split**	**80/20 split**
100	92	87	80	71	49	38
200	169	155	132	111	65	47
400	291	253	196	153	78	53
600	384	320	234	175	83	56
800	458	369	260	188	86	57
1,000	517	406	278	198	88	58
2,000	696	509	322	219	92	60
4,000	843	584	351	232	94	61
6,000	906	613	361	236	95	61
8,000	942	629	367	239	95	61
10,000	965	640	370	240	95	61
20,000	1,013	661	377	243	96	61
40,000	1,040	672	381	244	96	61
100,000	1,056	679	383	245	96	61
1,000,000	1,066	683	384	246	96	61
1,000,000,000	1,067	683	384	246	96	61

Sources: Dillman, 2000, 2007; Salant & Dillman, 1994

With regard to the level of precision at ±5%, the level of confidence at 95%, and the degree of variability in the participants' points of view on the OCWM methods determined for the present questionnaire survey, Table 3.13 informs the sample size of 196 participants for the survey. A total number of 196 questionnaires were then sent to the email addresses of individuals, randomly selected from the list of qualified professionals. Probability random sampling was employed to select the participants. The email addresses of the potential participants were found from their companies' web sites or by contacting the companies by phone. Although it might be some minor errors due to lack of published information in the companies web sites or Internet, this did not affect the research objective (as sampling method was probability sampling).

Sampling technique

Sampling is used to predict the behaviour of a population as accurately as possible. However, this raises the issue of possible errors because results are obtained from analysing a sample instead of the entire population. The probability sampling method was used for this research because it is required to carry out statistical analysis (White, 2000). Furthermore, to have appropriate number of participants, a representative sample was required to generalise the outcomes (Saunders et al. 2009). Different categories were included in the research population in an attempt to consider differences in the opinions of individuals. As a result, a stratified random method was adopted for sampling to create a more representative sample. To select participants from each stratum, a simple random sampling technique using random number tables was adopted. This technique was compatible with the adopted probability sampling methodology (Saunders et al. 2009).

Table 3.14 illustrates the final numbers of individuals selected for the four different categories of the research sample frame.

Table 3.14. The number of participant randomly selected from four strata of qualified individuals

Contractor's project managers	Site superintendents	Project consultants	Engineers	Total
49	53	48	46	196

Questionnaire pilot study

To improve the questionnaire, fill in gaps and determine the time required for completion, pilot questionnaires were administered. To do so, five participants were chosen with characteristics similar to the survey population. This number of participants was determined regarding the resources (budget, time and person) available to carrying out the questionnaires pilot study. As White (2000) suggested, the pilot study was conducted to help eliminate uncertainties or possible issues in the questionnaire survey. As a result, the pilot questionnaire was improved to form the final questionnaire.

Table 3.15 illustrates the modifications made to the pilot questionnaire, leading to produce the final questionnaire.

Table 3.15. Modifications made to the pilot questionnaire, leading to produce the final questionnaire

Item of modification	Pilot questionnaire	Final questionnaire	Rationale
Shortening some instructions	To the best of your knowledge and experience, please rate the following on-site concrete waste minimising methods in terms of cost of implementation.	Please rate the following on-site concrete waste minimising methods in terms of cost of implementation.	These sentences were unhelpfully too long in the pilot questionnaire, for which there was no real benefit.
	Please consider 1 for very expensive; 2 for expensive; 3 for neither expensive, nor cheap; 4 for cheap; and 5 for very cheap.	Please consider 1 for very expensive, and 5 for very cheap.	
Clarifying some main questions	Purchase management	Purchase management (e.g., better estimation of total concrete requirements, on-time ordering, etc.)	These modifications led to more clarity of main questions, providing respondents with some implications and/or examples of the OCWM methods in question.
	On-site inventory management	On-site inventory management (including on-site sorting of construction and demolition materials)	
	Waste prevention during on-site transport	Waste prevention during on-site transport (include use of volumetric trucks to determine the exact quantities needed)	
	Use of information technology on-site	Use of information technology on-site (e.g., BIM in order to avoid mistakes and misfit of designs)	
Revising the instruction of the time frame	The questionnaire has been designed to take approximately 10 minutes to be completed.	The questionnaire has been designed to take approximately 10-15 minutes to be completed.	The revised instruction gives a wider time frame to which respondents could adapt themselves.

Table 3.15: Continued

Item of modification	Pilot questionnaire	Final questionnaire	Rationale
Adding to the confidentiality statement	-	Data will not be stored and will be destroyed after the questionnaire result.	This sentence added to the confidentiality statement could build more trust, leading to effectively engagement of respondents.
Putting 'Other' option into background questions	What is the category of your company? There was no 'Other' option	What is the category of your company? 'Other' option was inserted.	The respondent's company might belong to the categories other than those listed in the pilot questionnaire.
Adding to the participant information sheet	-	There are no trick questions in this survey. There are no right or wrong answers. Please not that participation is always voluntary and you can withdraw your information at any point of the research and the data collected will immediately be destroyed.	These sentences added to the participant information sheet could build more trust, leading to effectively engagement of respondents.
Adding to the participant consent sheet	-	I understand that my participation is entirely voluntary, and that I can withdraw at any time without prejudice.	The sentences added to the participant consent sheet could build more trust, leading to effectively engagement of respondents.
Redesigning the rating scale	1 2 3 4 5	1 2 3 4 5 ☐ ☐ ☐ ☐ ☐	It was found easier placing a tick mark in the box designed for each point of the rating scale.

(Source: Author)

Strategies to increase the response rate

The process of sending the questionnaires out and receiving them (by mail) took six weeks. Participants were asked to complete and send back the questionnaires within 10 days of receipt. Within three days of the passed deadline, telephone follow-ups were made for candidates who had not returned a completed questionnaire. The follow-ups indicated that the deadline was extended to 10 days after the reminder mail-out. Within three days of the second deadline, a further reminder was sent with another 10-day deadline extension.

Questionnaire response rate

The acceptable response rate for the survey was adopted from Saunders et al. (2009). Accordingly, at least 60 responses from 196 potential participants were needed for a reliable survey (Saunders et al., 2009). In response, 73 qualified professionals completed the questionnaires and returned them to the researcher. Therefore, the active response rate for the survey was 37.2%.

Data storage

All completed questionnaire are stored in the researcher's private files. In addition, one electronic scan of completed questionnaires is archived in separate files.

3.8.3. Questionnaire survey in Iran (Research objective 3)

Questionnaire's aims

The aim was to discover the most preferred methods for on-site concrete waste minimisation in the Iranian construction projects by having the methods to be ranked in order to achieve the research's objective 3.

Questionnaire design and development

The same questionnaire was employed in Iran as the one used in the UK. The same general considerations of simplicity, compatibility (Saunders et al. 2009; White, 2000) were applied. A sample questionnaire and other additional documents are presented in Appendix (2). In addition to the above considerations, the following points (Saunders et al. 2009) were applied:

i. For research objectives 2 and 3, closed questions were used.

ii. To achieve research objective 3, a five-point numeric rating scale was used as well.

iii. To get a higher response rate, the "delivery and collection administration" method was also used.

Population criteria

Participants were selected from a group of professionals who were recently involved in at least one multi-story concrete frame building project. Participants were selected from those holding positions that include consultants, engineers, contractors' project managers and site superintendents. This varied population was chosen to obtain the opinions of the main professionals involved in projects and create reliable results. Moreover, this population was used to deliver the best possible variety of knowledge to achieve the research objectives as appropriately as possible (White, 2000). According to Eisenhardt and Graebner (2007), the specific population criteria were determined as: (1) holding a managerial or directory position, and (2) having been recently involved in a multi-story concrete structure development project. These criteria were determined to prevent bias due to lack of knowledge (Burton-Jones, 2009) and sample frame bias (White, 2000), and to minimize researcher tendency bias (Burton-Jones, 2009).

Sample frame

To have a valid sample that represented the determined population, a list of qualified individuals was compiled. According to Saunders et al. (2009), the list was used as the research sample frame from which to draw the representative sample.

The initial list was prepared using the following directories:

1- Iran Engineering Association;

2- Iran Association of Construction Companies;

3- Iran Association of Consulting Companies.

The next step was contacting candidates by phone or e-mail to determine if they properly met the population criteria. By removing individuals who did not completely meet the population criteria, the final list for the sample frame was produced. Table 3.16 illustrates the number of individuals in the sample frame.

Table 3.16. Numbers of individuals in the research sample frame

Contractor's project managers	Site superintendents	Project consultants	Engineers	Total
52	51	49	48	200

Source: Author

Sampling technique

A stratified random sampling method was adopted to create a more representative sample. To select participants from each stratum, random number tables were used (Saunders et al, 2009; White, 2000). This technique is well matched with probability sampling methodology (Saunders et al. 2009). Probability sampling was implemented because it was required to carry out statistical analysis (White, 2000). Furthermore, a representative sample was required to generalize the outcomes (Saunders et al, 2009).

Determining the sample size

The sample size in Iran was determined to be same as the sample size for the questionnaire survey conducted in the UK. The reason for having same number of participants in the UK and Iran was to have more accurate comparability between the outcomes of the questionnaire surveys from each country. To have the same number of participants as the questionnaire in the UK, a list of participants in Iran with relatively similar backgrounds was prepared as explained earlier.

The random sampling method used resulted in having the number of participants from four strata as given in Table 3.17.

Table 3.17. The number of participant randomly selected from four strata of qualified individuals

Contractor's project managers	Site superintendents	Project consultants	Engineers	Total
55	58	43	40	196

Source: Author

Therefore the total number of 196 questionnaires was sent to the potential participants.

Questionnaire pilot study

To check the suitability of the questionnaire for Iran, fill in gaps and determine the time required for administration, five pilot questionnaires were administered. To conduct the pilot test, five individuals with characteristics similar to the survey population were chosen. This number of participants was determined regarding the resources (budget, time and person) available to carrying out the questionnaires pilot study.

The pilot study helped eliminate uncertainties or possible issues in the questionnaire survey as the questionnaires pilot study carried out in the UK. As a result, the pilot questionnaire was improved to form the final questionnaire.

Strategies to increase the response rate

The same procedures used in the UK were adopted in Iran to collect responses. The process of sending out the questionnaires and receiving them (by mail) took ten weeks in Iran. Participants were asked to complete and send back the questionnaires within 10 days of receipt. However, the researcher expected more time would be required to receive completed questionnaires because of differences between the mailing systems in the UK and Iran. Within one day of the deadline passing, telephone follow-ups indicating that the deadline was extended to two weeks were made for candidates who had not returned a completed questionnaire. Within three days of the second deadline, a further reminder was sent out with another two-week extension of the deadline. However, after this period, the number of received questionnaires was not equal to that in the UK. Therefore, it was decided to conduct delivery and collection methods for the participants who did not response. At the end of 10th week, 110 completed questionnaires were collected.

Questionnaire response rate

Questionnaire survey administration concluded at the end of the tenth week of the survey. The acceptable response rate for the survey was adopted from Saunders et al. (2009). Accordingly, at least 60 responses from 196 potential participants were needed for a reliable survey (Saunders et al., 2009). In response, 110 qualified professionals completed the questionnaires and returned them to the researcher. Therefore, the active response rate for the survey was 56.1%.

Data analysis methods

According to Dillman (2000, 2007), in random samples, the elements or units from which data are collected serve as the units of data analysis. Having said the elements or units from which data were collected through the present questionnaire surveys were the points of view on the OCWM methods expressed as responses to questionnaires by the professionals of construction projects.

Quantitative data analysis was used to examine the responses. Since the collected data from the survey is mainly in the form of an ordinal scale, it would be analyzed based on the mean rating of responses. The results and findings would be presented in the bar chart and a summary table indicates the categories and ranking of the mean responses. The rankings compare the methods from the most to the least preferred.

The collected data for research objectives 2 and 3 were in the form of numeric data scores from one to five, which represents lowest to highest significance.

To achieve a mean rating for each method, equation (2) was applied.

The mean rating is calculated as Eq. (2) where:

W=Weight of answer choice and

X=Response count for answer choice

$$\frac{X1W1 + X2W2 + X3W3 + \ldots + XnWn}{\text{Total}} \qquad \text{(Eq.2)}$$

Using this standard and clear ranking with the clear definitions of the methods in the questionnaire reduced the possible uncertainty and inconsistency arising from the subjective expert judgment (Long et al., 2004).

3.8.4. Interviews in Iran (Research objective 4)

The purpose of the semi-structured face-to-face interviews conducted in Iran was to identify the most used on-site concrete waste minimisation methods in the country. While these methods were identified through the questionnaire survey in Iran, the specific goal of these interviews was to confirm the outcome from the questionnaire survey, with an addition goal of identifying the reasons for differences between the most favourite methods of concrete waste minimisation in the UK and in Iran.

According to Bryman (2012) and Van Tulder (2008), the sample sizes for the interviews with the purpose of complementing previous studies, such as the questionnaire surveys conducted within the present research, vary considerably depending on the resources available. For this research, limited resources, particularly time and budget, were available to conducting the interviews. That is, there was only one interviewer (the researcher) and large number of qualified professionals for the interviews. With this regard, conducting one-to-one interviews with all these qualified professionals was realised as very demanding exercise due to the lots of time needed, the budget needed, as well as difficulty of taking notes from the large number of interviewees, and then sorting the notes for further exercise of analysis.

To deal with the above-mentioned limitations, purposive non-random sampling method was employed to select interview participants. According to White (2000) and Saunders et al. (2009), purposive sampling is used when there is a specific reason for selecting a certain participant in a study in order to retrieve the relevant data to meet the research objectives. In practice, it was attempted to identify the potential interviewees by their background. In doing so, senior managers or executives of companies with sufficient and reliable knowledge, experience and success in the construction projects were identified.

Then, the profiles of the all identified individuals were checked to determine whether they met a set of criteria. By the criteria set, the potential interviewees should be the individuals who had recently been involved in at least one multiple-story, concrete structure building project, had more than 20 years of experience in the construction industry, and had proper, up-to-date knowledge about construction waste management strategies, so they could confirm the most used on-site concrete waste minimisation methods in Iran which was the outcome of questionnaire survey in the country, and to share their points of view regarding the reasons for differences between the favourite methods of concrete waste minimisation in the UK and in Iran.

After corresponding with the potential interviewees, 10 individuals agreed to participate in interviews. Interviewees were chosen from candidates from the same sample frame as the questionnaire's sample frame.

To allow interviewees to prepare for the interview and collect proper data as relevant as possible, the interview schedule, a participant information sheet and a consent form were sent to interviewees (Fowler, 2008). The interview schedule included aim and objectives, an agenda and interview questions. The participant information sheet illustrated the contact information of the researcher, a short explanation about the research, sampling methods and ethical considerations. The consent form was signed by the researcher and interviewee. All documents were in the Farsi language (All interview's documents are available in Appendix 3).

Moreover, as Van Tulder (2008) and Bryman (2012) suggested, the following advantages of face-to-face interviews were taken through the interview process in order to reduce the bias about small number of interviewees:

- Interviewer could make sure that right person has been selected as interviewee;
- Interviewer could answer interviewees' questions, and clarify any ambiguity that might arise during the interview;
- Interviewer could make sure that interviewee properly understood the questions, as well as answered the questions that have been formulated in advance; and
- Face-to-face interview provided opportunity for probing and prompting.

During the interviews, the participants were asked to express their understanding of and experiences with approaches to minimising concrete on-site waste, and generously shared their knowledge and experience. Data was recorded through note taking and audio recording, with a focus on capturing key points confirming the most used on-site concrete waste minimisation methods in Iran, and addressing the reasons for differences between favourite methods of concrete waste minimisation in the UK and in Iran.

After all above-mentioned considerations, including the resources available to conducting the interviews, criteria set to identify the potential interviewees, sampling method used to select the interviewees, availability of interviewees, preparing interviewees for interview, and administration of the interview process, the researcher realised that the outcomes from the 10 interviews fulfilled the goals of the interviews, completing the relevant outcomes from the questionnaire survey in Iran. With all these considerations, it can be claimed that the interviews resulted in to achieve research objectives 4.

Interview template

The interview template contained four sections:

- Section 1) Background information of interviewees (5 questions);
- Section 2) Existing policies and legislation for on-site concrete waste minimisation (2 questions);
- Section 3) Existing methods of on-site concrete waste minimisation and any recommendations (2 questions);
- Section 4) Reasons and causes for differences between common methods in Iran and the UK and any recommendations.

Questions contained in Sections 3 and 4 were open-ended. Questions in Section 2 and 3 were directly related to the findings of the literature review. Questions in Section 4 were extracted from the findings of questionnaires in the UK and Iran. The final version of the two-page interview template was finalized after a pilot study and subsequent revision.

Interview sampling methods

For the interviews, the same sample frame as that used for the questionnaire survey in Iran was employed. A purposive heterogeneous sampling method (Saunders et al. 2009) was used to nominate individuals who could properly answer the interview questions. It was important to conduct an in-depth study to address research objective 4. Because a non-probability method was used for sampling, the following considerations were applied:

Sample population: the same sample population as that used for the questionnaire survey was adopted.

Sample frame criteria: Interviewees possessed comprehensive knowledge and a background in management infrastructure projects so as to collect as much information as possible (Further details in section 5.3.1).

Sampling technique: from each position, at least one expert was selected whether or not s/he met the sample frame criteria.

Interview process

To enhance the clarity of the questions, check the time required for answering the questions, and have a practice session prior to actual interviews, two pilot interviews were conducted with construction managers who graduated from the Department of Civil and Building Engineering at Tabriz University/Iran and the Department of Civil Engineering at University of Science and Technology Tehran/Iran.

Interviews lasted 45 minutes. Conducting five interviews took approximately five weeks between August and October 2013. Interviews were recorded using note taking and audio recording techniques with the permission of the respondent. The interviews proceeded as explained earlier.

Data analysis methods

To achieve objective 4, the collected data were analysed in two main steps: (1) identifying the reasons for differences between the most favourite methods in the UK and Iran; and (2) conducting statistical analysis. As discussed earlier, the first critical goal to achieve objective 4 was to identify and confirm the most used on-site concrete waste minimisation methods in Iran, which was the outcome of questionnaire survey in the country. Then, reasons for differences between the most favourite methods in the UK and Iran were discussed with the participants. Next, opinions of interviewees were compared and a final list of common ideas was produced.

The collected data was analysed by following steps (Saunders et al., 2009):

- Comprehending the meaning of the data;
- Discovering regularities among the data;
- Reflection.

The above three steps were employed for data unification, developing categories and verifying conclusions.

3.8.5. Case Study Observation (Research objective 5)

Research objective 5 was to investigate the reasons for differences between the most preferred methods in the UK and the most preferred methods in Iran. Therefore (as the main reason for differences was identified to be cost related), the cost and on-site concrete waste production of three existing methods for concrete works in a construction project in Iran was observed in a case study. As discussed earlier, this part of the research aims to conduct an in-depth exploration to examine and clarify the actual reasons for differences and confirm the factors determined through semi-structured interviews in Iran. In construction management research, the case study approach is used or the following purposes (Hillebrant and Cannon, 1990):

- As a source of insights and ideas in the early stages of investigating a subject.
- To describe phenomena that do not occur regularly enough for the researcher to find a large number of participants demonstrating the phenomenon for study, for instance, particular types of construction problems.
- For project-biography, which employs theories and principles to understand the management of a project, for instance, project success factors.

Therefore a case study was obtained for this stage of the research.

Brief description of the project

The selected project was a seven-story building with a concrete frame structure in North Tehran, Iran. The contractor used three methods for casting concrete elements:

- In-situ concrete (making and pouring): for floors 5 and 6;
- Ready mix concrete: for floors 3 and 4;
- Pre-fabricated concrete elements: for floors 1 and 2.

Aims

The aim is to investigate the reasons for differences between the most preferred methods in the UK and the most preferred methods in Iran by illustrating the cost and waste production of these three methods of making and pouring concrete in a sample construction project in Tehran, Iran. These three methods include: in-situ concrete, ready mix concrete, and pre-fabricated concrete elements.

Introduction

To collect quantitative and quantitative data for this research, case study observation was conducted. One of the seven important aspects of a case study is that a data can be quantitative and/or qualitative. Such a study provides an in-depth investigation within a real-life context (Yin, R.K., 2009). Case studies involve the analysis of real world problems, which can be experienced or observed (Hong et al., 2012). The case study approach facilitates in-depth investigation of particular instances of a phenomenon.

Find and choose a suitable case

Before observation, the researcher communicated with the contractor of the project by email and phone. The contractor and client agreed on using the three methods of concrete work outlined previously. The project was a seven-story concrete structure building, which fit with the research objectives.

Determine data collecting and recording methods

Qualitative and quantitative data was collected by the researcher and recorded by digital camera and note taking. Before data collection, a consent form, information sheet and observation schedule was sent to the contractor.

The statistic and financial data was provided by the contractor-based on instruction made by the researcher. The instruction expressed which data and when should be collected. Data collected has been kept also in an electronic copy in a secure place.

Data analysis methods

To determine the total cost for each method, equations from ICBQ (2013) were used. To compare the cost of each method by percentage, normal mathematical equations were:

$$C_{TC} = C_{IN} + C_{RM} + C_P$$

$$PC_{IN} = (C_{IN} / C_{TC}) \text{ X } 100$$

$$PC_{RM} = (C_{RM} / C_{TC}) \text{ X } 100$$

$$PC_P = (C_P / C_{TC}) \text{ X } 100$$

To measure waste production, the equations below were applied:

$$W = P - BM$$

where W is amount of waste measured in cubic meters, P is the purchased amount in cubic meters and BM is the measurement of concrete works in the project's plan in cubic meters.

To calculate percentages and compare the waste production of each method, the following simple equations were used:

$$W_{TC} = W_{IN} + W_{RM} + W_P$$

$$PW_{IN} = (W_{IN} / W_{TC}) \text{ X } 100$$

$$PW_{RM} = (W_{RM} / W_{TC}) \text{ X } 100$$

$$PW_P = (W_P / W_{TC}) \text{ X } 100$$

where W_{TC} is total concrete waste, W_{IN}, W_{RM} *and* W_P are concrete waste generated from in-situ, ready mix concrete, and pre-fabricated element methods, respectively, and PW_{IN}, PW_{RM} and PW_P are percentages of waste generated by each method.

Further explanations are provided in Chapter 6. For each concrete work method, two sets of data were collected and the averages of data were used for further analysis (see White, 2000). The results were also analysed using descriptive statistics.

3.8.6. Propose a Framework in Iran (Objective 6)

The final phase of the research focussed on the development and validation of a framework to propose in Iran. Figure 3.5 illustrates the approach to OCWMF development and indicates the key stages and methods that were followed to develop the framework.

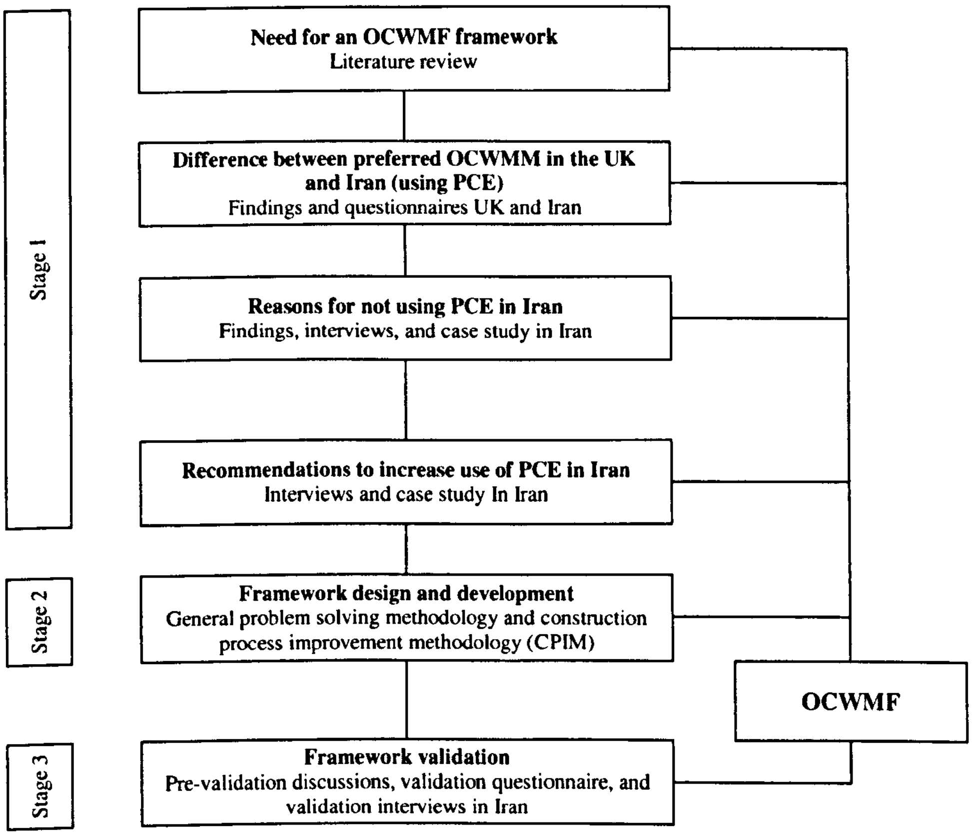


Fig.3.5. Methodological approach to OCWMF development (Source: Author)

Stage 1 was focused on content that identified a need for the OCWMF for Iran, reasons for not using PCE in Iran, and possible recommendations for increasing use of PCE in construction projects in Iran. Stage 2 was focused on OCWMF design and development. Stage 3 was aimed at OCWMF validation and recommendations for improvement.

OCWMF design and development methods

There is no clear evidence in the literature on on-site concrete waste minimisation framework of previous models. The findings of the questionnaire survey and interviews in Iran clearly suggested that there is great opportunity to develop a mechanism to minimise on-site concrete waste.

The basic concept of the OCWMF design and its structure was established based on the principles of general problem-solving methodology. Problem-solving methodology is a method that can be used to understand the problems related to a situation and explore related improvement activities (Serpell and Alarcon, 1998). The key principles of problem-solving methodology are: (1) diagnosis of current issues and (2) identification of improvement activities for those issues. The two key principals used in this research to develop the OCWMF were: (1) to identify the reasons for not using PCE in Iran; and (2) to provide possible recommendations for increasing usage of PCE in Iran. Further explanation of OCWMF design and development is provided in chapter 7.

OCWMF validation methods

Validation is a judgment process and helps to enhance the credibility of research findings. The validation process may involve collecting reviews from initial respondents at the first research. Messick (1989) stated "validation is essentially a type of scientific inquiry, that a validity judgement is an inductive summary of all available information, with issues of meaning and interpretation central to the processes" (Mishler, 1990, p.418). Thus, these views suggest that validation is a judgemental process which helps to improve credibility, explanation and understanding research findings (Gamage, 2011).

Mishler (1990, p.415) stated, "Validation is a process through which a community of researchers evaluates the trustworthiness of a particular study as the basis for their own work". Bernard (1994) argued that validation is the collective judgement of the scientific community about the validity of a particular concept and its measures. Validation process also can involve getting reviews from respondents those who responded at first place for the research (Patton, 2003; Lincoln and Guba, 1985). Moreover, if respondents are provided an opportunity to examine and comment on research findings, researchers can improve the accuracy, completeness, and fairness of the final research outcome (Patton, 2003). Researcher's value and decisions involve in the theme identification process. As such there is always ground for arguments on the validity of identified themes and arrived conclusions (Ryan and Bernard, 2003). As literature indicates, the potential way of addressing such arguments on the validity is to outline in details of the techniques used in the research process, whereas particular reader has the opportunity to understand the context of the research findings and conclusions (Patton, 2003; Agar, 1996). Therefore, the adopted research methodology of this study outlined a number of attempts that were made throughout the research process to ensure richness of validity of findings (e.g. selection of data collection methods, sampling, data analysis, dealing with research bias).

Themes identification and refining itself do not produce a unique solution for the issues investigated in the research (Ryan and Bernard, 2003). Therefore, there are as many ways of seeing and arranging them to gain useful application (s). One such potential way is proposed (i.e. OCWMF) in section 2.10.1 by interrogating key themes emerged from this research. Subsequently, there is still question of validity after transformed the findings of the study to a different format. How does one know if the proposed OCWMF and the themes identified in it are valid Based on the above discussion, the validation process of this study involves evaluation and judgement of the developed OCWMF by the involvement of (1) researcher (i.e. Initially, the development of OCWMF by identifying and synthesising key themes and then analysing the responses of validation respondents); (2) research community (i.e. OCWMF refinement discussions with construction management researchers University); and (3) study's respondents (i.e. OCWMF validation questionnaire and interviews). The subsequent section describes the process to be adopted for the proposed OCWMF validation.(see similar approach by Gamage, 2011)

The aim of the framework validation is to refine and examine the appropriateness of the proposed OCWMF. In light of achieving the above, the three specific objectives of the evaluation were set out: determine the clarity and information flow of the proposed OCWMF; determine the information flow and appropriateness; examine the appropriateness and practicalities of the proposed improvement measures. (see similar approach by Gamage, 2011).

The validation process consisted of three stages: OCWMF refinement pilot study (i.e. OCWMF pre-validation refinement discussions with construction management researches), validation questionnaire and face-to-face semi- structured interviews (i.e. a OCWMF validation questionnaire followed by a series of semi-structured interviews). While semi-structured interviews were considered as the main validation approach, pre-validation questionnaire was used as a tool to get respondents' attention about the developed OCWMF prior to the OCWMF validation interviews (Gamage, 2011). The data generated both through OCWMF validation semi-structured interviews (qualitative) and OCWMF validation questionnaire (quantitative) was used in the framework validation data analysis as both approaches provided a solid basis to framework validation (Gamage, 2011).

The validation process comprised three steps: the OCWMF pilot study, validation questionnaires, and face-to-face, semi-structured interviews. While semi-structured interviews were used as the main validation method, questionnaires were used as a pre-validation tool to obtain initial feedback and improve the results of the validation interviews.

OCWMF pilot study

The pilot study was aimed to refine the development of the OCWMF structure, improve the clarity of content and information flow, and provide additional suggestion to improve the framework. Two researchers in the field of construction management from University of Liverpool participated in this pilot study. The framework was initially refined based on comments received from the pilot study. For instance, formatting was changed according to comments.

OCWMF validation questionnaire

The aim of the pre-validation questionnaire was to further refine and improve the framework in terms of clarity, information flow, appropriateness of identified barriers, and proposed remedies. Questionnaires were sent to six participants from the same sample frame as used for the first questionnaire survey in Iran. Further information is provided in chapter 7.

OCWMF validation interviews

A similar sampling approach as used for the interviews in Iran was adopted to select respondents. Five out of 10 interviewees from the interviews in Iran participated in this part of the research. Moreover, after corresponding with Tehran Construction Waste Management Organisation, two managers in top positions agreed to take part in the validation interviews as well. Thus, a total of seven participants agreed to take part in the validation interviews. Further details are provided in chapter 7.

3.9. Validity and Reliability of the Research

Validity was satisfied by using proper data collecting methods and insuring the validity of data sources (Saunders et al, 2009). Reliability was achieved by clarifying general rules and adopting detailed procedures (Voss et al, 2002).

The Validity of the research was determined from (Bryman, 2012; Yin, 2008):

- Construct validity: refers to determining proper measurements for the concepts studied. In this research, construct validity was mostly applied to data collection.
- Internal validity: refers to the extent to which the causal relationships discovered between causes and effects in the research are valid. In this research, internal validity was mainly applied to data analysis.
- External validity: refers to the extent to which the results of the research can be generalized to other cases. In this research, external validity was mostly applied to the research design.

In terms of reliability, this research, reliability was considered as the extent to which the results can be replicated if the same design is implemented by other researchers or at a different time (White, 2000). In the following sections, particular initiatives implemented to improve the validity and reliability of the research are discussed. These initiatives are outlines in separate sections for qualitative and quantitative methods.

3.9.1. Qualitative Methods

In this research, the validity of the data collected through qualitative methods was achieved using proper data collecting techniques, ensuring the validity of the sources of the data (Saunders et al., 2009), while the reliability of the data and outcomes were enhanced through clarifying general rules and detailed procedures (Voss et al., 2002), detailed documentation and database development (Willig and Maidenhead, 2008). Particular initiatives employed in the qualitative methods are presented in Table 3.18.

Table 3.18. Validity and reliability improvement initiatives of qualitative methods

Validity/Reliability Concept	Employed Initiatives	Associated Research Phase
Construct Validity	Adequate definition of variables and measurement (Creswell, 2013).	Literature survey, case study and interviews.
Internal & External Validity	Triangulation. Secondary data quality control criteria (Scott, In: Mogalakwe, 2006). Small sample size to minimize validity threats in qualitative data collection (Creswell & Plano Clark, 2010).	Literature survey, case study and interviews. Literature survey and case study. Case study and semi-structured interviews.
Reliability	Checking data for participant and observer errors. Selecting a purposive sample frame to reduce sample frame bias (White, 2000) and observer tendency bias (Burton-Jones, 2009).	Literature survey, case study and interviews. Case study and interviews.

Source: Author

3.9.2. Quantitative Methods

The validity of quantitative methods in this research were generally enhanced by adopting appropriate sampling and data collection approaches (Creswell and Clark, 2010; Saunders et al., 2009). To improve the reliability of the quantitative methods, the researcher attempted to eliminate or restrict subject and participant error, subject and participant bias, observer errors and observer bias (Saunders et al., 2009). Table 3.19 indicates the initiatives employed to improve validity and reliability of the quantitative research methods.

Table 3.19. Validity and reliability improvement initiatives of quantitative methods

Validity/Reliability Concept	Employed Initiatives
Construct Validity	Adequate definition of variables and measurement (Creswell, 2008).
Internal and External Validity	Triangulation. Large sample size to achieve a high level of certainty and precision (Ghauri, and Gronhaug, 2005; Saunders et al., 2009).
Reliability	Checking data for participant and observer errors. Using delivery and collection administration approaches to reduce non-response bias (Saunders et al., 2009). Providing clear definitions about overrun factors to reduce participant misunderstandings.

Source: Author

Another test, which usually are used in order to check the reliability of data, is: missing data analysis.

3.9.3. Missing Data Analysis

The result of missing values can be misleading interpretations and may reduce the accuracy of calculated statistics (SPSS version 22). Therefore, missing value analysis was conducted for the questionnaire surveys. However there were not missing values for the framework validation questionnaire.

Further details about the results of missing value analysis are provided in chapter 4. As long as missing data values are less than 10% of total data for each question, then the numerical analysis is presented based on non-missing values as the index whilst the total sample kept unchanged (Bryman and Cramer, 2005)

3.10. Ethical Considerations

This research implemented the following ethical considerations to protect participants' rights appropriately use others' work or intellectual property. According to Saunders et al. (2009), participants' rights can be satisfied by the following implementations:

1- Respecting the privacy of the participants.
2- Considering the participants' right to withdraw partially or completely from the research and the voluntary nature of participation.
3- Obtaining consent from participants or owners of data before using the data.
4- Maintaining confidentiality of the participants' information and the provided data.

The works or intellectual property of others used in this research were obtained from accessible and academic permitted sources and were have cited cautiously complying with the Harvard Referencing System. Moreover, the research process, including the questionnaire and interview surveys, was approved by the Kingston University Ethical committee.

3.11. Summary

In this chapter, the details of the research methodology including process and considerations, justifications and initiatives required in order to achieve the study's aim and objectives have been explained. This chapter has reviewed the literature in research strategies, type of research, research design, and data collection methods. Moreover, adopted research strategy, and data collection methods have been explained in this chapter.

A mixed research strategy, including qualitative and quantitative approaches, was employed in this research. To collect the appropriate qualitative and quantitative data, mailed questionnaires and face-to- face semi-structured interviews were conducted as data collection methods. First, interviews were conducted in the UK to complete the findings of the literature review and identify the common methods of on-site waste minimisation in the UK. The next step was to conduct the questionnaire surveys in the UK and Iran to rank on-site waste minimisation methods in the UK and Iran. Next, interviews were conducted in Iran to identify differences between common methods in the UK and Iran and explore the possible reasons for these differences. Then, a case study was observed to complete the research objectives and to investigate the reasons for differences between methods. Finally a framework was created and validated through questionnaires and semi-structured interviews. Furthermore, this chapter explains the research process administration, and considerations and tests that are conducted in this research in order to check the validity and reliability of the study have been explained. A brief Ethical Considerations are provided at the end of this chapter.

4. Studies in the UK

4.1. Introduction

This chapter explains the process of the research conducted in the UK, including data collection, analysis, and results. This chapter contains two main sections: interviews in the UK, and questionnaire survey in the UK. This part of the study addresses research objectives 1 and 2. Therefore, this chapter explains the identification of the common methods of on-site concrete waste minimization methods in the UK by interviews and the determination of the favoured methods in the UK by questionnaire survey. The results of each stage of the research are presented separately at the end of each section. Results of the open-ended questions from the interviews are presented as narratives and quotations (qualitative), and classifications and ratings from the questionnaires are presented as descriptive statistics (quantitative).

4.2. Interviews in the UK

The aim and objective of this stage of data collection was to determine the existing methods for on-site concrete waste minimization in the UK in order to have updated information about current methods used by construction companies: This information was subsequently used to create reliable and complete questionnaires during the next phase of the research. Although most on-site concrete waste minimization methods were identified in literature reviews and recent studies, to be confident the most updated information was acquired, face-to-face interviews were conducted. As mentioned previously, semi-structured face-to-face interviews were conducted to obtain up-to-date data and add depth to the study (Sounders et al, 2009) using reliable, viable, and feasible current methods. Moreover, the results of this stage of the study were used to create the questionnaire for the next stage of the research.

Five interviews were conducted with professionals in the construction projects, including senior managers and executives of companies, who had sufficient and reliable knowledge, experience, and success in the projects. Companies from which interviewees were selected were chosen from lists of the 100 leading construction companies, 100 leading homebuilders, and 100 leading consulting firms in the UK.

4.2.1. Respondents' Profiles

Table 4.1 displays the profiles of the five interviewees. The interviewees were selected from different companies and using the same sample frame as the one used for the questionnaire survey.

Table 4.1. Respondents' profiles

Role	Number	Minimum Qualification	Average Years of Experience
Contractor's Project Manager	1	MSc	24
Site Superintendent	2	BEng	25
Project Consultant	2	MSc	30
Total	5	N/A	N/A

The respondents were asked to describe their experience and the extent of their involvement in project waste minimisation. All respondents held senior managerial positions within their companies and had been involved in a variety of building projects. All respondents had over 24 years of experience in construction projects, had performed diverse roles in their professional careers, and were involved in their companies' waste minimisation strategies and practices.

4.2.2. Results and Analysis

For this step (which addresses research objective 1), as discussed earlier, the first aim was to determine the most common on-site waste minimization methods in the UK through qualitative data collection methods. Therefore, for data analysis, the emphasis was on deductive methodology through conceptualization (Saunders et al. 2009).

Moreover, because this stage of the research was designed to identify as many on-site concrete waste minimization methods as possible, each additional method discovered was added to the list of methods for the next stage of the research, the questionnaire survey. During the interviews, the participants were asked to express their understanding of and experiences with approaches to minimizing concrete on-site waste. The responses provided in-depth understanding about possible and existing methods. Data was recorded through note taking, with a focus on capturing key points. Through clarifying and coding the responses, different methods were recognized. While most of the mentioned methods had already been extracted during the literature review, other methods such as "Purchase management" and "On-site inventory management" were discovered. Further details of the results of interviews are provided below.

Use of pre-fabricated building components

All respondents took the view that the use of pre-fabricated or precast concrete elements reduces the amount of on-site concrete waste generated. In this regard, one site superintendent said: 'Although use of precast concrete elements increases the total cost of concrete works, it can significantly decrease the amount of concrete waste generated on the construction site'.

Education and training

All interviewees stated that education and training is one of the best methods to decrease on-site concrete waste. This was echoed by a project consultant interviewee who said that 'education and training for reducing waste is one of the most effective methods to decrease the amount of on-site concrete waste'.

Purchase management

Four out of five participants stated that high quality purchase management reduces on-site concrete waste production by activities such as better estimation of total concrete requirements, avoiding over-ordering, and just-in-time ordering. One interviewee said: 'Over-ordering is one of the main causes of concrete waste on-site, therefore, proper purchase management can reduce the amount of waste'.

Governmental incentives for waste reduction practices

The majority of interviewees stated that governmental incentives for reducing waste are an effective method to minimise on-site concrete waste. One respondent said that 'governmental incentives in reducing waste can significantly encourage the contractors to reduce concrete waste generation on-site'.

Waste prevention during on-site transport

An example of waste prevention during on-site transport was given by an interviewee who stated that 'waste prevention during on-site transport includes activities such as the use of volumetric trucks to determine the exact quantities needed would reduce the amount of concrete waste on-site'.

Implementation of environmental management systems

Almost all participants stated that implementation of environmental management system is one of the most efficient methods to minimise concrete waste on-site.

Use of information technology on-site

Use of information technology on-site was one of the most mentioned methods for minimising on-site concrete waste production. For instance, an interviewee said that 'using information technology methods such as BIM in order to avoid mistakes and mis-fit of designs significantly reduces the amount of waste produced'.

On-site waste recycling operation

Over half of interviewees (three out of five) listed on-site waste recycling operations is one of the common methods for on-site concrete waste minimisation. One participant said: 'Waste recycling operations is always one of the options for minimising on-site waste. Concrete waste can be recycled and used as aggregate material'.

Quality management

Two respondents stated that quality management is a method for minimising waste on-site. For instance, one site superintendent explained: 'Procurement of concrete with appropriate characteristics such as slump is one of the activities involved in quality management, and proper quality management can help to minimise on-site concrete waste production'.

On-site reuse

On-site reuse was stated by a site superintendent who said that 'on-site reuse of concrete waste for unloaded embankments or landscape designs can help to minimise the waste leaving a construction site'.

Identification of available recycling facilities

One project consultant stated that identifying available recycling facilities is one of the activities that can reduce waste and mentioned: 'Identification of available recycling facilities is a proper method to help to minimise on-site concrete waste'.

Proper site layout planning

Proper site layout planning was stated as a method for reducing on-site concrete waste, and one interviewee said that 'proper site layout planning, for instance, location of site entrances or on-site access roads can help to reduce the amount of concrete waste'.

On-site inventory management

One out of five interviewees stated that on-site inventory management is one of the most efficient methods of on-site waste minimisation. However, this method and the following method (4.2.2.14) apply only for in-situ concrete works in terms of storage of concrete materials such as cement and aggregates.

Central area for storage

One respondent mentioned that 'on-site concrete waste can be reduced by on-site inventory management and central area storage of cements or aggregates'.

On-site waste conservation

On-site waste conservation was stated by an interviewee as a method of concrete waste minimisation.

Use of ready-mixed concrete

One respondent stated that 'using ready mixed concrete instead of on-site concrete can reduce concrete waste production on construction sites'.

A summary of the results is provided in Table 4.2. While participants mentioned different possible and common approaches, most referred to "Use of pre-fabricated components", "Education and training", and "Purchase management" as the most effective waste reduction methods.

Table 4.2. Current on-site concrete waste minimization methods in the UK

Methods	Number of positive responses
Use of pre-fabricated building components	5
Education and training	5
Purchase management (e.g., better estimation of total concrete requirements, on-time ordering, etc.)	4
Governmental incentives for waste reduction practices	4
Waste prevention during on-site transport (include use of volumetric trucks to determine the exact quantities needed)	4
Implementation of environmental management systems	4
Use of information technology on-site (e.g., BIM in order to avoid mistakes and misfit of designs)	4
On-site waste recycling operation	3
Quality management (e.g., use of concrete with proper characteristics such as slump, etc.)	2
On-site reuse	1
Identification of available recycling facilities	1
Proper site layout planning	1
On-site inventory management (including on-site sorting of construction and demolition materials)	1
Central area for storage	1
On-site waste conservation	1
Use of ready-mixed concrete (reducing direct production of concrete on construction sites)	1

Almost all interviewees mentioned that legislation and regulations in the UK are the main drivers for construction waste reduction, for instance, increasing the Landfill Tax, increasing costs of waste disposal, and compliance requirements with Site Waste Management Regulations 2008.

4.3. Questionnaire Survey in the UK

4.3.1. Introduction

This section presents the results of the questionnaire survey administrated to the UK's top 100 contractor companies and top 100 consultant companies. This part of the research was conducted due to a lack of published information on the topic in the literature. This stage of the research aimed to identify favoured waste reduction methods , and to rank the methods currently used by construction companies in the UK.

The first section presents the administration procedures for the questionnaire survey and response rate. This is followed by insights into background information about the participants and their companies. Then, the resulting preferred on-site concrete waste minimisation methods are provided in subsequent sections. Accordingly, the results of categorical and rating questions are presented as quantitative data in tables.

4.3.2. Questionnaire Survey Administration and Response Rate

Questionnaire administration

A total of 196 questionnaires were sent to potential participants, including consultants, contractors' project managers, and site superintendents. Participants were chosen from the 100 top construction contractor companies and top 100 consultant companies in the UK.

All questionnaires were mailed to potential participants over the course of three consecutive days. As explained in section 3.6.2.1.5 (Methodology), after 10 days, email follow-ups were sent. According to Saunders et al., (2009), in order to have reliable survey, a total of 60 responses are needed. Some of the main reasons for a lack of received questionnaire after the first attempt were that some respondents:

- Were out of the office for vacation.
- Did not receive the questionnaire.
- Did not want to respond to the questionnaire.

Since the desired response rate was not achieved, it was decided to extend the duration of the questionnaire survey in the hopes that an acceptable response rate would be achieved. Another round of email follow-ups was conducted to increase the response rate. A total of 68 questionnaires were received at the end of the fifth week of the follow-up period. The questionnaire survey administration concluded at the end of the sixth week with 73 completed questionnaires. Figure 4.1 illustrates the number of questionnaires received over time.

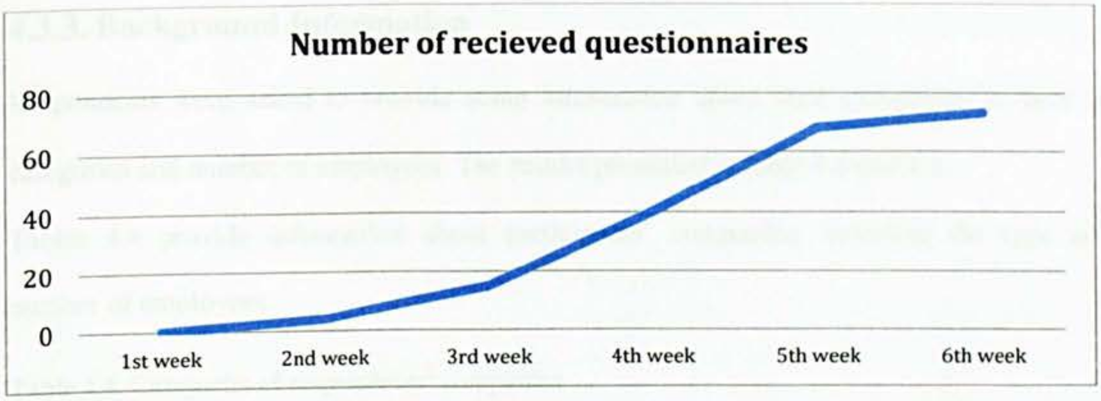


Fig. 4.1. Distribution of received questionnaires over time

Response rate

Table 4.4 illustrates the active response rate (discussed in section 3.6.2.9). The response rate is based on the total number of questionnaires sent and the total number of respondents. A total of 196 questionnaires were sent, with 73 responses. Therefore, the active response rate for the survey was 37.2%. Surveys from engineers had the highest active response rate at 36.9% whereas surveys from project consultants had the lowest response rate at 31.2 %. Table 4.3 presents the number of questionnaires sent and number of completed questionnaires received as well as response rate by group.

Table 4.3. Response rate of participants by group

Role	Number Sent	Number Received	Response Rate
Contractor's Project Manager	49	17	34.7%
Site Superintendent	53	18	33.9%
Project Consultant	48	15	31.2%
Engineer	46	17	36.9%
Unspecified	0	6	
Total	196	73	37.2%

Missing value analysis

To address concerns about incomplete data, missing value analysis was conducted for each question of the survey. Results of the missing value analysis revealed that missing data for all questions were less than 3%. Thus, statistical analysis results can be considered as based on non-missing values because the number of participants in the questionnaire survey was at an acceptable level.

4.3.3. Background Information

Respondents were asked to provide some information about their companies in term of categories and number of employees. The results presented in table 4.4 and 4.5.

Tables 4.4 provide information about participants' companies, including the type and number of employees.

Table 4.4. Categories of respondents' companies

Category of company	Number of respondents
Registered General Building Contractor	22
Registered Specialist Contractor	15
Developer	4
Consultant or Quantity Surveyor	32
Total	73

Table 4.5 provides a brief overview of the size of the respondents' companies.

Table 4.5. Number of employees in participants' companies

Number of employees	Number of respondents
Less than 50 people or unspecified	7
51 to 300 people	3
301 to 500 people	10
501 to 1000 people	27
More than 1000 people	26
Total	73

Figures 4.2 and 4.3 below, illustrates the percentages of participants' companies categories and the number of their employees.

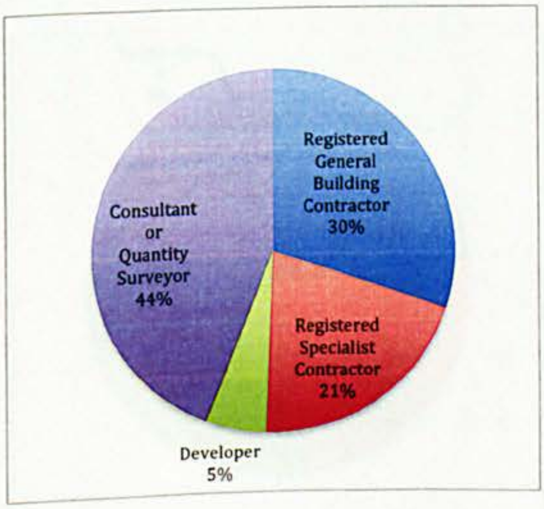


Fig. 4.2. Participants' companies by category

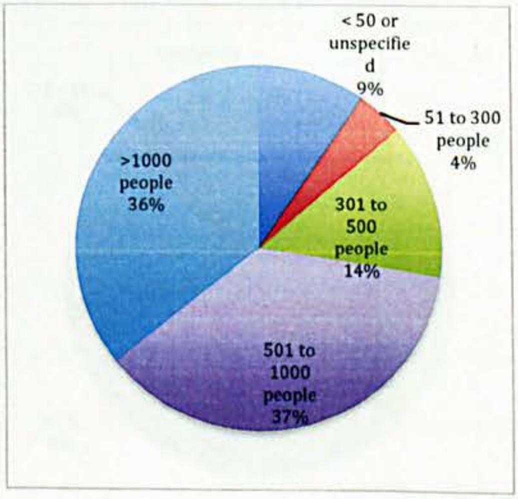


Fig. 4.3. Number of participants' companies' employees

Table 4.6 illustrate the roles of practitioners who replied to the questionnaire. Approximately 47.9% of respondents were contractors' project managers or site superintendents, and approximately 39.6% of respondents had more than 20 years of experience.

Table 4.6. Role of respondents

Role	Number of Respondents	Percentage of Total
Contractor's Project Manager	17	23.3%
Site Superintendents	18	24.6%
Consultants	15	20.5%
Engineer	17	23.3%
Unspecified	6	8.2%

As shown in Table 4.7, respondents with between 15 and 20 years of experience represented the largest number of respondents at 23.3%, followed by respondents with between 20 and 25 years of experience at 20.5%.

Table 4.7: Years of experience of respondents

Years	Number of Respondents	Percentage of Total
Over 30	9	12.3%
25 - 30	11	13.7%
20 - 25	15	20.5%
15 - 20	17	23.3%
10 - 15	12	16.4%
5 - 10	3	4.1%
0 - 5	0	0
Unspecified	6	8.2%

Figures 4.4 and 4.5 present the percentage of participants by their role and experience.

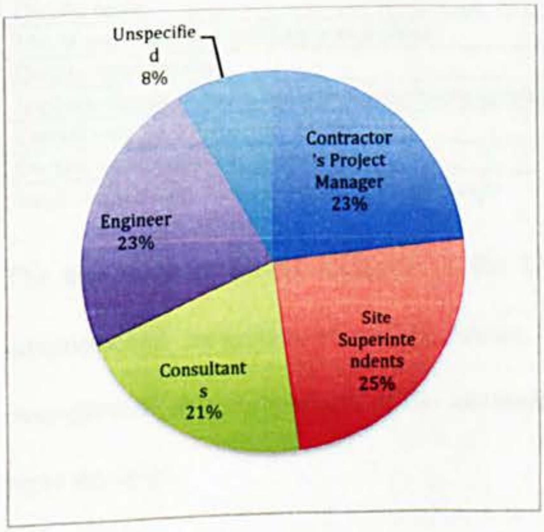


Fig. 4.4. Percentage of participants by role

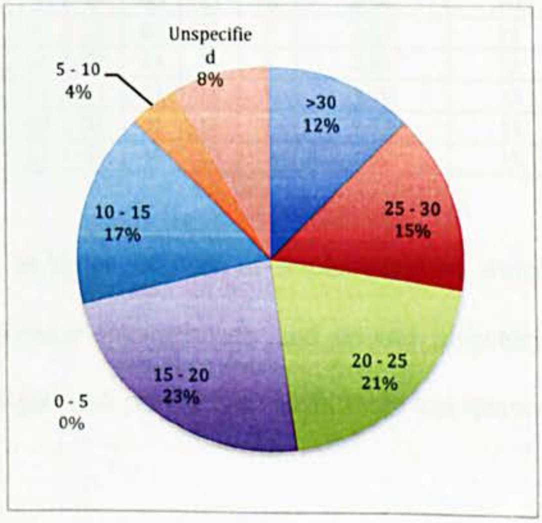


Fig.4.5. Percentage of participants by experience

4.3.4. Preferred On-site Concrete Waste Minimization Methods

Survey participants were asked about their understanding of and experiences with methods to minimize concrete waste on-site. Participants were asked to rate the listed on-site concrete waste minimization methods in terms of:

a) Cost of implementation (Table 4.8)

b) Difficulty of implementation (Table 4.9)

c) Cost efficiency (Table 4.10)

d) The overall worthiness of spending on the method to create savings or minimize waste (Table 4.11)

On-site concrete waste minimization methods in terms of cost of implementation

Question 4 asked respondents to rate the methods in terms of cost of implementation on a scale of 1 (very expensive) to 5 (very cheap). The results are shown in Table 4.8.

Table 4.8. On-site concrete waste minimization methods in the UK in terms of cost of implementation

On-site concrete waste minimization methods	Responses						
	Percentage					Mean rating	Ranking
	1	2	3	4	5		
Governmental incentives to reduce waste	0	0	12	38	50	4.38	1
Purchase management	0	9	17	37	37	4.02	2
On-site inventory management	3	9	25	31	32	3.8	3
Waste prevention during on-site transport	2	10	25	35	28	3.77	4
Identification of available recycling facilities	6	6	26	41	21	3.65	5
Education and training	6	10	28	36	20	3.54	6
On-site waste conservation	7	13	40	24	16	3.29	7
Use of information technology on-site	7	15	45	19	14	3.18	8
Proper site layout planning	8	12	47	23	10	3.15	9
On-site reuse	8	13	46	23	10	3.14	10
Use of pre-fabricated building components	9	12	49	23	7	3.07	11
Quality management	10	22	48	14	6	2.84	12
Implementation of environmental management systems	11	23	47	14	5	2.79	13
Central area for cutting and storage	10	21	51	16	2	2.79	14
On-site waste recycling operation	12	29	46	13	0	2.6	15

Rated on a scale of 1 (very expensive) to 5 (very cheap)

The top three preferred methods in the UK in terms of cost of implementation were: governmental incentives to reduce waste, purchase management, and on-site inventory management. For comparison of the methods, figure 4.6 provides a visual, more transparent representation.

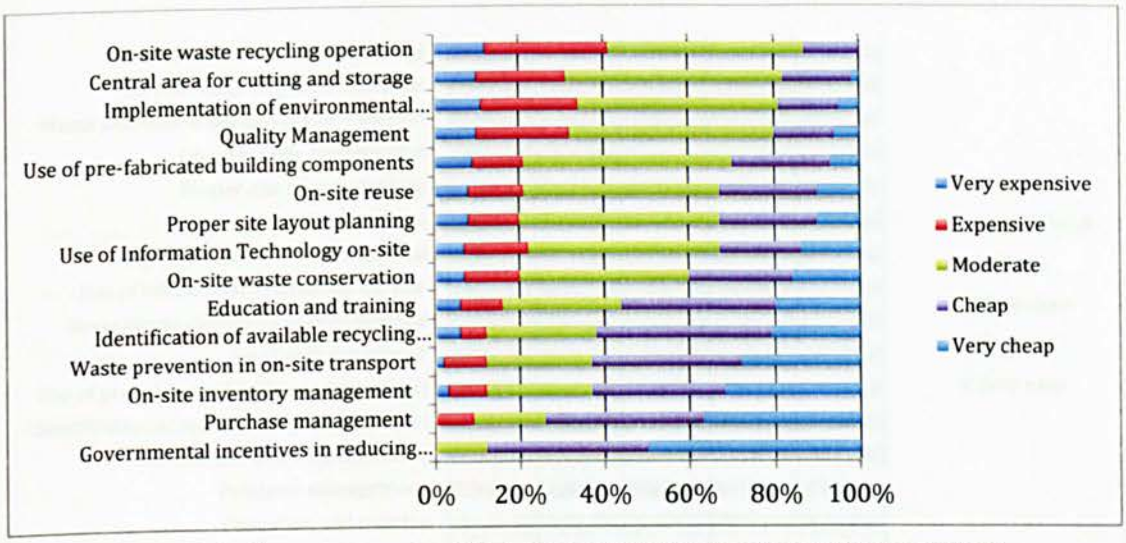


Fig. 4.6. On-Site concrete waste minimization methods in terms of cost of implementation

On-site concrete waste minimization methods in terms of difficulty of implementation

Question 5 asked respondents to rate the methods in terms of difficulty of implementation and on scale of 1 (very difficult to implement) to 5 (very easy). Table 4.9 illustrates the results.

Table 4.9. On-site concrete waste minimization methods in the UK in terms of difficulty of implementation

On-site concrete waste minimization methods	Responses						
	Percentage					Mean rating	Ranking
	1	2	3	4	5		
Education and training	0	0	13	38	49	4.36	1
Purchase management	0	9	18	37	36	4	2
On-site inventory management	3	9	26	31	31	3.78	3
Identification of available recycling facilities	2	10	25	35	28	3.77	4
Use of pre-fabricated building components	6	6	26	41	21	3.65	5
Quality management	6	10	28	36	20	3.54	6
Government incentives to reduce waste	5	13	40	24	18	3.37	7
Use of information technology on-site	6	16	34	26	18	3.34	8
Implementation of environmental management systems	7	12	40	26	15	3.3	9
On-site reuse	7	10	44	29	10	3.25	10
Proper site layout planning	8	9	45	28	10	3.23	11
On-site waste conservation	9	22	48	15	6	2.87	12
Waste prevention during on-site transport	10	23	47	15	5	2.82	13
On-site waste recycling operation	9	23	51	15	2	2.78	14
Central area for cutting and storage	11	29	46	14	0	2.63	15

Rated on a scale of 1 (very difficult) to 5 (very easy)

The three easiest methods in terms of implementation were: education and training, purchase management, and on-site inventory management.

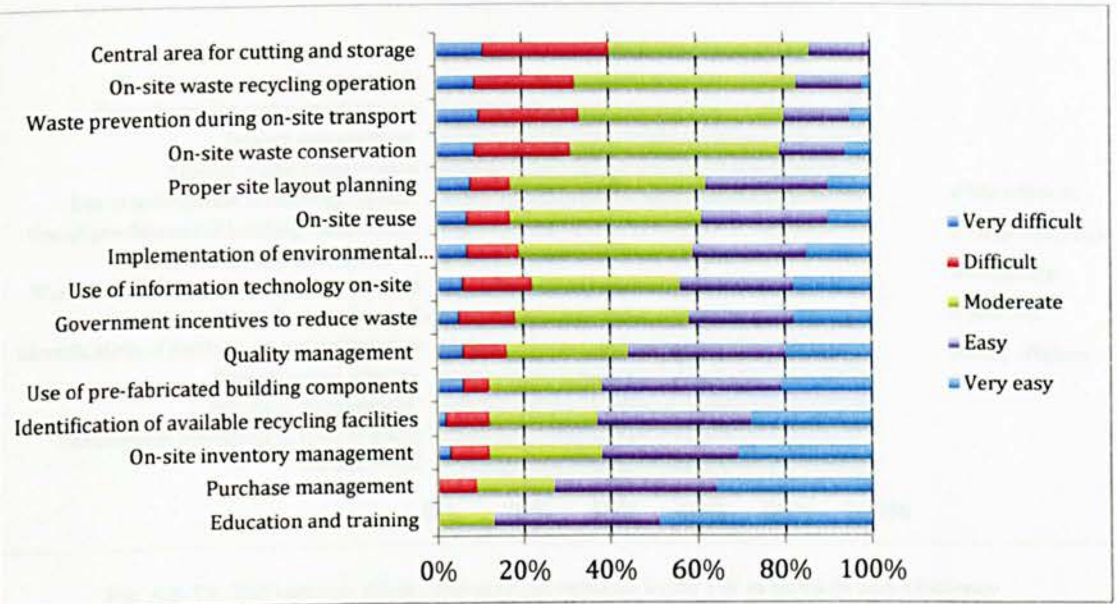


Fig. 4.7. On-site concrete waste minimization methods in terms of difficulty of implementation

On-Site concrete waste minimization methods in terms of cost efficiency

Table 4.10 shows the ranking of methods in terms of cost efficiency. Participants were requested to rate methods on a scale of 1 (not efficient at all) to 5 (very efficient).

Table 4.10. On-Site concrete waste minimization methods in the UK in terms of cost efficiency

On-site concrete waste minimization methods	Responses						
	Percentage					Mean rating	Ranking
	1	2	3	4	5		
On-site reuse	0	2	21	37	40	4.15	1
Government incentives to reduce waste	0	8	19	36	37	4.02	2
Purchase management	5	9	23	31	32	3.76	3
Education and training	2	10	25	35	28	3.77	4
Identification of available recycling facilities	6	6	26	41	21	3.65	5
Implementation of environmental management systems	7	16	34	25	18	3.31	6
Waste prevention during on-site transport	5	13	40	24	18	3.37	7
On-site inventory management	6	16	34	26	18	3.34	8
Use of pre-fabricated building components	7	10	44	29	10	3.25	9
Use of information technology on-site	8	9	45	28	10	3.23	10
On-site waste conservation	8	12	47	23	10	3.15	11
Quality management	8	13	46	23	10	3.14	12
Central area for cutting and storage	9	12	49	23	7	3.07	13
On-site waste recycling operation	12	20	43	22	2	2.835	14
Proper site layout planning	12	30	41	17	0	2.63	15

Rated on a scale of 1 (not efficient) to 5 (very efficient)

As seen the three most cost efficient methods were: on-site reuse, government incentives to reduce waste, and purchase management.

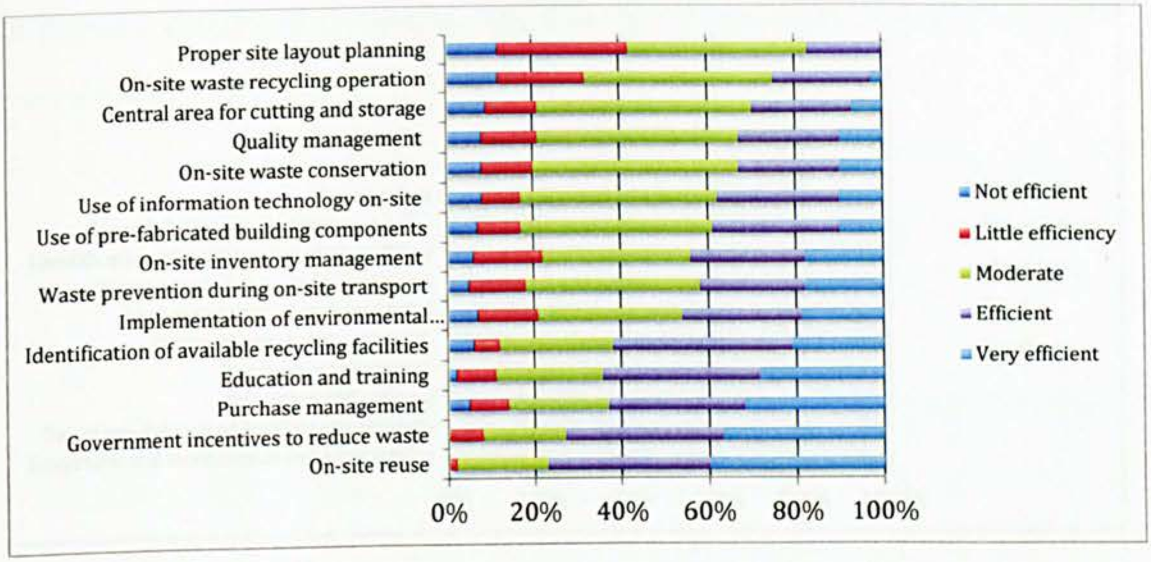


Fig. 4.8. On-Site concrete waste minimization methods in the UK in terms of cost efficiency

On-site concrete waste minimization methods in terms of overall worthiness

Table 4.11 shows the ranking of methods in terms of the overall worthiness of spending on them to create savings or minimize waste. Participants were asked to rate the items on a scale that ranged from 1 (improper) to 5 (excellent). While participants rated different approaches, the most highly rated were: governmental incentives in reducing waste, use of pre-fabricated components, and education and training.

Table 4.11. On-site concrete waste minimization methods in the UK in terms of overall worthiness

On-site concrete waste minimization methods	Responses						
	Percentage					Mean rating	Ranking
	1	2	3	4	5		
Governmental incentives in reducing wastes	0	2	21	37	40	4.15	1
Use of pre-fabricated building components	0	8	19	36	37	4.02	2
Education and training	5	9	23	31	32	3.76	3
Purchase management	4	12	21	35	28	3.71	4
Onsite inventory management	6	6	26	39	23	3.67	5
Implementation of environmental management systems	6	10	28	36	20	3.54	6
Waste prevention in onsite transport	7	15	33	24	21	3.37	7
Identification of available recycling facilities	7	16	34	25	18	3.31	8
Use of Information Technology onsite	8	12	40	25	15	3.27	9
On site reuse	8	10	44	28	10	3.22	10
Onsite waste conservation	9	9	45	27	10	3.2	11
Quality management	10	22	45	15	8	2.89	12
Central area for cutting and storage	11	25	44	15	5	2.78	13
On-site waste recycling operation	12	20	43	22	2	2.835	14
Proper site layout planning	12	30	41	17	0	2.63	15

Rated on a scale of 1 (improper) to 5 (excellent)

A visual comparison of the results is provided in figure 4.9.

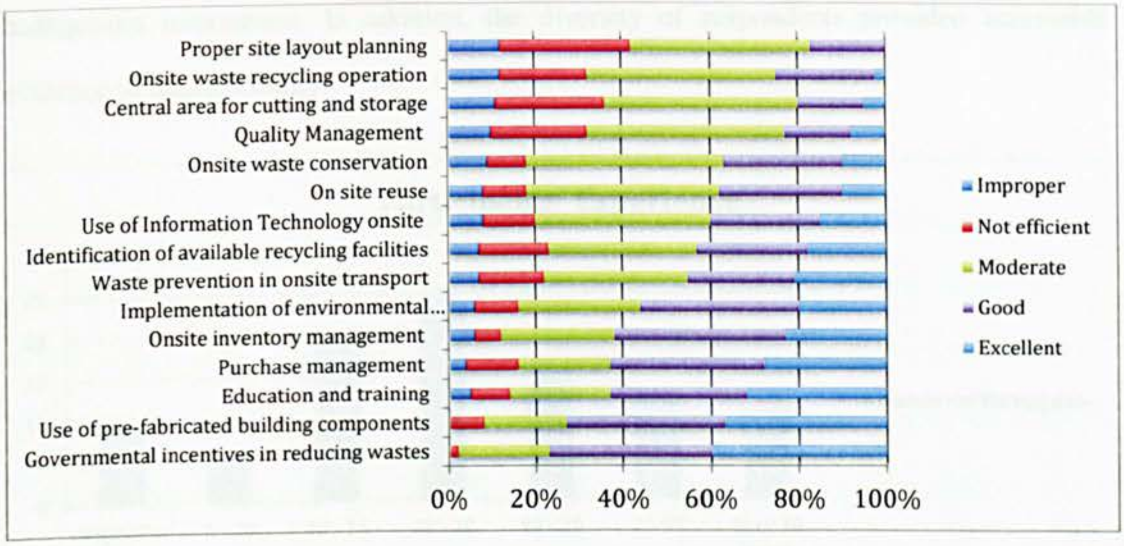


Fig. 4.9. On-Site concrete waste minimization methods in overall

The overall mean rating for each method is provided in figure 4.10.

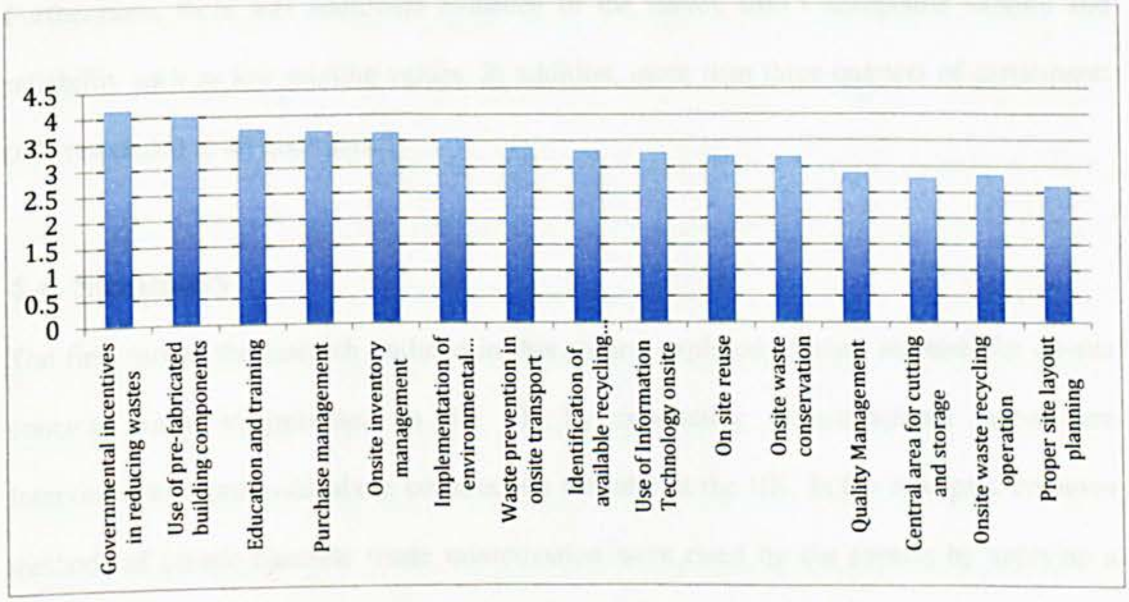


Fig 4.10. Overall mean ratings for on-site concrete waste minimization methods

4.3.5. Validity and reliability

As explained in section 3.7.6, to ensure validity and reliability of the achieved data, certain measures were taken. Content validity of the data on which the questionnaire was based was confirmed through the literature review and pilot questionnaires. To ensure data reliability, respondents were carefully selected; chosen respondents were required to be satisfactorily experienced experts in the field. Moreover, a majority of the respondents provided their background information. In addition, the diversity of respondents provided acceptable evidence of data reliability.

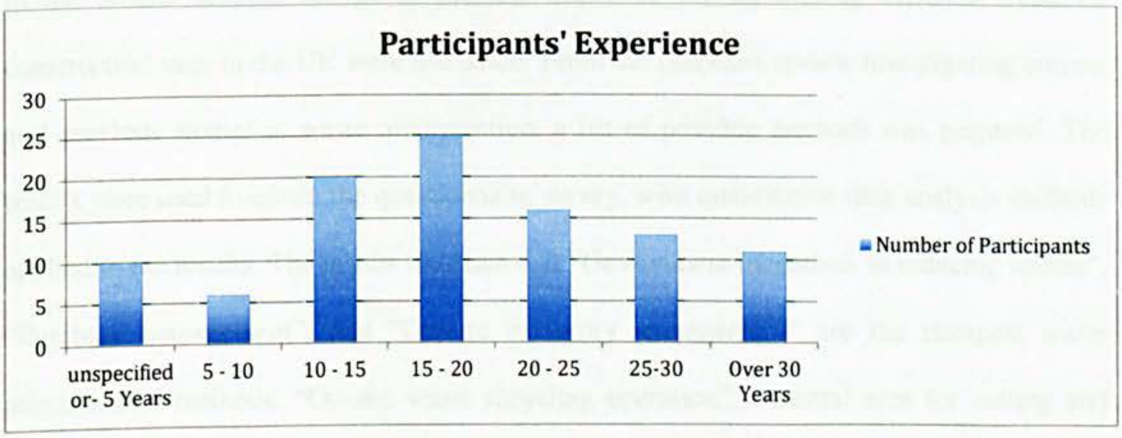


Fig. 4.11. Participants' experience

Furthermore, there was additional evidence of the survey data's acceptable validity and reliability such as low missing values. In addition, more than three-quarters of participants (62) responded to all questions.

4.4. Summary

The first part of the research outlined in this section explored existing methods for on-site concrete waste minimization in the UK by conducting semi-structured face-to-face interviews with professionals in construction industry in the UK. In the next part, common methods of on-site concrete waste minimization were rated by the experts by applying a questionnaire survey in the UK. Results of this research are presented in tables and graphs. In the first section of the chapter, possible initiatives for minimizing concrete wastes on construction sites in the UK were introduced. These initiatives were determined through semi-structured face-to-face interviews and using qualitative data analysis methods. The results illustrated several on-site concrete waste minimisation methods such as "Use of pre-fabricated building components", "Education and training" and "Purchase management" that are the most recommended methods in the UK. Furthermore, legislation and regulations in the UK were mentioned as the main drivers for construction waste reduction, for instance, increasing the Landfill Tax, increasing costs of waste disposal, and compliance requirements with Site Waste Management Regulations 2008.

In the second section, ratings of possible initiatives for minimizing concrete waste on construction sites in the UK were discussed. From the literature review investigating current and previous studies in waste minimization, a list of possible methods was prepared. The results were used to create the questionnaire survey, with quantitative data analysis methods applied to the results. The results illustrate that "Government incentives in reducing wastes", "Purchase management", and "On-site inventory management" are the cheapest waste minimization methods. "On-site waste recycling operation", "Central area for cutting and storage", and "Implementation of environmental management systems" are the most expensive methods. "Education and training", "Purchase management", and "On-site inventory management" are the easiest methods to implement. "Central area for cutting and storage", "On-site waste recycling operation", and "Waste prevention during on-site transport" are the most difficult methods. "On site reuse", "Government incentives to reduce waste", and "Purchase management" are the most cost efficient methods. "Proper site layout planning", "On-site waste recycling operation", and "Central area for cutting and storage" are the least cost efficient methods. Finally, "Governmental incentives in reducing wastes", "Use of pre- fabricated building components" and "Education and training" are the most recommended methods in the UK. "Proper site layout planning", "On-site waste recycling operation", and "Central area for cutting and storage" are the least recommended methods.

The next chapter present the finding of surveys about on-site waste minimisation methods in Iran.

5. Studies in Iran

5.1. Introduction

This chapter explains the process of data collection and analysis and provides a discussion of the results of the questionnaire survey and interviews conducted in Iran. This part of research was executed to address objectives 3 and 4. Hence, this chapter aims to rank the common methods of on-site concrete waste minimization in Iran using the results of a questionnaire survey administered to determine the favoured methods in Iran, then comparing the results to the preferred methods in the UK. Finally, the chapter explains the interviews conducted in Iran to establish the possible reasons for differences between prefered methods in Iran and in the UK. The results of each stage of the research are presented separately at the end of each section.

5.2. Questionnaires in Iran

5.2.1. Introduction

This section presents the outcomes of the questionnaire survey administrated to employees of the 100 top contractors and consultant companies in Iran. This part of the research was conducted due to a lack of reliable published information about on-site concrete waste minimization methods in Iran. This part aimed to explore the common methods of on-site concrete waste minimization in Iran, identify the favoured methods, and rank the current methods used in construction projects in Iran.

The first section presents the questionnaire survey administration method and response rate. This is followed by insight into background information about the participants and their companies. Then, the results of preferred on-site concrete waste minimisation methods are provided in subsequent sections. Accordingly, the results of categorical and rating questions are presented as quantitative data in tables.

5.2.2. Questionnaire Survey Administration and Response Rate

Questionnaire administration

A total of 196 questionnaires were sent to the potential participants that included consultants, general contractors' project managers, and site superintendents. Participants were chosen from first-grade construction contractor companies and first-grade consultant companies in Iran. Probability sampling method was adopted for this part of the research. Questionnaires were sent to potential participants mainly by mail, accompanied with a pre-paid, addressed envelope to return completed questionnaires to the researcher. However, some questionnaires were sent using other delivery and collection methods due to prior communication of the researcher with some of the participants. Companies were selected from first-grade construction companies in Iran as rated by the Planning and Budgeting Organisation, a governmental organisation. The organisation rates companies on a scale of 1 (large) to 5 (small). (A list of Iranian first-grade construction companies is available in http:/www.sajat.mporg.ir). Questionnaires were mailed over four consecutive days. However, as mentioned earlier, 50 questionnaires were personally delivered. After two weeks, telephone follow-ups were conducted for those who had not yet responded to the questionnaire. Figure 5.1 demonstrates the number of received questionnaires over the survey time frame.

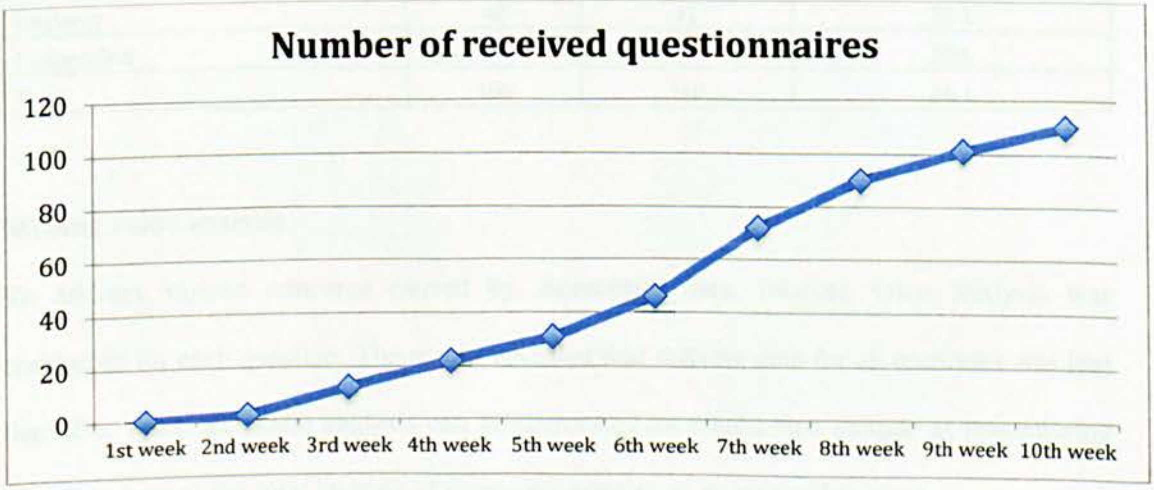


Fig. 5.1. Distribution of received questionnaire over time

For this survey, some participants could not participate initially because they were out of the office for vacation, did not receive the questionnaire, or did not want to respond to the questionnaire. Therefore, it was decided to extend the duration of the survey time frame in order to achieve an acceptable response rate. In this stage, delivery and collection method was conducted and another round of telephone follow-ups was conducted. A total of 101 completed questionnaires were received at the end of ninth week. Finally, at the end of the tenth week of the questionnaire administration period, a total of 110 questionnaires were received.

Response rate

Table 5.1 outlines the active response rate for the questionnaire (discussed in section 3.6.2.2.7). The response rate was based on the total number of questionnaires sent and the number of completed surveys received. A total of 196 questionnaires were sent, and 110 were returned. Therefore, the active response rate for the survey was 56.1%. Site superintendents had the highest active response rate at 63.8% whereas project consultants had the lowest response rate at 46.5%. Table 5.1 presents the response rate per group.

Table 5.1. Response rate of participants by group

Role	**Sent**	**Received**	**Response Rate**
Contractor's Project Manager	55	32	58.1
Site Superintendent	58	37	63.8
Project Consultant	43	20	46.5
Engineer	40	21	52.2
Unspecified	0	0	N/A
Total	196	110	56.1

Missing value analysis

To address various concerns caused by incomplete data, missing value analysis was conducted for each question. The results revealed that missing data for all questions was less than 2%. Thus, statistical analysis can be performed on results that include as non-missing values as long as the total number of responses remains at an acceptable level.

5.2.3. Background Information

In the questionnaire, respondents were asked to provide some information about their companies in term of categories and number of employees. Tables 5.2 and 5.3 provide information about respondents' companies such as type of companies and number of employees.

Table 5.2. Category of respondents' companies

Category of company	Number of companies
Registered general building contractor	29
Registered specialist contractor	33
Developer	7
Consultant	41
Total	110

Table 5.3 presents the size of respondents' companies in terms of number of employees.

Table 5.3. Number of employees in participants' companies

Number of employees	Respondent number
Less than 50 people	13
Between 51 to 300 people	30
Between 301 to 500 people	41
Between 501 to 1000 people	16
More than 1000 people	10
Total	110

Figures 5.2 and 5.3 below, shows the percentages of participants' companies types and the number of their employees.

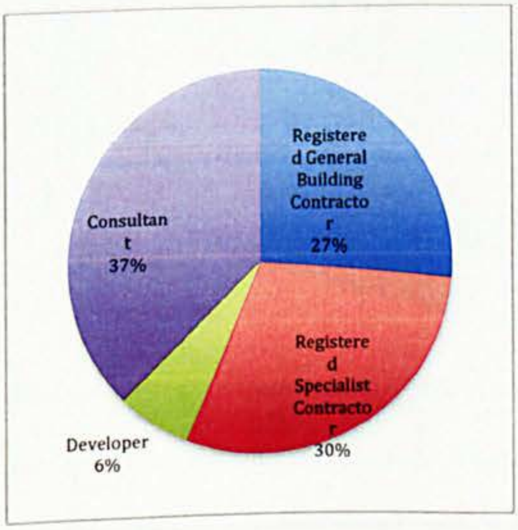


Fig.5.2. Participants' companies by category

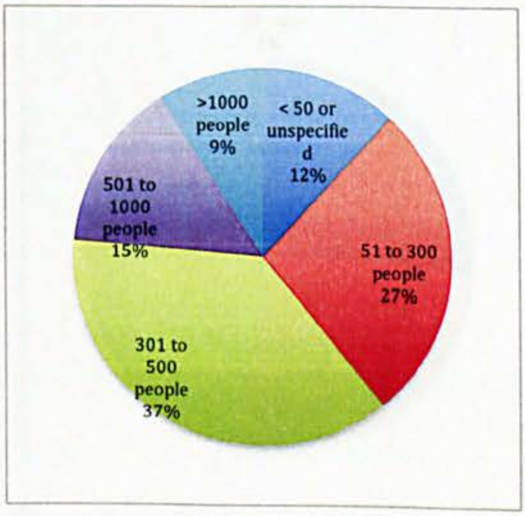


Fig. 5.3. Number of participants' companies' employees

Tables 5.4 present the roles of practitioners who replied to the questionnaire. Approximately 62.7% of respondents were project managers or site superintendents, and approximately 26% of respondents had more than 30 years of experience.

Table 5.4. Role of respondents

Role	Number of Respondents	Percentage of Total
Contractor's Project Manager	32	29.1
Site Superintendent	37	33.6
Project Consultant	20	18.2
Engineer	21	19.1

As shown in Table 5.5, respondents with between 20 and 25 years of experience represented the largest number of respondents at 45%, followed by respondents with between 25 and 30 years of experience at 28%.

Table 5.5. Years of experience of respondents

Years	Number	Percentage
Over 30	29	26%
25 - 30	31	28%
20 - 25	49	45%
15 - 20	1	1%
10 - 15	0	0%
5 - 10	0	0%
0 – 5 and unspecified	0	0

Figures 5.4 and 5.5 present the percentage of participants by their role and experience.

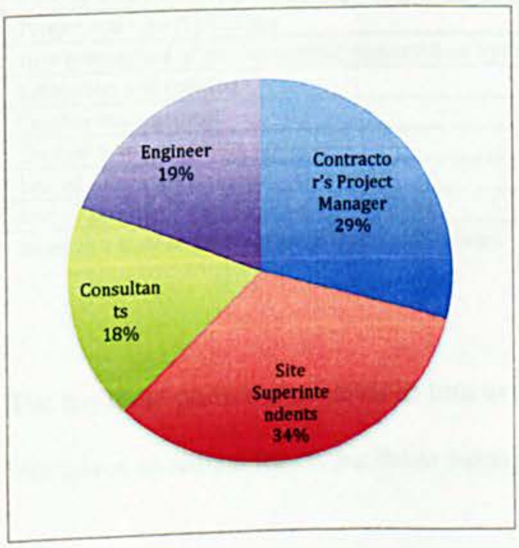


Fig. 5.4. Percentage of participants by role

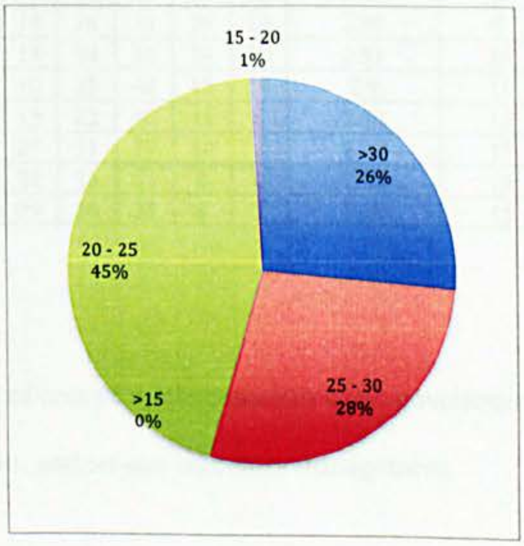


Fig.5.5. Percentage of participants by experience

5.2.4. Preferred On-site Concrete Waste Minimization Methods

Questionnaire respondents were asked to express their understanding of and experiences with methods to minimize concrete waste on-site (in situ). Participants were asked to rate on-site concrete waste minimization methods in terms of:

a) Cost of implementation (Table 4)

b) Difficulty of implementation (Table 5)

c) Cost efficiency (Table 6)

d) Overall worthiness in terms of spending on them to create savings or minimize waste (Table 7)

On-site concrete waste minimization methods in terms of cost of implementation

Question 4 asked respondents to rate the methods in terms of cost of implementation on a scale of 1 (very expensive) to 5 (very cheap). The results are presented in Table 5.6.

Table 5.6. On-site concrete waste minimization methods in Iran in terms of cost of implementation

On-site concrete waste minimization methods	Responses						
	Percentage					Mean rating	Ranking
	1	2	3	4	5		
Government incentives to reduce waste	0	8	38	26	28	3.74	1
Purchase management	2	12	27	30	29	3.72	2
On-site inventory management	4	15	18	35	28	3.68	3
Waste prevention during on-site transport	6	6	26	38	24	3.68	4
Identification of available recycling facilities	6	10	28	36	20	3.54	5
On-site reuse	2	20	35	30	13	3.32	6
On-site waste conservation	13	12	36	24	15	3.16	7
Central area for cutting and storage	15	15	35	20	15	3.05	8
Proper site layout planning	15	16	34	25	10	2.99	9
Implementation of environmental management systems	15	19	36	20	10	2.91	10
Education and training	10	25	40	15	10	2.9	11
Quality management	15	22	40	15	8	2.79	12
On-site waste recycling operation	27	31	29	10	3	2.31	13
Use of information technology on-site	22	35	35	8	0	2.29	14
Use of pre-fabricated building components	29	26	35	8	2	2.28	15

Rated on a scale of 1 (very expensive) to 5 (very cheap)

The top three preferred methods in Iran in terms of cost of implementation were: government incentives to reduce waste, purchase management, and on-site inventory management.

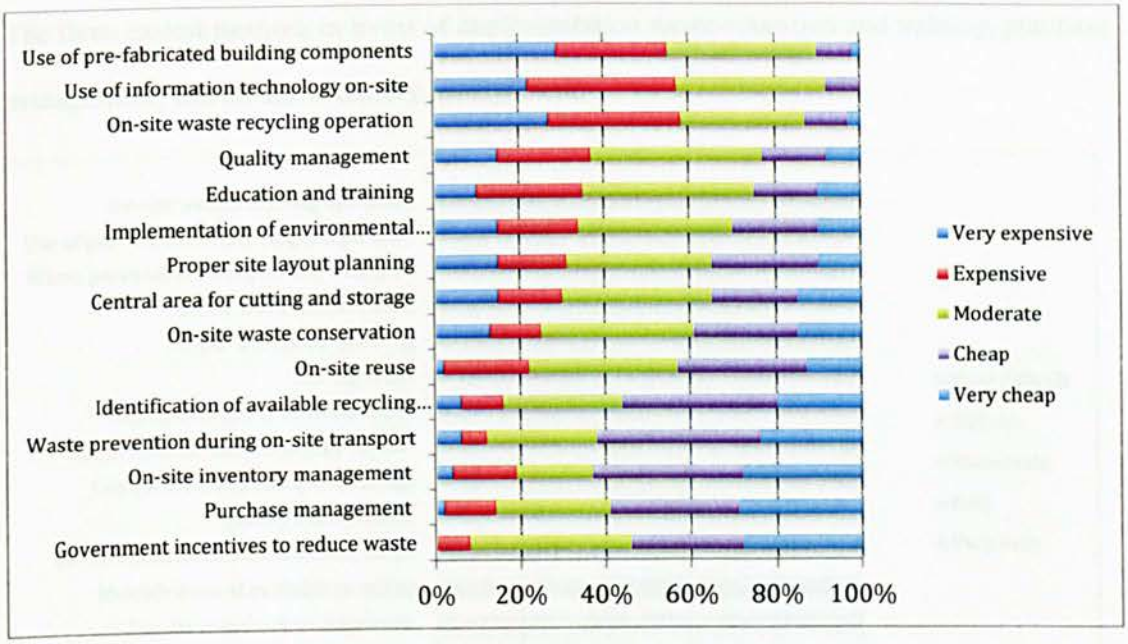


Fig. 5.6. On-site concrete waste minimization methods in Iran in terms of cost of implementation

On-site concrete waste minimization methods in terms of difficulty of implementation

Question 5 asked respondents to rate the methods in terms of difficulty of implementation and on scale of 1 (very difficult to implement) to 5 (very easy). Table 5.7 illustrates the results.

Table 5.7. On-site concrete waste minimization methods in Iran in terms of difficulty of implementation

On-site concrete waste minimization methods	Responses						
	Percentage					Mean rating	Ranking
	1	2	3	4	5		
Education and training	3	5	20	36	36	3.97	1
Purchase management	5	10	23	30	32	3.74	2
On-site inventory management	4	15	18	35	28	3.68	3
Identification of available recycling facilities	6	10	28	36	20	3.54	4
Government incentives to reduce waste	3	15	40	35	7	3.28	5
Quality management	6	16	40	22	16	3.26	6
Central area for cutting and storage	10	14	38	20	18	3.22	7
Use of information technology on-site	11	15	35	20	19	3.21	8
Implementation of environmental management systems	12	16	34	23	15	3.13	9
On-site reuse	16	10	36	28	10	3.06	10
Proper site layout planning	13	17	40	18	13	3.04	11
On-site waste conservation	13	17	36	18	15	3.02	12
Waste prevention during on-site transport	18	24	26	18	14	2.86	13
Use of pre-fabricated building components	28	25	32	13	2	2.4	14
On-site waste recycling operation	25	37	18	15	5	2.38	15

Rated on a scale of 1 (very difficult to implement) to 5 (very easy to implement)

The three easiest methods in terms of implementation were: education and training, purchase management, and on-site inventory management.

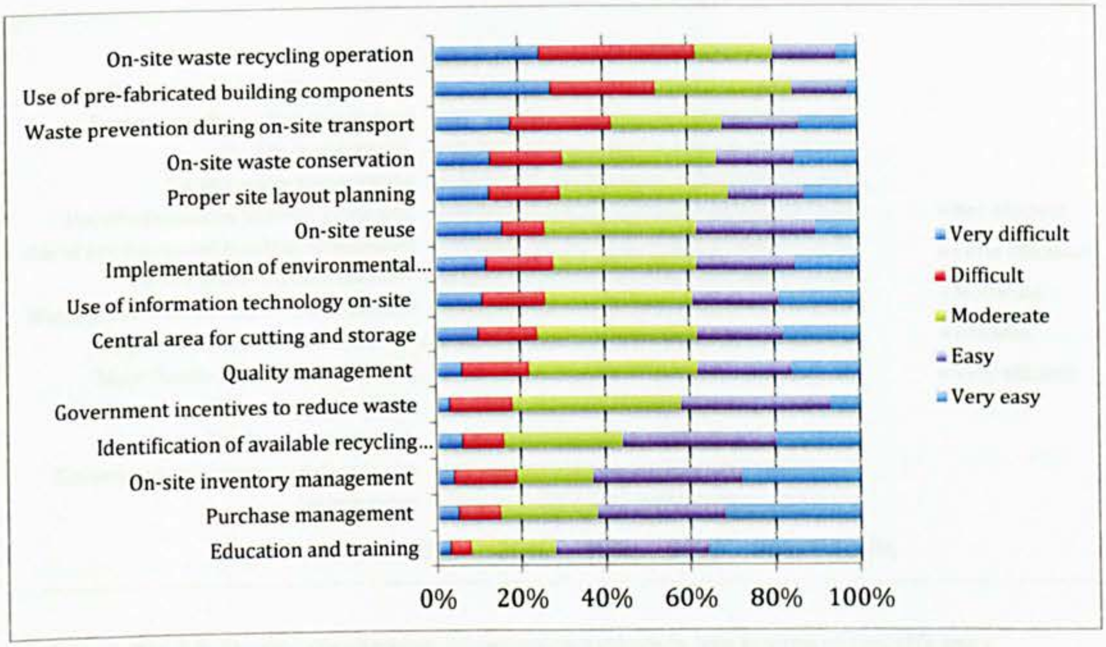


Fig. 5.7. On-site concrete waste minimization methods in Iran in terms of difficulty of implementation

On-Site concrete waste minimization methods in terms of cost efficiency

Table 5.8 shows the ratings of methods in terms of cost efficiency. In question 7, participants were asked to rate items on a scale of 1 (not efficient at all) to 5 (very efficient).

Table 5.8. On-site concrete waste minimization methods in Iran in terms of cost efficiency

On-site concrete waste minimization methods	Responses						
	Percentage					Mean rating	Ranking
	1	2	3	4	5		
On-site reuse	2	5	28	32	33	3.89	1
Government incentives to reduce waste	2	8	26	34	30	3.82	2
Purchase management	5	10	23	30	32	3.74	3
Education and training	4	8	30	29	29	3.71	4
Identification of available recycling facilities	6	10	24	28	32	3.7	5
Implementation of environmental management systems	5	16	22	28	29	3.6	6
Waste prevention during on-site transport	6	6	38	26	24	3.56	7
On-site inventory management	4	15	30	29	22	3.5	8
Use of pre-fabricated building components	10	15	25	26	24	3.39	9
Use of information technology on-site	11	15	35	20	19	3.21	10
On-site waste conservation	13	12	36	24	15	3.16	11
Quality management	10	20	35	15	20	3.15	12
Central area for cutting and storage	15	25	40	15	5	2.7	13
On-site waste recycling operation	22	20	32	22	3	2.63	14
Proper site layout planning	13	30	40	17	0	2.61	15

Rated on a scale of 1 (not efficient at all) to 5 (very efficient)

The top three most cost efficient methods were: on-site reuse, government incentives to reduce waste, and purchase management.

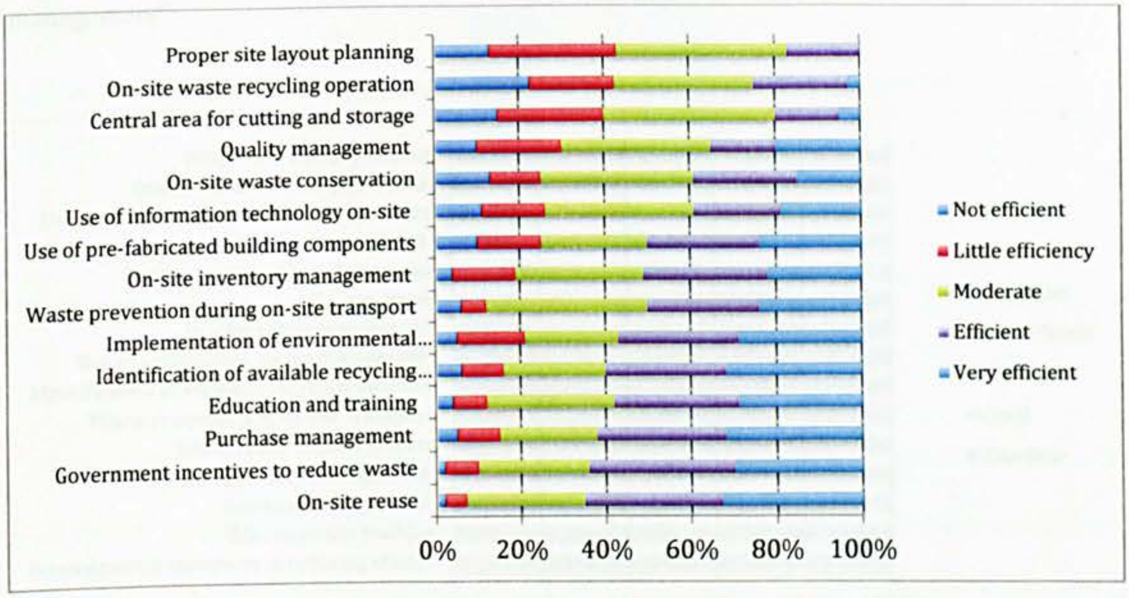


Fig. 5.8. On-site concrete waste minimization methods in Iran in terms of cost efficiency

On-site concrete waste minimization methods in terms of overall worthiness

Table 5.9 shows the ranking of methods by their overall worthiness in terms of spending on them to create savings or minimize waste. Participants were asked to rate items on a scale ranging from 1 (improper) to 5 (excellent).

Table 5.9. On-site concrete waste minimization methods in Iran in terms of overall worthiness

On-site concrete waste minimization methods	Responses						
	Percentage					Mean rating	Ranking
	1	2	3	4	5		
Governmental incentives in reducing wastes	0	7	18	35	40	4.08	1
Education and training	4	8	18	35	35	3.88	2
Purchase management	5	10	23	30	32	3.74	3
On-site inventory management	4	15	18	36	28	3.68	4
Use of ready mixed concrete	6	6	26	38	24	3.67	5
Waste prevention in on-site transport	6	10	28	36	20	3.54	6
Identification of available recycling facilities	11	15	35	20	19	3.21	7
Use of Information Technology on-site	10	16	34	25	15	3.19	8
On-site waste conservation	13	12	36	24	15	3.16	9
On-site reuse	16	10	36	28	10	3.06	10
Implementation of environmental management systems	18	8	38	26	10	3.02	11
Quality management	15	22	40	15	8	2.78	12
Use of pre-fabricated building components	15	25	40	15	5	2.70	13
On-site waste recycling operation	23	20	32	23	2	2.62	14
Proper site layout planning	13	30	40	17	0	2.62	15

Rated on a scale of 1 (improper) to 5 (excellent)

As seen in Table 5.9 most preferable on-site concrete waste minimization methods in Iran are: "Governmental incentives in reducing waste", "education and training", and "Purchase management".

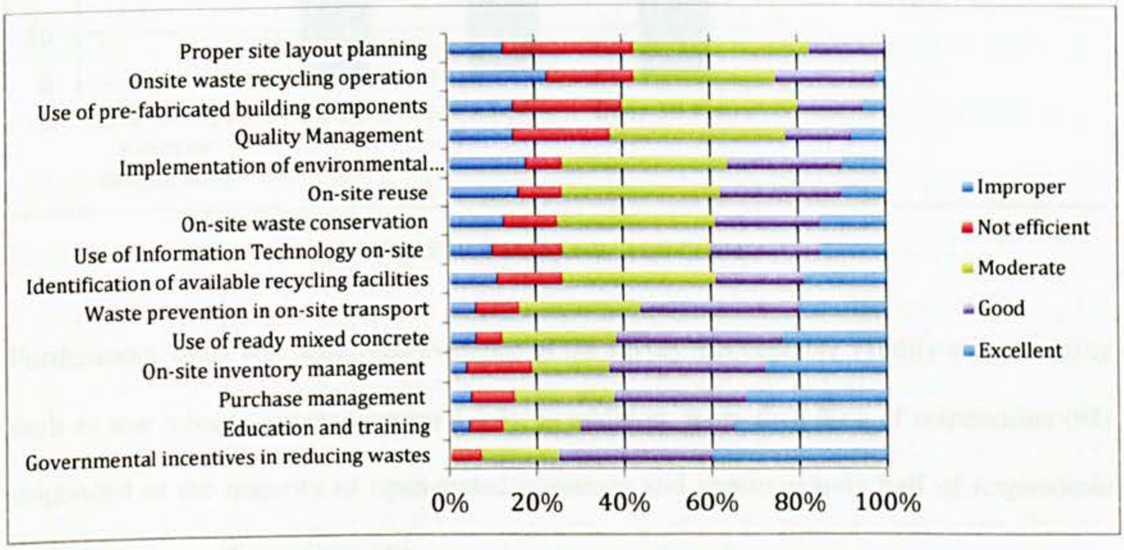


Fig. 5.9. On-site concrete waste minimization methods in Iran in terms of overall worthiness

While participants mentioned different approaches, most rated "Use of ready-mix concrete" as an effective method for waste reduction. "Education and training", "Purchase management", and "On-site inventory management" were also among the top ranked methods in Iran.

5.2.5. Validity and Reliability

As explained in section 2.7.6, measurements were conducted to ensure validity and reliability of the collected data. Content validity of the questionnaire data was confirmed through the literature review and pilot questionnaires. To ensure data reliability, respondents were carefully selection for participation. Chosen respondents were required to satisfactorily experienced experts in the field. Moreover, a majority of the respondents provided their background information. In addition, the diversity of respondents provided acceptable evidence of reliability related to data sources.

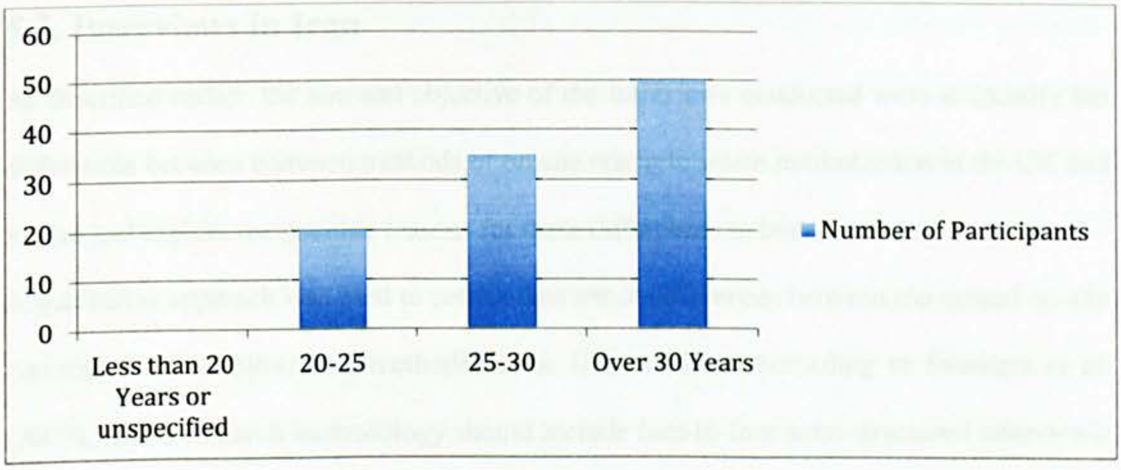


Fig. 5.10. Participants' experience

Furthermore, there was additional evidence of the survey's acceptable validity and reliability such as low missing values (section 4.2.3). In addition, more than 80% of respondents (91) responded to the majority of open-ended questions and approximately half of respondents (60) gave consent for an interview.

According to the results of the questionnaire in the UK, top ranked methods of on-site waste minimization in the UK were use of pre-fabricated building components, education and training, purchase management, and on-site inventory management. The preferred methods in Iran were education and training, purchase management, on-site inventory management, and use of ready-mix concrete. The differences between methods in the UK and Iran are in use of pre- fabricated building components and use of ready-mix concrete. Although use of pre- fabricated building components was the most favoured method for on-site concrete waste minimization, it was not even in the top four of favoured methods in Iran.

Therefore, further investigation was conducted to determine the reasons for these differences. Interviews were conducted, which are presented in the next section, and a case study was undertaken for more in-depth exploration.

5.3. Interviews in Iran

As described earlier, the aim and objective of the interviews conducted were to identify the differences between common methods of on-site concrete waste minimization in the UK and in Iran and explore the possible reasons for these differences in both countries.

A qualitative approach was used to collect data about differences between top ranked on-site concrete waste minimization methods in the UK and Iran. According to Saunders et al. (2009), such a research methodology should include face-to-face semi-structured interviews. Moreover, for in-depth study, interviews with experts in the relevant field are vital. Purposive heterogeneous sampling was used to select interviewees (Saunders et al. 2009: 232). Ten interviews were conducted with professionals in the construction industry, including senior managers and executives of companies who had recently been involved in at least one project with a multiple-story concrete structure building, had more than 20 years of experience in the construction industry, and were graduates of a UK or US university or had proper, up-to-date knowledge about global waste management strategies so they could compare the methods. The companies were chosen from lists of the 100 leading construction companies, 100 leading homebuilders, and 100 leading consulting firm in Iran.

5.3.1. Respondents' Profiles

Table 5.10 provides the profiles of the 10 interviewees who participated in interviews. The interviewees were selected from different companies and the same sample frame as that used for the questionnaire survey.

Table 5.10. Respondents' profiles

Role	Number	Minimum Qualification	Average Years of Experience
Contractor's Project Manager	4	MSc	27
Site Superintendent	4	MSc	31
Project Consultant	2	MSc	28
Total	10	N/A	N/A

The respondents were asked to describe their experience and the extent of their knowledge of waste minimisation practises and strategies in developed countries. All respondents held senior managerial position within their companies and were involved in a variety of building projects. All respondents had over 27 years of experience in the construction projects and performed diverse roles in their professional careers. In addition they had been recently involved in academic positions (including part-time lecturing or research activities) that allowed them to gain updated information regarding current waste minimisation issues in the UK and US.

5.3.2. Results and Data Analysis

To achieve objective 4 of the research (to identify the differences between common methods of on-site concrete waste minimization in the UK and in Iran and explore the possible reasons for these differences) the collected data were analysed in two main steps: (1) identifying the reasons for differences among most favoured methods in the UK and Iran, and (2) conducting statistical analysis. As discussed earlier, the first critical goal to achieve objective 4 was to identify and confirm the most favoured on-site concrete waste minimization methods in Iran, which were identified by the questionnaire survey in Iran. Then, reasons for the differences between the most favoured methods in the UK and Iran were discussed with the participants. The opinions during the interviews were then compiled and compared to create a complete list of reasons. During the interviews, participants were asked to express their points of view about possible reasons for differences between methods in the UK and Iran according to their understanding and experiences about minimizing on-site concrete waste. By clarifying and coding the responses, possible causes were recognized.

Lack of concern about waste minimization in Iran

Lack of concern about waste minimisation in Iran was stated by five respondents. One interviewee said: ‘There is not sufficient concern about waste minimisation in construction sites in Iran at the moment. This is even worse in residential building projects’.

Lack of pre-fabricated concrete manufacturers

Almost half of the respondents (4) stated that there is a lack of pre-fabricated concrete manufacturers in Iran at the moment. One interviewee said: 'Very few manufacturers remain active at the moment due to the low demand for precast concrete components; therefore, there are very limited options for project stakeholders to choose a pre-fabricated product'.

Limited production of pre-fabricated concrete products in Iran

Four respondents stated that limited production of pre-fabricated concrete products in Iran is one of the major reasons for not using this method for concrete works in projects in the country. A project manager said: 'There are very limited pre-fabricated concrete products in the market in Iran at the moment. Consequently it is very difficult for designers and contractors to use these precast products'.

Use of pre-fabricated building components is far more expensive than other concrete works

The vast majority of interviewees (nine out of 10) stated that the use of pre-fabricated components is far more expensive than other concrete work methods. Furthermore, several interviewees said that most pre-fabrication manufacturer in Iran no longer produce any building components because of high prices of products and the consequent low demand for them. For instance, one interviewee said: 'Use of precast concrete elements significantly increases the cost of concrete works in comparison with in-situ or ready mixed concrete works'.

Differences between proportion of manpower and machinery costs in Iran and the UK

Half of respondents stated that difference between the proportion of manpower and machinery costs in Iran and the UK is one of the possible reasons for difference between common methods of on-site concrete waste minimization in these countries. In this regard, one superintendent said: 'In a building project in the UK, the cost of material is almost less than half of the manpower cost whereas in Iran, the cost of materials is approximately double the cost of manpower. This encourages contractors to use as much manpower as they can instead of using machinery on sites'.

High transportation costs for PCE

Three interviewees stated that high cost for transport of pre-fabricated elements is a reason for not using this method for concrete works in Iran. A consultant interviewee said that 'issues related to pre-fabrication concrete elements transport would considerably increase the cost of work, and high cost has been always one of the causes of ignoring use of pre-fabricated concrete in Iran'.

Low charges for landfill tax

Four out of ten interviewees stated that low charges for the landfill tax in Iran is one of the reasons for differences in methods between the countries. This was made clear by a project consultant who stressed that 'the low landfill rate in Iran discourages contractors to use any specific on-site waste minimisation methods'.

Difficulty of execution of pre-fabricated concrete elements on-site due to lack of proper equipment

Difficulty of execution of pre-fabricated concrete elements on-site due to lack of proper equipment was mentioned by four participants as a reason for lack of interest in using pre-fabricated concrete elements in Iran.

Difficulty transporting pre-fabricated elements due to congested traffic in Iran and night-time regulations for lorry transport

Four out of 10 interviewees stated that transporting pre-fabricated elements in Iran, particularly at night, is difficult due to congested traffic and regulations for lorry transport. A site superintendent explained the issue further by stating; 'Regulations for lorry transport in Iran, especially Tehran, are very strict and special permissions are required. For instance, lorries cannot move in Tehran from 6am until 12pm unless they have specific permission. Therefore, pre-fabricated elements must be delivered to sites at night. However, contractors cannot work at night unless they have special permission. Accordingly, this is a reason contractors do not use pre-fabricated concrete elements '.

On-site execution mistakes

One interviewee claimed that 'on-site execution mistakes is one of the reasons that discourage designers from using pre-fabricated concrete elements in projects'.

A summary of the results is presented in Table 5.11.

Table 5.11. Reasons for differences between on-site concrete waste minimization methods in the UK and Iran

Causes	Number of repeated responses
Use of pre-fabricated building components is far more expensive than other concrete works	9
Differences between proportion of manpower cost and machinery cost in Iran and the UK	5
Lack of concern about waste minimization in Iran	5
Low charge for landfill tax	4
Lack of pre-fabricated concrete manufacturers	4
Difficulty of execution of pre-fabricated concrete elements on-site due to lack of proper equipment	4
Difficulty transporting pre-fabricated elements due to congested traffic in Iran and night time regulations for lorry transport	4
Limited pre-fabricated concrete products produced in Iran	4
High transportation costs for pre-fabricated elements	3
On-site execution mistakes	1

5.4. Summary

This chapter aimed to rank on-site concrete waste minimization methods in Iran, and identify the differences between common methods of on-site concrete waste minimization in the UK and in Iran and explore the possible reasons for these differences. The chapter report the key results that emerged from questionnaire survey and semi-structured face-to-face interviews in Iran.

In first section of this chapter, possible methods for minimizing on-site concrete wastes in construction building project in Iran were ranked according to results of a questionnaire survey conducted in Iran. This questionnaire survey included the same questions as the first questionnaire survey conducted in the UK. Quantitative data analysis methods were applied to generate results. The results illustrate that "Government incentives to reduce waste", "Purchase management", and "On-site inventory management" were identified as the cheapest methods. "Use of pre-fabricated building components", "Use of information technology on-site", and "On-site waste recycling operation" were identified as the most expensive methods. "Education and training", "Purchase management", and "On-site inventory management" are the easiest methods to implement. "On-site waste recycling operation", "Use of pre-fabricated building components", and "Waste prevention during on-site transport" are the most difficult methods. "On site reuse", "Government incentives to reduce waste", and "Purchase management" were identified as the most cost efficient methods. "Proper site layout planning", "On-site waste recycling operation", and "Central area for cutting and storage" were identified as the least cost efficient methods. Finally, "Governmental incentives in reducing waste", "Education and training", and "Purchase management" as the most recommended methods in Iran among current practices. "Proper site layout planning", "On-site waste recycling operation", and "Central area for cutting and storage" were the least recommended methods.

After comparing the recommended methods in Iran to the preferred methods in the UK (which are outlined in the previous chapter), differences were revealed. The main differences between proposed on-site concrete waste minimization methods in Iran and in the UK were in the use of pre-fabricated concrete elements and the use of ready-mix concrete. Therefore, it was determined that interviews should be conducted with experts in the construction industry in Iran to explore the possible reasons for these differences.

In next section, possible reason for differences between top ranked on-site concrete waste minimization methods in the UK and in Iran were investigated through 10 face-to-face semi-structured interviews. Results clear that many responses were focused on the cost of using pre-fabricated concrete elements. Therefore, in order to collect more data and further investigate the topic, a case study in Iran was observed, which is explained in the next chapter.

6. Case Study in Iran

6.1. Introduction

This chapter explains the process of achieving objective 5 of the research (to investigate the reasons for differences between the methods used in the UK and in Iran) by examining the costs associated with the use of pre-fabricated concrete elements in Iran, which is the proposed reason for differences between the preferred methods of on-site concrete waste minimization in the UK and in Iran. This chapter aims to provide observations on the cost and waste production of three different concrete work methods, which are: "Use of pre-fabricated concrete elements", "Use of ready-mix concrete", and "Traditional in situ concrete" as three case studies in one project in northern Tehran in Iran. As explored in pervious chapters, the two main preferred methods for on-site concrete waste minimization were identified as: "Use of pre-fabricated concrete elements" and "Use of ready-mix concrete". The last section of chapter 5 explains that semi-structured face-to-face interviews were conducted to determine the main reasons behind these differences. One of the most mentioned reasons was the high cost of pre-fabrication in Iran. Therefore, in order to more deeply explore the issue, the following case studies was observed.

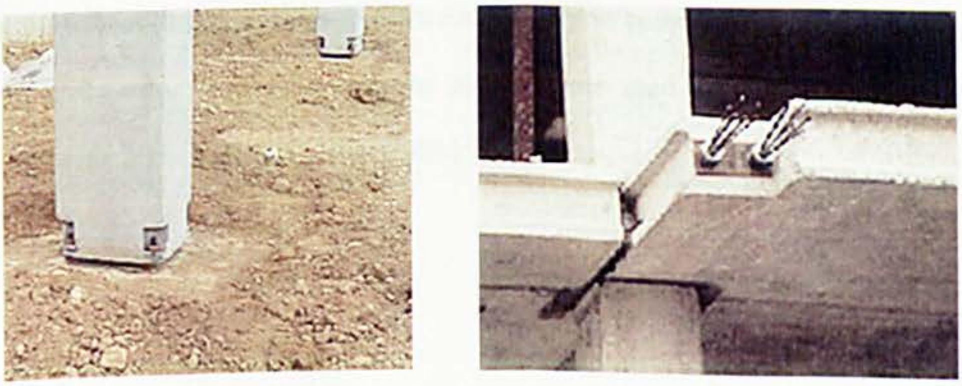
6.2. Brief Descriptions of the Three Main Concrete Work Methods

According to Lu and Yuan (2011), current construction and demolition waste management research has mainly focused on the use, demolition, recycling, and disposal of construction materials. Therefore, future research is recommended to be extended to the production and delivery of construction materials such as concrete. As stated above, the use of ready-mix concrete and pre-fabricated concrete elements are two effective methods for minimizing concrete waste in comparison with traditional in situ concrete (Bakhtiar et al., 2008; De Silva & Vithana, 2008: Osmani et al., 2007; Tam, 2007; WRAP, 2007; Poon et al., 2004b). The following section explains the three concrete work methods investigated in the research case study.

Pre-fabricated concrete elements

Previous studies have illustrated that using pre-fabricated concrete elements instead of in situ concrete can reduce construction and demolition waste (De Silva & Vithana, 2008). One estimate shows that using pre-fabricated concrete elements reduces the amount of waste by 20% to 50% compared to the amount of waste generated on similar sites using traditional construction methods (WRAP, 2007). Poon et al. (2004b) claimed that the use of pre-fabricated concrete elements can lead to a significant decrease in the amount of waste produced by approximately 30% to 40%. Pre-fabricated building components can contribute considerably to "zero waste production" because of the dry construction works on-site, flexibility in installation, high adaptability, and the re-use of elements (Straatman et al., 2001). Although pre-fabricated concrete elements and in situ concrete are created with the same process, the pre-fabricated elements are produced under more controllable conditions. The following are some of the reasons for reduced from use of pre-fabricated concrete elements compare with equivalent concrete work in situ (WRAP, 2007).

- Lack of long and continuous concrete-making and pouring operations
- Significant decrease or even prevention of temporary shuttering
- Controlled curing of concrete
- Enhanced quality control at manufacturing location
- No unforeseeable stops during the concrete works due to weather conditions.



PCEs

Ready-mix concrete

Ready-mix concrete manufacturers claim that modern formwork systems and efficient site management minimize ready-mix concrete wastage to less than 2% (The Concrete Centre, 2010). There is very little waste associated with ready-mix concrete as the precise volume required can be delivered (WRAP, 2014; BRMCA, 2014). Ready-mix concrete is used widely all over the world for concrete works. For instance, there are around 1200 ready-mix concrete plants in the UK, producing 23.5 million cubic metres of concrete each year (Sealey et al., 2001).

Ready mixed concrete works

In situ concrete

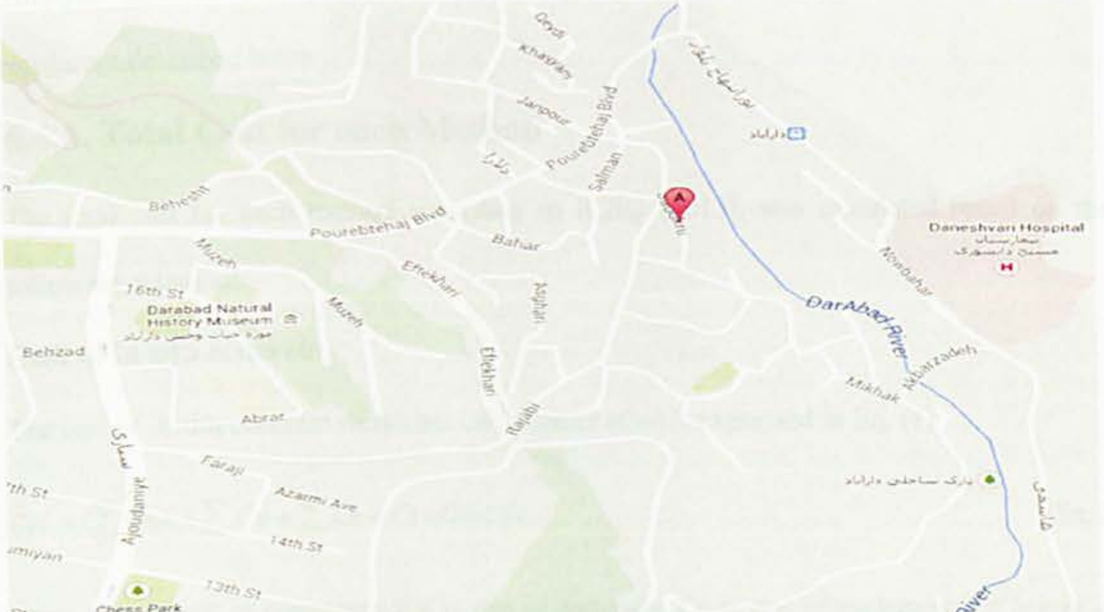
The method of pouring liquid concrete material into forms at the building site is called in situ concrete (Britannica, 2014). This was the main method used for concrete works until the early part of the 20th century (CCNAZ, 2014).

In-situ concrete works

Studies from all over the world have compared these three methods of concrete work. For instance, the work of De Silva and Vithana (2008) compared the three methods in Sri Lanka. In the UK, a WRAP case study compared pre-cast concrete with in situ concrete in terms of waste production (WRAP, 2007). However, there is limited work that compares the aforementioned three methods in Iran due to scarce use of pre-fabricated concrete elements in the Iranian construction projects. As a result, it is hoped that the case study in this paper may shed some light on the use of adequate methods in terms of concrete waste minimization. A case study approach was used because case studies demonstrate valuable insights in situations where existing knowledge is limited (Harris & Ogbonna, 2002).

6.3. Project

The total floor space of the case study project was approximately 2,100 m^2. Construction of the concrete frame structure took approximately three months. All expenditure was recorded by both the researcher and the contractor. The contractor agreed to provide the recorded data for research purposes.



Location of the Project

The executed methods are described below:

- *In situ concrete* was made on-site. The contractor ordered and purchased materials (fine and coarse aggregates, cement, and water) by approximate estimates of consumption for each floor. Materials were delivered to the site and the concrete was produced and mixed manually by the sub-contractor using manpower and on-site equipment such as a concrete mixer.

- *Ready-mix concrete* was ordered from ready-mix concrete companies and poured by concrete pumps.
- *Pre-fabricated elements* were attached by bolts and junction re-bar to their positions and pasted by grout. The required operations on site were preparation of the foundations, placing the elements into position by crane, sliding junction re-bar in loops and grouting.

6.4. Results and Data Analysis

Analysis methods and equations for measuring the cost and waste generation of concrete works are described below.

6.4.1. Total Cost for each Method

The total cost for each method according to ICBQ (2013), was calculated based on the following equations.

Cost of in situ concrete

The cost of in situ concrete works per cubic metre (C_{IN}) is expressed in Eq. (1)

$$C_{IN} = (\sum C_{MP} + \sum C_M + \sum C_E + C_S + C_O) / V_C \qquad \text{(Eq.1)}$$

where C_{MP} is cost of manpower, C_M is cost of materials, C_E is cost of equipment, C_S is cost of shattering, C_O is overhead cost, and V_C is volume of concrete work.

Cost of manpower includes masons and labour costs for transportation inside the site, making and pouring concrete, and any construction work within the site. Cost of materials includes the materials (fine and coarse aggregate, cement, water, etc.) and delivery to the site. Cost of equipment includes any machinery or equipment used in the process. Overhead costs include the cost of the contractor's internal expenditures and personnel.

Cost of ready-mix concrete

The cost of ready-mix concrete works per cubic metre (C_{RM}) is expressed in Eq. (2)

$$C_{RM} = (\sum C_{MP} + \sum C_M + \sum C_E + C_S + C_O) / V_C \qquad \text{(Eq.2)}$$

where C_M includes the cost of purchased concrete.

Cost of pre-fabricated concrete elements

The cost of pre-fabricated concrete elements method per cubic metre (CP) is expressed by Eq. (3)

$$C_P = \sum C_{MP} + \sum C_M + \sum C_E + C_O) / V_C \qquad \text{(Eq.3)}$$

where C_M includes the cost of purchased pre-fabricated elements and C_E includes the cost of a crane if required for installation (ICBC 2014).

6.4.2. Measuring Waste Generated

The total waste generated from each method was calculated based on the following equations (De Silva and Vithana, 2008).

$$W = M_A - M_R \qquad \text{(Eq.4)}$$

$$W(\%) = (W / M_R) \times 100 \qquad \text{(Eq.5)}$$

where W is amount of waste generated in cubic metres, M_A is the quantity of actual material (concrete) used by volume, and M_R is the quantity of required materials based on the structural drawings. In other words, M_A is the purchased amount in cubic metres and M_R is the measurement in cubic metres of concrete works in the project plan.

Equations (1), (2), (3), (4), and (5) were used to calculate the collected data from the case study and determine the total cost of each method and waste generated in the Tehran case study project. The results are presented in Table 6.1 and illustrated in Figures 6.1 and 6.2.

Table 6.1. Cost and concrete waste generated by method

Concrete work method	Total amount of concrete works (m^3)	Cost per cubic metre of concrete	W=Total waste generated (m^3)	W (%)
In situ concrete (Floors 5 & 6)	470	Equal to £72	4.5	0.96
Ready-mix concrete (Floors 3 & 4)	470	Equal to £103	4.3	0.91
Pre-fabricated elements (Floors 1 & 2)	470	Equal to £170	0.04	0.01

Source: Author

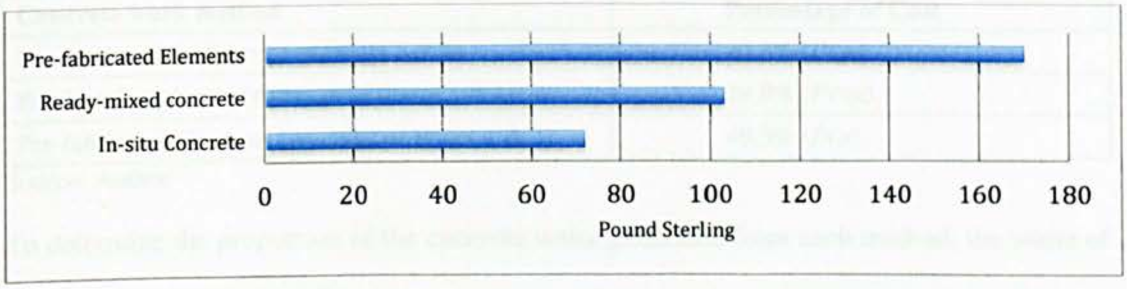


Fig. 6.1. Total cost of methods per cubic metre (Source: Author)

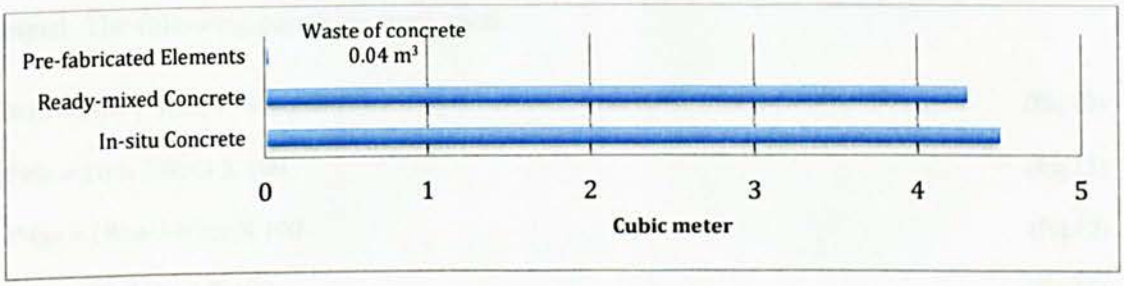


Fig. 6.2. Concrete waste generated by method (Source: Author)

To determine the proportions of expenditure for each method, the cost percentages of each method are needed. The percentage of the cost of each method in comparison to the total cost of concrete works was calculated by the following equations:

$C_{TC} = C_{IN} + C_{RM} + C_{P}$ (Eq.6)

$P_{C_{IN}} = (C_{IN} / C_{TC}) \text{ X } 100$ (Eq.7)

$P_{C_{RM}} = (C_{RM} / C_{TC}) \text{ X } 100$ (Eq.8)

$P_{C_{P}} = (C_{P} / C_{TC}) \text{ X } 100$ (Eq.9)

where C_{TC} is the total cost of concrete works, $P_{C_{IN}}$ is the percentage of cost of in situ concrete works, $P_{C_{RM}}$ is the percentage of cost of ready-mix concrete works, and $P_{C_{P}}$ is the percentage of cost of pre-fabricated concrete works.

By using equations (6), (7), (8), and (9), the cost percentages of each method in terms of the total cost of concrete works were determined. The results are presented in Table 6.2.

Table 6.2. Cost percentages of methods

Concrete work method	Percentage of Cost
In situ concrete (Average of floors 5 & 6)	20.8% (PC_{IN})
Ready-mix concrete (Average of floors 3 & 4)	29.9% (PC_{RM})
Pre-fabricated elements (Average of floors 1 & 2)	49.3% (PC_{P})

Source: Author

To determine the proportion of the concrete waste generated from each method, the waste of each method was divided by the total amount of concrete waste generated by all three methods. This was done because the planned volume of concrete works on each floor was equal. The following equations were used:

$$W_{TC} = W_{IN} + W_{RM} + W_{P} \qquad \text{(Eq.10)}$$

$$PW_{IN} = (W_{IN} / W_{TC}) \text{ X } 100 \qquad \text{(Eq.11)}$$

$$PW_{RM} = (W_{RM} / W_{TC}) \text{ X } 100 \qquad \text{(Eq.12)}$$

$$PW_{P} = (W_{P} / W_{TC}) \text{ X } 100 \qquad \text{(Eq.13)}$$

where W_{TC} is total concrete waste, W_{IN} is concrete waste generated from in situ concrete, W_{RM} is concrete waste generated from ready-mix concrete, W_{P} is concrete waste generated from pre-fabricated elements, PW_{IN} is the percentage of waste generated from in situ concrete works of total concrete waste, PW_{RM} is the percentage of waste generated from ready-mix concrete works of total concrete waste, and PW_{P} is the percentage of waste generated from pre-fabricated concrete elements of total concrete waste.

Equations (10), (11), (12), and (13) were used to measure the waste generated from each method. The results are shown in Table 6.3, which illustrates the percentage of concrete waste of each method in terms of the total amount of concrete waste for all concrete works.

Table 6.3. Waste of concrete by volume

Concrete work method	Total Concrete Works	Concrete Waste	Percentage of Total Concrete Waste
In situ concrete (Average of floors 5 & 6)	235 m^3	2.25 m^3	50.9 (PW_{IN})
Ready-mix Concrete (Average of floors 3 & 4)	235 m^3	2.15 m^3	48.3 (PW_{RM})
Pre-fabricated elements (Average of floors 1 & 2)	235 m^3	0.02 m^3	0.8 (PW_{P})

Source: Author

Finally, in order to illustrate the differences between the methods in a more comprehensible way, the following figures were created, which show the cost (Fig. 6.4) and waste generation (Fig. 6.3) proportions associated with each method.

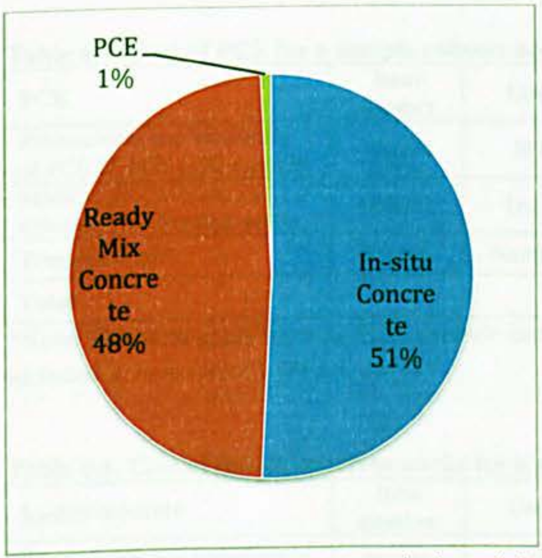


Fig. 6.3. Percentage of concrete waste generation by methods
(Source: Author)

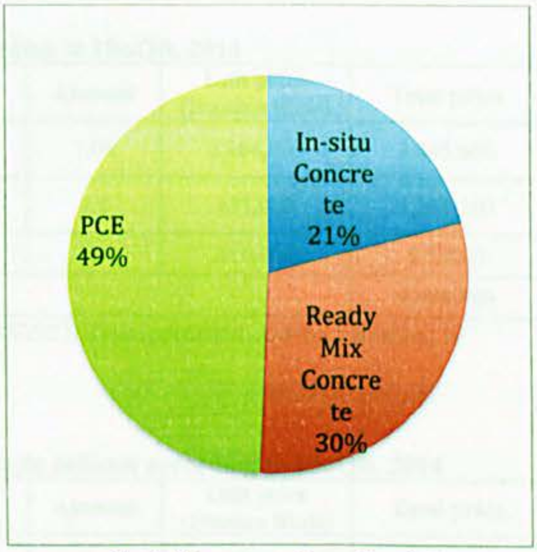


Fig. 6.4. Percentage of cost of methods
(Source: Author)

The case study observations indicate that the use of pre-fabricated concrete elements had the greatest cost and least on-site concrete waste in comparison with the other two methods. On the other hand, in situ concrete (making concrete on-site) had the least cost and produced the most concrete waste. However, the amount of waste generated from using ready-mix concrete can significantly increase due to poor purchase management, excess ordering of materials, large quantities of concrete remaining in the pump car and pump pipe, and poor quality workmanship on-site (De Silva and Vithana, 2008). Therefore, it appears that Iranian contractors would prefer to use either in situ or ready-mix concrete instead of pre-fabricated elements due to their high cost. Contractors would rather pay the tax for waste instead of paying nearly double the concrete price in order to reduce waste by a maximum 0.95%.

The study below has been conducted in order to investigate more in-depth about the significant difference between cost of PCEs and in-situ concrete in Iran. Therefore, price of the sample column (dimensions=0.6 x 0.6 x 3 m, transportation distance for material 30km) was calculated according to the Iran's Book of Bills of Quantities for Buildings (IBoQB, 2014) published by Planning and Budgeting Organisation of Iran (PBOI, 2014) for each of these methods (PCE and in-situ). Price of re-bars is exclusive, as the same amount would be added to both methods. Unit prices and Item numbers were extracted from IBoQB (2014).

Table 6.4. Cost of PCE for a sample column according to IBoQB, 2014

PCE	Item number	Unit	Amount	Unit price (Iranian Rials)	Total price
Procurement and instalment of PCE 25 MPa (350 Kg/m3)	120204	M3	1.08	2,264,500	2,445,660
Material procurement and execution of Grouting works	080502	Dm3	7.2	171,000	1,231,200
Transportation*	421006	Number	1	810,000	810,000
Total					**4,486,860**

*Note: This item apply for only PCE, exclude item 080502. Transportation cost for Grouting is included in item 080502 (PBOI, 2014)

Table 6.5. Cost of in-situ concrete works for a sample column according to IBoQB, 2014

In-situ concrete	Item number	Unit	Amount	Unit price (Iranian Rials)	Total price
Procurement and execution of Shuttering	060301	M2	7.2	188,000	1,353,600
Material procurement and execution of in-situ concrete 25 MPa	080107	M3	1.08	876,000	946,080
Total					**2,299,680**

In another approach, cost of execution of a sample single PCE column (same dimensions as the above) was requested from a first grade contractor in Iran (Chosen from the same list that used for the questionnaire). The contractor was asked to provide the break done of the PCEs, ready mixed, and in-situ concrete work for procurement and erection of a single column in the project. Table 3 has compares the cost of three different works for the single column.

Table 6.6. Break done cost of three methods for concrete works

Costs	PCE	Ready-mixed	In-situ
Materials	PCE=1,500,000 Transportation= 800,000 Unloading in site= 200,000	Concrete=730,000	Cement=250,000 Water = 1,000 Aggregates= 50,000 Mixer and other equipment= 100,000
Execution	Crane=500,000 Manpower=800,000 Grout= 500,000	Shuttering and Pouring concrete= 1,200,000	Shuttering and Pouring concrete= 1,300,000
Overhead cost	200,000	600,000	300,000
Total	4,500,000	2,530,000	2,000,000

Source: Author

The above studies can confirm the significant differences between the cost of these three mentioned methods for concrete works, although these numbers cannot be generalized for whole concrete works as these prices are for a sample column and the total prices can be different according to the situation and amount of the total work.

Finally, as discussed earlier, these presented case studies focused only in concrete waste production on-site. Therefore concrete waste productions of PCEs or ready-mixed concrete in their manufacturers have not been calculated in this study. However according to the literature and as it is been claimed by several PCEs manufacturers, waste generation of the PCE production process can be as little as 0.6 %. For instance: According to MPA (2010) the pre-fabricated concrete sector in the UK uses more waste than it produces. One tonne of pre-fabricated product consumes 218kg of secondary materials and by-products and produces only 6kg of waste that goes to landfill. Moreover, according to WRAP (2012) PCEs manufacturers in manufacturing process can generate less than 1% waste. Some reasons for reduced waste in production process of PCEs in comparison with in-situ concrete according to WRAP (2007) would be:

- Lack of long and continuous concrete-making and pouring operations
- Significant decrease or even prevention of temporary shuttering
- Controlled curing of concrete
- Enhanced quality control at manufacturing location
- No unforeseeable stops during the concrete works due to weather conditions

Also, in ready-mixed manufacturer, modern formwork systems and efficient site management can reduce ready-mixed concrete wastage, which is estimated at less than 2 per cent. Systems are available to re-use 'returned ready-mixed concrete' and this does not go to landfill.

However waste production during the demolition process for all three concrete work methods (PCEs, ready-mixed, and in-situ) seems to be equivalent, although it has been claimed that some PCEs can be re-used further in projects.

6.5. Validity and Reliability of the Research

In this study, validity was guaranteed by using proper data collection methods and ensuring the validity of data sources (Saunders et al., 2009). Reliability was achieved by clarifying general rules and adopting detailed procedures (Voss et al., 2002). The validity of this research was determined according to the following standards (Bryman, 2012; Yin, 2008):

- Construct validity: refers to determining proper measurements for the concepts studied. In this research, construct validity was mostly applied to data collection implementation.
- Internal validity: refers to the extent to which the causal relationships discovered between causes and effects in the research are valid. In this research, internal validity was mostly applied to data analysis implementation.
- External validity: refers to the extent to which the results of the research can be generalized to other cases. In this research, external validity was mostly applied to the research design.

This research was considered reliable since the results could be replicated if the same design is implemented by other researchers or in another time (White, 2000). In the following sections, initiatives implemented to improve validity and reliability of the research are discussed. These initiatives are illustrated in separate sections for qualitative and quantitative methods.

6.5.1. Qualitative Methods

In this research, the validity of the data collected through qualitative methods were achieved using proper data collection techniques, ensuring the validity of the sources of the data (Saunders, Lewis & Thornhill, 2009). The reliability of the data and outcomes were enhanced through clarifying general rules and detailed procedures (Voss, Tsikriktsis & Frohlich, 2002), detailed documenting, and database development (Willig & Maidenhead, 2008). The particular initiatives employed in the qualitative methods are presented in Table 6.4.

Table 6.7. Validity and reliability improvement initiatives of qualitative methods

Validity/Reliability Concept	Employed Initiatives	Associated Research Phase
Construct Validity	Adequate definition of variables and measurement (Creswell, 2008).	Literature survey, case study and interviews.
Internal & External Validity	Triangulation. Secondary data quality control criteria (Scott, In: Mogalakwe, 2006). Small sample size to minimize validity threats in qualitative data collection (Creswell & Plano Clark, 2010).	Literature survey, case study and interviews. Literature survey and case study. Case study and semi-structured interviews.
Reliability	Checking data for participant and observer errors. Selecting a purposive sample frame to reduce sample frame bias (White, 2000) and observer tendency bias (Burton-Jones, 2009).	Literature survey, case study and interviews. Case study and interviews.

Source: Author

6.5.2. Quantitative Methods

The validity of quantitative methods in this research was generally enhanced by adopting appropriate sampling and data collection approaches (Creswell & Plano Clark, 2010; Saunders, Lewis & Thornhill, 2009). To improve the reliability of quantitative methods, attempts were made to eliminate or restrict subject and participant errors, subject and participant bias, observer errors, and observer bias (Saunders, Lewis & Thornhill, 2009). Table 6.5 indicates the initiatives employed to improve validity and reliability of the quantitative research methods used.

Table 6.8. Validity and reliability improvement initiatives of quantitative methods

Validity/Reliability Concept	Employed Initiatives
Construct Validity	Adequate definition of variables and measurement (Creswell, 2008).
Internal and External Validity	Triangulation. Large sample size to achieve a high level of certainty and precision (Ghauri, P.N. and Gronhaug, 2005; Saunders, Lewis and Thornhill, 2009).
Reliability	Checking data for participant and observer errors. Using delivery and collection administration approaches to reduce non-response bias (Saunders, Lewis and Thornhill, 2009). Providing clear definitions about overrun factors to reduce participant misunderstandings.

Source: Author

6.6. Summary

The case study aimed to examine concrete waste production and the associated costs of three different methods of making and pouring concrete in a construction project in Tehran. The triangulation research approach was used in this study, which is a combination of quantitative and qualitative approaches. The data collection methods used were interviews accompanied by the collection of hard documentary data. Semi-structured interviews and audits of cost and waste were conducted as well.

The results of the case study indicate that the use of pre-fabricated concrete elements is the most costly (£170 per cubic metre of concrete) and produces the least on-site concrete waste (0.01% waste production) than the other two methods. In situ concrete is the least costly (£72 per cubic metre of concrete), and produces the most concrete waste (0.96% waste production). Furthermore, although there is a significant reduction in waste when pre-fabricated elements are used, the consultants and contractors involved in the case study were not interested in using this method in their projects in the Iranian construction industry due to the high costs involved. Finally, although there are some other ways for reducing the concrete waste apart from wider usage of PCEs, the reason for focusing on PCEs was because this method has been completely ignored in Iran at the moment.

Some recommendations for implementation are highlighted. Waste associated with ready-mix concrete can be reduced by proper purchase management, accurate ordering of materials, and decreasing the quantity of concrete remaining in the pump car and pump pipe. In addition, high quality workmanship at the site level and education and training could also help to reduce waste. Recommendations for further study are also outlined. More research needs to be conducted regarding issues with using pre-fabricated elements in Iran in order to explore the reasons for their high cost. By conducting such research, the main drivers of the high cost of pre-fabricated elements can be determined. By reducing the cost of using pre-fabricated elements, this method can be implemented in more construction projects in Iran in the future as the most preferred method of concrete waste minimization.

7. Propose a Framework in Iran

7.1. Introduction

This chapter presents the development and validation of the proposed on-site concrete waste minimisation framework (OCWMF) for construction projects, which could be potentially applicable and achievable in Iran by focusing on motivating the projects' stakeholders to use prefabricated concrete elements (PCE). The OCWMF illustrates the barriers of using PCE in Iran and attempts to offer recommendations can increase PCE usage in Iran in order to improve current waste minimisation in the country. The case study in the present research confirmed that using PCE significantly decreased the amount of concrete waste production on-site. Interviews and case study observation in Iran also identified several barriers to using PCE.

The first section of this chapter presents the development process of the OCWMF, which is based on the findings from the literature review (Chapter 2), surveys in the UK (Chapter 4), surveys in Iran (Chapter 5), and the case study (Chapter 6). This section also describes the development methodology for the OCWMF and its key components.

The second section of this chapter presents the OCWMF validation process, describes the methodological approach, and analyses the results.

The third section summarises the key improvement that emerged from the validation process and presents key actions taken to amalgamate suggestions for potential improvements to the OCWMF.

7.2. OCWMF Design and Development

7.2.1. OCWMF Development Methodology

Problem-solving methodology is an effective approach to understanding and exploring solutions to improve issues related to a particular situation. The general problem-solving methodology aims to rectify a situation where what is happening is less than desirable by specifically addressing the situation (Straker, 1995). One of the easiest ways to explain this methodology is the DRIVE technique (Table 7.1).

Table 7.1. DRIVE technique

Define	Define the scope of the problem, the criteria by which success will be measured, and the agreed upon deliverables and success factors
Review	Review the current situation, understand the background, and identify and collect information, including performance, identify problem areas, improvements, and 'quick wins'
Identify	Identify improvements or solutions to the problem and required changes to enable and sustain the improvements
Verify	Check that the improvements will bring about benefits that meet the defined success criteria and prioritise and pilot the improvements
Execute	Plan the implementation of the solutions and improvements, agree and implement them, plan a review, gather feedback, and review

Source: Gamage, 2011

Serpell and Alarcon (1998) developed a construction process improvement methodology (CPIM) to improve the construction process and reduce waste (Figure 7.1). The foundation of CPIM is a traditional problem-solving methodology, which is quite similar to the DRIVE technique.

The key principles of CPIM are, first, to diagnose the current issues, including whether the current situation is less than desirable and, second, to identify improvement measures, aiming to move improvement activities forward.

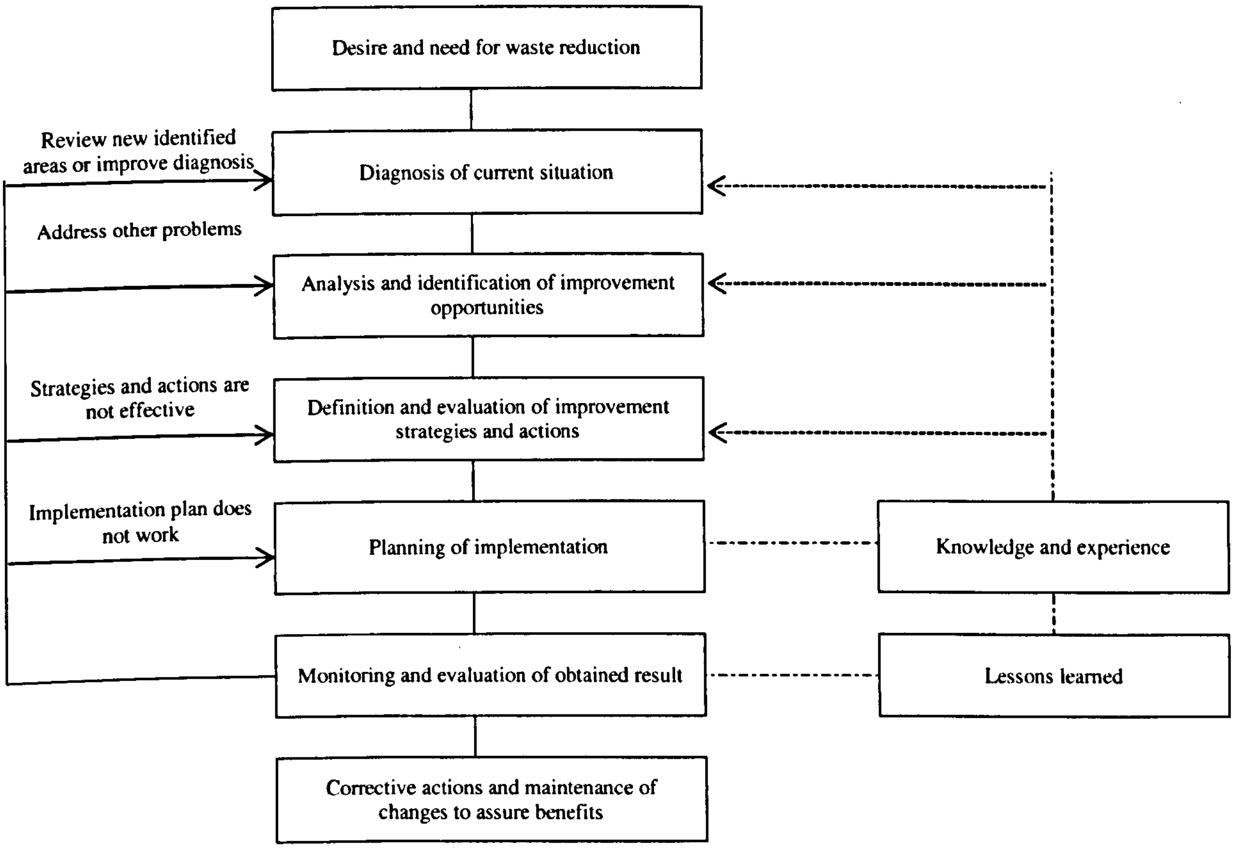


Fig. 7.1. Construction Process Improvement Methodology (CPIM)
(Serpell and Alarcon, 1998)

The application of general problem-solving methodology to the outcomes of this study (literature review, questionnaire surveys, interviews, case study findings) helps to arrange the outcomes in a logical order (refer to section 3.9).

The findings of this research cover three key aspects: identification of the preferred methods of on-site concrete waste minimisation on construction sites in the UK and Iran; identification of differences between preferred methods in the UK and Iran' and examination of the reasons for differences between preferred methods in these two countries. As discussed previously, the main difference between on-site concrete waste minimisation methods in the UK and Iran, which has been confirmed also through case study, is the use of PCE.

7.2.2. Aim of the OCWMF

The proposed OCWMF analyses the reasons for differences between preferred on-site concrete waste minimisation methods in the UK and Iran (particularly avoidance of PCE by project stakeholders in Iran) and attempts to propose improvement to current waste minimisation efforts in Iran. It is expected that the proposed OCWMF will provide assistance to professionals in determining reasons for not using PCE in Iran and respective potential waste minimisation improvement in the country.

7.2.3. Structure of the OCWMF

The structure of the proposed OCWMF constitutes following aspects:

The OCWMF: constitutes three stages:

Stage 1 presents an overview of the main reasons for not using PCE in Iran, with regards to the interviews and case study;

Stage 2 presents the sub-reasons that are linked to the stage 1 and provides detailed information to diagnose specific reasons; and

Stage 3 presents respective recommendations to improve usage of PCE in Iran related to each sub-reasons in the second stage for all involved parties (policymakers, clients, designers engineers, contractors, PCE manufacturers and suppliers).

Axis: Horizontal and vertical axes represent the reasons of avoiding use of PCE in Iran and the barriers involved, respectively.

Coding system: The OCWMF is subjected to a coding system that correlates to the first two stages of OCWMF (identification of reasons), and the next stage proposed recommendations for each reasons identified in the first two stages.

As previously discussed, the main confirmed difference between on-site concrete waste minimisation methods used in the UK and those used in Iran is the implementation of PCE. This was identified through the process shown in Table 7.2

Table 7.2. Identification of differences between on-site concrete waste minimisation methods (UK vs. Iran)

Methods identified in literature review	Methods identified after interviews in the UK	Differences between preferred methods in the UK and Iran after questionnaires in the UK and Iran	After interview in Iran	After case study in Iran
Governmental incentives to reduce waste	Governmental incentives to reduce waste	Use of prefabricated building components	Use of prefabricated building components	Use of prefabricated building components
Use of prefabricated building components	Use of prefabricated building components	Use of ready-mixed concrete	Use of ready-mixed concrete	
Education and training	Education and training	Implementation of environmental management systems		
Implementation of environmental management systems	Purchase management			
Waste prevention during on-site transport	On-site inventory management			
Identification of available recycling facilities	Implementation of environmental management systems			
Use of information technology on-site	Waste prevention during on-site transport			
On-site reuse	Identification of available recycling facilities			
On-site waste conservation	Use of information technology on-site			
Implementation of environmental management systems	On-site reuse			
Central area for cutting and storage	On-site waste conservation			
On-site waste recycling operation	Quality management			
	Central area for cutting and storage			
	On-site waste recycling operation			
	Proper site layout planning			

Source: Author

7.2.4. Stage 1 of the OCWMF

Several researchers have identified the barriers of using PCE in different countries (e.g. Tam et al., 2007d). The first stage of OCWMF is generic and provides an overview of the main reasons of avoiding use of PCE in Iran. The horizontal axis of the first stage chart includes the four key areas that describe why PCE are not used in Iran. In retrospect, the prioritised and clustered result analysis of the interviews and case study in Iran culminated in the identification of four thematic areas: cost, execution issues, availability, and lack of attention to construction waste management (Figure 7.2).

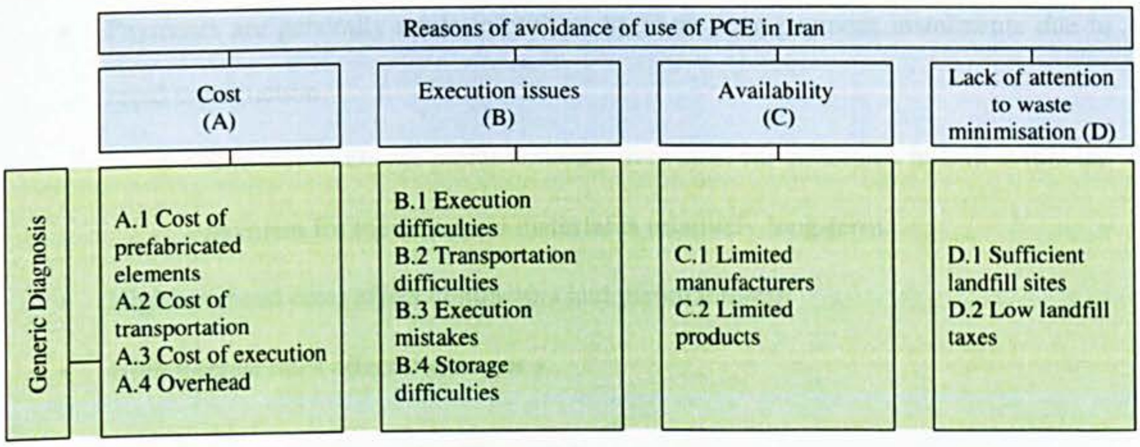


Fig. 7.2. Main reason areas of not using PCE in Iran

7.2.5. Stage 2 of the OCWMF

Each of the four main areas in the Stage 1 of the OCWMF represent one key reason area: (A) cost, (B) execution issues, (C) availability, and (D) lack of attention to construction waste management in Iran. The second stage of OCWMF components follows the same rationale. The components in the second stage are designed according to the first stage of OCWMF with regard to the aspects denoted by the horizontal axis, the vertical axis, and the coding system (Figures 7.3 and 7.4). However, the last two areas had no sub-reasons (Figures 7.5, and 7.6).

Cost (A)

The interview and case study findings both revealed that the cost of using PCE is one of the main reasons project stakeholders avoid using them. During the interviews and case study in Iran, the following causes were claimed regarding cost.

- PCE are very expensive in Iran compared to other concrete work methods.
- Low-cost labour and manpower affect the contractor and client.
- Costs have increased due to the high cost of machinery, and high cost of fuel, all of which affect the manufacturer.
- High inflation rates can affect contractors, clients, and suppliers.
- Unforeseen inflation can affect contractors, clients, and suppliers.

- Payments are generally made in cash or by short-term payment instalments due to rapid construction.
    - One reason clients prefer concrete over steel for structures in Iran is that the payment for the structural material is relatively long-term.
- High overhead costs affect contractors and manufacturers.
- High interest rates affect contractor s.

The above reasons are summarised in Figure 7.3.

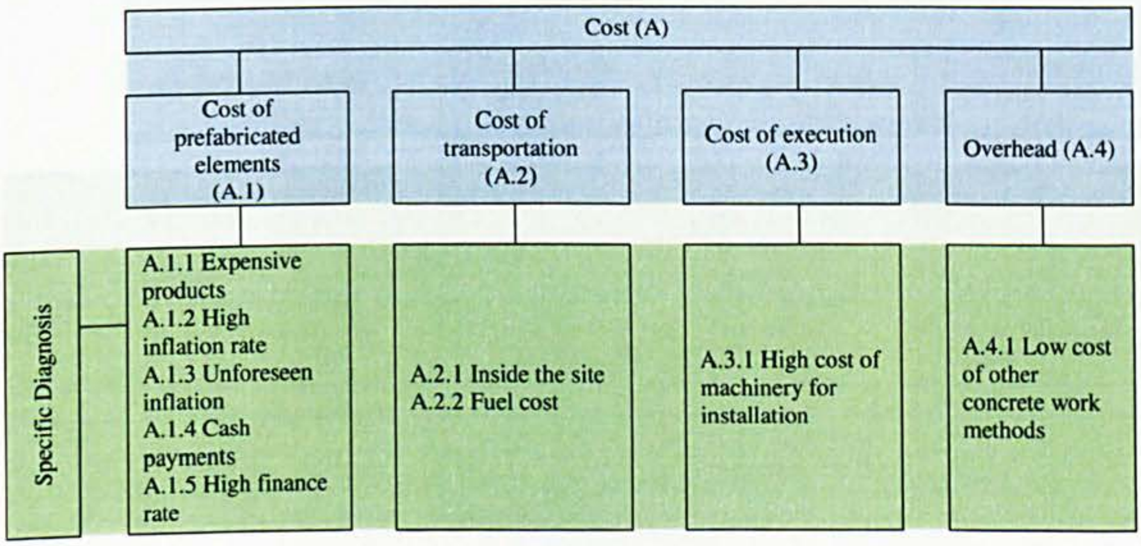


Fig. 7.3. Specific reasons for not using PCE related to cost

Execution issues

In light of the results provided in the study, execution issues and impacts on use of PCE are as follows:

- Site lacks adequate space for a crane to move and install concrete elements.
- On-site storage is difficult.
- Just-in-time ordering is very difficult in Iran because of traffic regulations and congestion.
- Delays in delivery may occur due to unreliable suppliers.

- Delays in delivery may occur due to traffic congestion in major cities such as Tehran.
- Delays in delivery may occur due to traffic regulations.
- Mistakes may be made due to a lack of experienced contractors and subcontractors for execution of prefabricated elements, unclear drawings, and incomplete execution details.

A summary of the above reasons is presented in Figure 7.4.

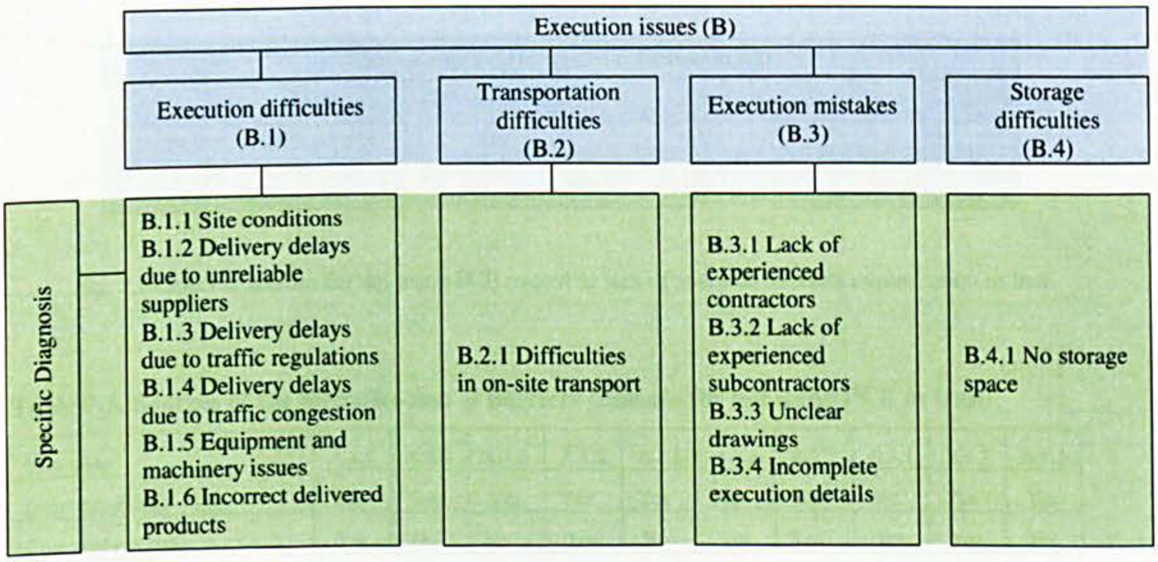


Fig. 7.4. Specific reasons for not using PCE related to execution issues

Availability

The research findings suggest that limited manufacturers and limited product availability are two main reasons of lack of availability of PCE in Iran, as shown in Figure 7.5.

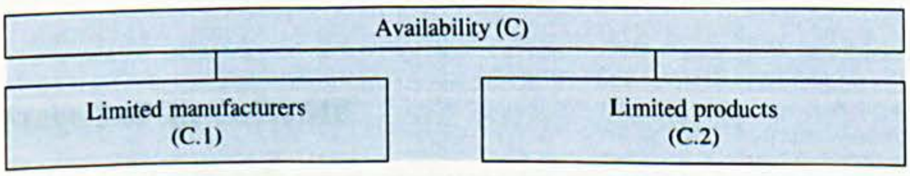


Fig. 7.5. Specific reasons for not using PCE related to availability

Lack of attention to waste minimisation in Iran

The below components have been identified through semi-structured face-to-face interviews in Iran or Case study in Iran. Table 7.3 illustrates the source of barrier identifications.

- Low landfill taxes
- Sufficient landfill sites at the moment
- Lack of proper legislation to reduce and control waste production

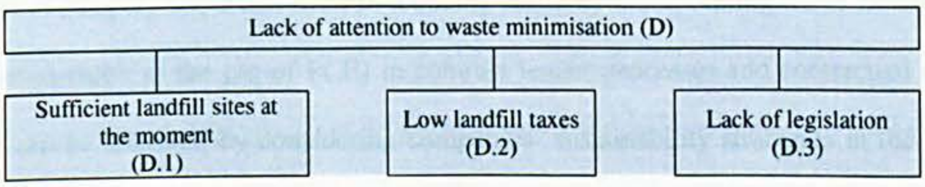


Fig. 7.6. Specific reasons for not using PCE related to lack of attention to waste minimisation in Iran

Table 7.3. Sources of the identification of barriers (reasons for not using PCE in Iran)

Item code	A.1.1	A.1.2	A.1.3	A.1.4	A.1.5	A.2.1	A.2.2	A.3.1	A.4.1	B.1.1
Interview in Iran	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes
Case study in Iran	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes

Item code	B.1.2	B.1.3	B.1.4	B.1.5	B.1.6	B.2.1	B.3.1	B.3.2	B.3.3	B.3.4
Interview in Iran	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No
Case study in Iran	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes

Item code	B.4.1	C.1	C.2	D.1	D.2	D.3
Interview in Iran	Yes	Yes	Yes	Yes	Yes	Yes
Case study in Iran	Yes	Yes	Yes	Yes	No	Yes

7.2.6. Stage 3 of the OCWMF

In the third stage of OCWMF, recommendations are proposed to improve usage of PCE in Iran, which could potentially be used for each reason in the second stage of OCWMF, are presented. These recommendations were determined through the interviews or the case study in Iran or were proposed by the author.

Recommendations for the construction industry

The research participants provided the following recommendations during interviews.

- Design stage: Although this project stage was not directly included in the research, clear specifications, high-quality design, and reducing errors can minimise concrete waste.
- Tender and contractual agreement stages: In this stage, the client, contractor, and architect can play important roles in reducing waste by incorporating waste minimisation activities (such as the use of PCE) in contract tender processes and contractual clauses. This can be achieved by considering companies' sustainability strategies in the bidding process.
- Construction stage: Effective on-site measures can be taken based on the results of this research. Industry stakeholders can increase investment in prefabrication to decrease the actual cost of prefabricated elements, consequently reducing waste.

Recommendations for policymakers

The recommendations provided below can accomplish two goals:

- Increase the cost of waste generation
- Reduce the cost of PCE (for instance, energy subsidies for PCE manufacturers)

Policy, legislation, and guidelines

A range of legislative, fiscal, and policy frameworks is required to affect concrete waste generation. Detailed legislation should to be prepared and publicized to ensure effective waste minimisation and compliance with waste management strategies. Legislation should discourage the waste of resources as well. Policy and legislation should motivate the construction sector through tactics such as funding, tipping reduction, tax reduction, and rapid granting of permissions and licenses. The prefabricated concrete industry can be endorsed by applying simple methods that increase the possibility of usage of PCE such as promoting the private sector and universities to investigate innovative methods of reducing the cost of PCE use in construction. Contractors and designers should be encouraged to use PCE to reduce waste production. High financial penalties for over-limit waste generation is mentioned in the literature as a general recommendation as well.

Government support

The government in Iran is undoubtedly one of the main stakeholders in the establishment of the construction materials market. The government should visibly support the goals listed above by promoting the use of PCE and discouraging traditional in situ concrete methods. Governments in some countries, including China, have already banned the use of in situ concrete for construction projects due to environmental problems. Suggestions regarding this area are:

- Incentives for contractors, clients, manufacturers, and suppliers to encourage use of PCE
- Payment of subsidies to manufacturers (e.g., a fuel subsidy) to reduce product prices

A summary of the recommendations to increase usage of PCE is presented in Table 7.4, which was used to validate the results of questionnaire and interviews.

Table 7.4. Recommendation to increase usage of PCE in Iran

Item code	Policymakers (PM)	Clients (CL)	Designers &Engineers (DE)	Contractor (CO)	Manufacturer (MF)	Supplier (SU)
A.1.1	Incentives for using PCE	N/A	N/A	N/A	1. Decreased overhead costs 2. Use of updated machinery and equipment	Use of updated machinery and equipment
A.1.2	Complicated	N/A	N/A	N/A	N/A	N/A
A.1.3	Complicated	Well-established contracts	N/A	Well-established project budgeting	N/A	N/A
A.1.4	Low interest rate financing (e.g., loans)	N/A	N/A	1. Well-established project budgeting and financing 2. Improving supply chain management	Acceptance of instalment payments	Acceptance of instalment payments

Item code	Policymakers (PM)	Clients (CL)	Designers &Engineers (DE)	Contractor (CO)	Manufacturer (MF)	Supplier (SU)
A.1.5	Complicated					
A.2.1	N/A	Handing over as much of the site as possible	N/A	Proper site layout planning	N/A	N/A
A.2.2	Specific subsidy	Reimbursement	N/A	Proper site layout planning	N/A	N/A
A.3.1	Reduce import tax	N/A	N/A	1. Financing 2. Qualified subcontractors	N/A	N/A
A.4.1	1. Penalty charges for over-limit waste production 2. Increase minimum wage 3. Work regulations, for instance,banning in-situ concrete	N/A	1. Site observation 2. Quality control	N/A	N/A	N/A
B.1.1	N/A			– Proper site layout planning – Proper site management	N/A	N/A
B.1.2	Grading suppliers			Purchase management		1. Supply chain 2. Reputation
B.1.3	Specific permissions	N/A	N/A	Permissions	N/A	Permissions
B.1.4	Complicated			Night shift		Night delivery
B.1.5	1. Import facilities 2. Education & training	Experienced contractors	Proper design of elements	1. Qualified subcontractor 2. Education & training	Use of updated machinery and equipment	Use of updated machinery and equipment
B.1.6	1. Grading suppliers 2. Grading manufacturers 3. Standardization	N/A	N/A	Qualified supplier	1. Qualified supplier 2. Quality control	Quality control
B.2.1	N/A	N/A	Proper design of elements	1. Proper site layout planning 2. Proper site management	N/A	N/A
B.3.1	Complicated	Experienced contractors			N/A	N/A
B.3.2	Education & training			1. Experienced subcontractor choose 2. Education & training	N/A	N/A
B.3.3	N/A	Document control	1. Drawing quality checks 2. Experienced consultants	Document control	N/A	N/A
B.3.4	N/A	Document control	1. Drawing quality checks 2. Experienced consultants	Document control	N/A	N/A
B.4.1	N/A	Handing over as maximum site as possible	N/A	1. Proper site layout planning 2. Proper storage management	Proper packaging	
C.1	1. Paying subsidies 2. Incentives for PCE production	More demand	More demand	More demand	1. Investment 2.Export goals and global market	N/A
C.2	1. Incentives for PCE production 2. Import facilities	More request for use	More use in design		1.Productivity 2. Global market	Import

Item code	Policymakers (PM)	Clients (CL)	Designers &Engineers (DE)	Contractor (CO)	Manufacturer (MF)	Supplier (SU)
D.1	1. Long-term plans 2. Sustainability departments	Consideration in the contract	N/A	N/A	N/A	N/A
D.2	Increase landfill tax	N/A	N/A	N/A	N/A	N/A
D.3	More legislation and regulations	Consideration in contractors' CSR strategies	Consulting services	Education & training	N/A	N/A

7.3. Validation of the Proposed OCWMF

7.3.1. Validation Aim and Objectives

The aim of the validation is to refine and examine the appropriateness of the reasons for not using PCE and recommendations to increase the use of PCE in Iran to help minimise on-site concrete waste and discuss implementation strategy.

The following validation objectives are:

1. Determine the clarity, information flow, and appropriateness of the proposed OCWMF components.
2. Examine the appropriateness and practicalities of the recommendations.
3. Identify the most effective recommendations to increase usage of PCE in Iran.

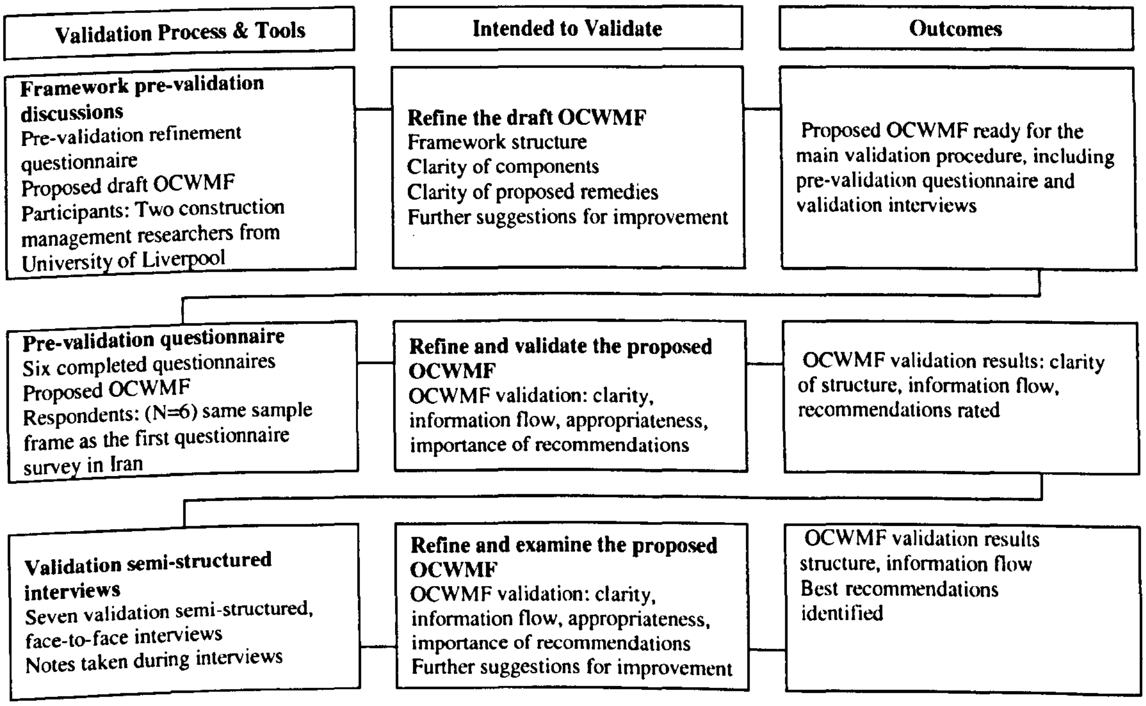
7.3.2. Validation Approach and Respondents' Profiles

The OCWMF validation procedure consists of three stages. Initially, several discussions were conducted with two construction management researchers from the University of Liverpool as a pilot study in order to refine the developed OCWMF prior to the actual validation process. The next step of the validation approach was administration of a pre-validation questionnaire followed by semi-structured interviews. The pre-validation questionnaire was conducted to refine the OCWMF in terms of clarity, information flow, and appropriateness of components and to narrow down the recommendations. Subsequently, validation interviews were conducted to further refine and examine the appropriateness and choose the most suitable and effective recommendations. Six participants from the first questionnaire survey sample frame in Iran agreed to complete in the pre-validation questionnaire. Five out of ten interviewees from the first round of interview data collection in Iran agreed to participate in the validation interviews in addition to two high-level managers from the Tehran Construction Waste Management Organisation, resulting in seven total interviewees. Table 7.5 provides the respondents' profiles for the validation interviews in Iran.

Table 7.5. Respondents' profiles

Participant	Position	Construction industry experience (years)	Education
Interviewee 1	Contractor's project manager	40	MSc
Interviewee 2	Site superintendent	38	MSc
Interviewee 3	Site superintendent	35	MSc
Interviewee 4	Consultant	30	MA
Interviewee 5	Consultant	30	MA
Interviewee 6	Top manager from Tehran Construction Waste Management Organisation	35	MSc
Interviewee 7	Top manager from Tehran Construction Waste Management Organisation	32	MSc

The structure and flow chart of the OCWMF validation process is mapped in Figure 7.7 below.



Validation Process & Tools	Intended to Validate	Outcomes
Framework pre-validation discussions Pre-validation refinement questionnaire Proposed draft OCWMF Participants: Two construction management researchers from University of Liverpool	**Refine the draft OCWMF** Framework structure Clarity of components Clarity of proposed remedies Further suggestions for improvement	Proposed OCWMF ready for the main validation procedure, including pre-validation questionnaire and validation interviews
Pre-validation questionnaire Six completed questionnaires Proposed OCWMF Respondents: (N=6) same sample frame as the first questionnaire survey in Iran	**Refine and validate the proposed OCWMF** OCWMF validation: clarity, information flow, appropriateness, importance of recommendations	OCWMF validation results: clarity of structure, information flow, recommendations rated
Validation semi-structured interviews Seven validation semi-structured, face-to-face interviews Notes taken during interviews	**Refine and examine the proposed OCWMF** OCWMF validation: clarity, information flow, appropriateness, importance of recommendations Further suggestions for improvement	OCWMF validation results structure, information flow Best recommendations identified

Fig. 7.7. OCWMF validation process map

The findings of the validation procedure based on the pre-validation questionnaire and validation semi-structured interviews are discussed in the following section.

7.3.3. Validation Results

First step of validation

Clarity of the structure

The pre-validation questionnaire participants were asked to rate their level of agreement with provided statements regarding the clarity of the OCWMF from 1 (Strongly Disagree) to 5 (Strongly Agree). The results (Table 7.6) revealed that at least three-quarters of the respondents agreed or strongly agreed with that the proposed OCWMF was clear in terms of its structure, contents, and proposed recommendations. Interestingly, all respondents stated that the content presented in the OCWMF was familiar to them.

Table 7.6. Clarity of OCWMF (Pre-validation questionnaire respondents' views)

Clarity	Strongly Disagree	Disagree	Neither Dis/Agree	Agree	Strongly Agree
The structure of the proposed framework is clear				3 (50%)	3 (50%)
Clarity of procurement waste causes is clear			1 (16.7%)	2 (33.3%)	3 (50%)
Clarity of proposed recommendations is clear				2 (33.3%)	4 (66.7%)

All the interviewees mentioned that the proposed OCWMF has a clear structure that enables the user to view and understand links between its proposed elements. For instance, one interviewee explained, 'The OCWMF contents and links as well as the proposed recommendations are clearly established and apparent'.

OCWMF information flow

The pre-validation questionnaire participants were asked to rate their level of agreement with provided statements on the information flow of the OCWMF from 1 (Strongly Disagree) to 5 (Strongly Agree). The majority of participants stated that they agreed or strongly agreed that the information flow of the proposed OCWMF is clear with regard to the process and the relationships between reasons and the respective recommendations (Table 7.7).

Table 7.7. Information flow of OCWMF (Pre-validation questionnaire respondents' views)

Information flow	Strongly Disagree	Disagree	Neither Dis/Agree	Agree	Strongly Agree
The information flow of the framework is clear				3 (50%)	3 (50%)
The information flow of the reasons is clear				3 (50%)	3 (50%)
Information flow of the proposed recommendations is clear			1 (16.7%)	2 (33.3%)	3 (50%)

The majority of the interviewees (6) agreed that the information flow of the proposed OCWMF was clear. One participant said, 'The information flow provides a proper judgment as to what the problems are and target areas with solutions to those problems'.

Second step of validation

The pre-validation questionnaire respondents were asked to determine the impact of each reason for not using PCE in Iran. All respondents believed that cost of products, low cost of other concrete work methods, a limited number of manufacturer, limited products, and lack of legislation in Iran have the highest impact on decision not to use PCE in the country.

Table 7.8. Impact of main reasons on PCE usage in Iran (Pre-validation questionnaire respondents' views)

Causes	Low Impact (1)	Medium Impact (2)	High Impact (3)	Mean rating
A.1.1			6 (100%)	3
A.1.2	1 (16.7%)	5 (83.3%)		1.83
A.1.3	1 (16.7%)	5 (83.3%)		1.83
A.1.4		1 (16.7%)	5 (83.3%)	2.83
A.1.5	3 (50%)	2 (33.3%)	1 (16.7%)	1.67
A.2.1	3 (50%)	3 (50%)		1.5
A.2.2	3 (50%)	3 (50%)		1.5
A.3.1		2 (33.3%)	4 (66.7%)	2.67
A.4.1			6 (100%)	3
B.1.1	2 (33.3%)	2 (33.3%)	2 (33.3%)	2
B.1.2	3 (50%)	2 (33.3%)	1 (16.7%)	1.67
B.1.3	3 (50%)	2 (33.3%)	1 (16.7%)	1.67
B.1.4	3 (50%)	2 (33.3%)	1 (16.7%)	1.67
B.1.5	1 (16.7%)	3 (50%)	2 (33.3%)	2.17
B.1.6	4 (66.7%)	1 (16.7%)	1 (16.7%)	1.5
B.2.1	3 (50%)	2 (33.3%)	1 (16.7%)	1.67
B.3.1	5 (83.3%)	1 (16.7%)		1.17
B.3.2	2 (33.3%)	2 (33.3%)	2 (33.3%)	2
B.3.3	2 (33.3%)	2 (33.3%)	2 (33.3%)	2
B.3.4	2 (33.3%)	2 (33.3%)	2 (33.3%)	2
B.4.1	1 (16.7%)	1 (16.7%)	4 (66.7%)	2.5
C.1			6 (100%)	3
C.2			6 (100%)	3
D.1		1 (16.7%)	5 (83.3%)	2.83
D.2	1 (16.7%)	1 (16.7%)	4 (66.7%)	2.5
D.3			6 (100%)	3

The next section of the pre-validation questionnaire was dedicated to determining the appropriateness and importance of the proposed recommendations through an agreement scale of 1 (Strongly Disagree) to 5 (Strongly Agree). The results are shown in Table 7.9.

Table 7.9. Second step of refining recommendations

Recommendations for Policymakers

	Recommendation code	Strongly Disagree (1)	Disagree (2)	Neither Dis/Agree (3)	Agree (4)	Strongly Agree (5)	Mean rating
Cost related	PM - A.1.1					6 (100%)	5.00
	PM - A.1.4				3 (50%)	3 (50%)	4.50
	PM - A.2.2				1 (16.7%)	5 (83.3%)	4.83
	PM - A.3.1				1 (16.7%)	5 (83.3%)	4.83
	PM - A.4.1.1			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
	PM - A.4.1.2		1 (16.7%)	5 (83.3%)			2.83
	PM - A.4.1.3		1 (16.7%)	4 (66.7%)	1 (16.7%)		3.00
Execution related	PM - B.1.2			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	PM - B.1.3			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
	PM - B.1.5.1			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	PM - B.1.5.2					6 (100%)	5.00
	PM - B.1.6.1			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
	PM - B.1.6.2			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
	PM - B.1.6.3			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
	PM - B.3.2					6 (100%)	5.00
Availability related	PM - C.1.1				1 (16.7%)	5 (83.3%)	4.83
	PM - C.1.2					6 (100%)	5.00
	PM - C.2.1					6 (100%)	5.00
	PM - C.2.2	1 (16.7%)	1 (16.7%)	3 (50%)	1 (16.7%)		2.67
WM related	PM - D.1.1			5 (83.3%)	1 (16.7%)		3.17
	PM - D.1.2			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	PM - D.2	1 (16.7%)	1 (16.7%)	2 (33.3%)	1 (16.7%)	1 (16.7%)	3.00
	PM - D.3			1 (16.7%)	2 (33.3%)	3 (50%)	4.33

Recommendations for Clients

	Recommendation code	Strongly Disagree	Disagree	Neither Dis/Agree	Agree	Strongly Agree	Mean rating
Cost related	CL - A.1.3			5 (83.3%)	1 (16.7%)		3.17
	CL - A.2.1			5 (83.3%)	1 (16.7%)		3.17
	CL - A.2.2		1 (16.7%)	5 (83.3%)			2.83
Execution related	CL - B.1.5			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	CL - B.3.1				2 (33.3%)	4 (66.7%)	4.67
	CL - B.3.3	1 (16.7%)	1 (16.7%)	3 (50%)	1 (16.7%)		2.67
	CL - B.3.4	1 (16.7%)	1 (16.7%)	3 (50%)	1 (16.7%)		2.67
	CL - B.4.1			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
Availability related	CL - C.1			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
	CL - C.2			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
WM related	CL - D.1			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
	CL - D.3			1 (16.7%)	2 (33.3%)	3 (50%)	4.33

Recommendations for Designers and Engineers

	Recommendation code	Strongly Disagree	Disagree	Neither Dis/Agree	Agree	Strongly Agree	Mean rating
Cost related	DE - A.4.1.1		1 (16.7%)	1 (16.7%)	3 (50%)	1 (16.7%)	3.67
	DE - A.4.1.2				3 (50%)	3 (50%)	4.50
Execution related	DE - B.1.5				3 (50%)	3 (50%)	4.50
	DE - B.2.1			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	DE - B.3.3.1				2 (33.3%)	4 (66.7%)	4.67
	DE - B.3.3.2				2 (33.3%)	4 (66.7%)	4.67
	DE - B.3.4.1				2 (33.3%)	4 (66.7%)	4.67
	DE - B.3.4.2				2 (33.3%)	4 (66.7%)	4.67
Availability related	DE - C.1			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	DE - C.2			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	DE - D.3			1 (16.7%)	3 (50%)	2 (33.3%)	4.17

Recommendation for Contractors

	Recommendation code	Strongly Disagree	Disagree	Neither Dis/Agree	Agree	Strongly Agree	Mean rating
Cost related	CO - A.1.3		1 (16.7%)	4 (66.7%)	1 (16.7%)		3.00
	CO - A.1.4.1		1 (16.7%)	4 (66.7%)	1 (16.7%)		3.00
	CO - A.1.4.2			4 (66.7%)	1 (16.7%)	1 (16.7%)	3.50
	CO - A.2.1				5 (83.3%)	1 (16.7%)	4.17
	CO - A.2.2			4 (66.7%)	1 (16.7%)	1 (16.7%)	3.50
	CO - A.3.1.1	1 (16.7%)	1 (16.7%)	3 (50%)	1 (16.7%)		2.67
	CO - A.3.1.2	1 (16.7%)	1 (16.7%)	3 (50%)	1 (16.7%)		2.67
Execution related	CO - B.1.1.1				2 (33.3%)	4 (66.7%)	4.67
	CO - B.1.1.2			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	CO - B.1.2				3 (50%)	3 (50%)	4.50
	CO - B.1.3			3 (50%)	3 (50%)		3.50
	CO - B.1.4				3 (50%)	3 (50%)	4.50
	CO - B.1.5.1				3 (50%)	3 (50%)	4.50
	CO - B.1.5.2				2 (33.3%)	4 (66.7%)	4.67
	CO - B.1.6				2 (33.3%)	4 (66.7%)	4.67
	CO - B.2.1.1					6 (100%)	5.00
	CO - B.2.1.2				2 (33.3%)	4 (66.7%)	4.67
	CO - B.3.2.1				3 (50%)	3 (50%)	4.50
	CO - B.3.2.2					6 (100%)	5.00
	CO - B.3.3				1 (16.7%)	5 (83.3%)	4.83
	CO - B.3.4				1 (16.7%)	5 (83.3%)	4.83
	CO - B.4.1.1			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
	CO - B.4.1.2			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	CO - C.1	1 (16.7%)	1 (16.7%)	3 (50%)	1 (16.7%)		2.67
	CO - D.3	1 (16.7%)	1 (16.7%)	2 (33.3%)	1 (16.7%)	1 (16.7%)	3.00

Recommendations for Manufacturers

	Recommendation code	Strongly Disagree	Disagree	Neither Dis/Agree	Agree	Strongly Agree	Mean rating
Cost related	MF - A.1.1.1			6 (100%)			3.00
	MF - A.1.1.2				3 (50%)	3 (50%)	4.50
	MF - A.1.4			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
Execution related	MF - B.1.6.1		1 (16.7%)	3 (50%)	2 (33.3%)		3.17
	MF - B.1.6.2				2 (33.3%)	4 (66.7%)	4.67
	MF - B.4.1			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
Availability related	MF - C.1.1				2 (33.3%)	4 (66.7%)	4.67
	MF - C.1.2				1 (16.7%)	5 (83.3%)	4.83
	MF - C.2.1				1 (16.7%)	5 (83.3%)	4.83
	MF - C.2.2				1 (16.7%)	5 (83.3%)	4.83

Recommendation for Suppliers

	Recommendation code	Strongly Disagree	Disagree	Neither Dis/Agree	Agree	Strongly Agree	Mean rating
Cost related	SU - A.1.1			1 (16.7%)	2 (33.3%)	3 (50%)	4.33
	SU - A.1.4		1 (16.7%)	3 (50%)	2 (33.3%)		3.17
Execution related	SU - B.1.2.1			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	SU - B.1.2.2			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	SU - B.1.3		1 (16.7%)	3 (50%)	2 (33.3%)		3.17
	SU - B.1.4			1 (16.7%)	3 (50%)	2 (33.3%)	4.17
	SU - B.1.6.1				2 (33.3%)	4 (66.7%)	4.67
	SU - B.1.6.2				2 (33.3%)	4 (66.7%)	4.67
	SU - C.2	1 (16.7%)	1 (16.7%)	2 (33.3%)	1 (16.7%)	1 (16.7%)	3.00

Third step of validation

The top-ranked recommendations from the pre-validation questionnaire were presented during the validation interviews (proposed recommendations with a mean rating of 4 or more). The low impact reasons (mean rating of 1.5 or less in Table 7.8) were removed from the validation interview question table so only the most important factors and recommendations were examined. Face-to-face, semi-structured interviews were conducted in order to validate the framework. Participants were asked to provide their opinions about each highly ranked proposed recommendation in terms of its efficiency in improving the usage of PCE. Table 7.10 presents the rankings of the proposed improvements by the interview respondents.

Table 7.10. Third step of refining recommendations

Recommendations for Policymakers

	Recommendation code	Not efficient at all	Less efficient	Moderate	Efficient	Very efficient	Mean rating
Cost related	PM - A.1.1					7	5.00
	PM - A.1.4				3	4	4.57
	PM - A.3.1				2	5	4.71
	PM - A.4.1.1				1	6	4.86
Execution related	PM - B.1.2			2	3	2	4.00
	PM - B.1.3			2	2	3	4.14
	PM - B.1.5.1				3	4	4.57
	PM - B.1.5.2				2	5	4.71
	PM - B.3.2					7	5.00
Availability related	PM - C.1.1					7	5.00
	PM - C.1.2					7	5.00
	PM - C.2.1					7	5.00
WM related	PM - D.1.2				3	4	4.57
	PM - D.3					7	5.00

Recommendations for Clients

	Recommendation code	Not efficient at all	Less efficient	Moderate	Efficient	Very efficient	Mean rating
	CL - B.1.5	5	1	1			1.43
	CL - B.4.1	5	2				1.29
	CL - C.1					7	5.00
	CL - C.2					7	5.00
	CL - D.1				2	5	4.71
	CL - D.3				1	6	4.86

Recommendations for Designers and Engineers

	Recommendation code	Not efficient at all	Less efficient	Moderate	Efficient	Very efficient	Mean rating
st rel ate	DE - A.4.1.2	3	2	2			1.86
Execution related	DE - B.1.5			4	3		3.43
	DE - B.3.3.1	3	2	2			1.86
	DE - B.3.3.2	3	2	2			1.86
	DE - B.3.4.1	3	2	2			1.86
	DE - B.3.4.2	3	2	2			1.86
Availability related	DE - C.1			1	3	2	3.57
	DE - C.2			1	3	3	4.29
	DE - D.3			1	3	3	4.29

Recommendations for Contractors

	Recommendation code	Not efficient at all	Less efficient	Moderate	Efficient	Very efficient	Mean rating
Execution related	CO - B.1.1.1	3	2	2			1.86
	CO - B.1.1.2	3	2	2			1.86
	CO - B.1.2	3	2	2			1.86
	CO - B.1.4	3	2	2			1.86
	CO - B.1.5.1			3	2	2	3.86
	CO - B.1.5.2			3	2	2	3.86
	CO - B.2.1.1	3	2	2			1.86
	CO - B.2.1.2	3	2	2			1.86
	CO - B.3.2.1		3	2	2		2.86
	CO - B.3.2.2		3	2	2		2.86
	CO - B.3.3	6	1				1.14
	CO - B.3.4	6	1				1.14
	CO - B.4.1.1	6	1				1.14
	CO - B.4.1.2	6	1				1.14

Recommendations for Manufacturers							
	Recommendation code	Not efficient at all	Less efficient	Moderate	Efficient	Very efficient	Mean rating
Cost related	MF - A.1.1.2				3	4	4.57
	MF - A.1.4			1	4	2	4.14
	MF - B.4.1		1	2	3	1	3.57
Availability related	MF - C.1.1				1	6	4.86
	MF - C.1.2				2	5	4.71
	MF - C.2.1				2	5	4.71
	MF - C.2.2				2	5	4.71
Recommendations for Suppliers							
	Recommendation code	Not efficient at all	Less efficient	Moderate	Efficient	Very efficient	Mean rating
st rel ate	SU - A.1.1		2	2	2	1	3.29
Execution related	SU - B.1.2.1	2	2	2	1		2.29
	SU - B.1.2.2	2	2	2	1		2.29
	SU - B.1.4	2	2	2	1		2.29

Next, participants were asked to provide their own improvement recommendations to the top-ranked proposed recommendations. Suggestions provided by participants were as below:

- Proposing a prior method for measuring site waste in Iran would be helpful for PM - A.3.1
- Collaboration with Iran's traffic police for PM - B.1.3
- Establish a sustainability department with specified duties, responsibilities, and powers for PM - D.1.2
- More legislation for reducing construction waste for PM - D.3
- More requests for PCE execution in contracts for CL - C.1
- More requests for use of PCE in drawings for CL - C.2
- Give more consideration to companies' CSR policies in contracts for CL - D.1
- Give more consideration to companies' CSR policies in contracts for CL - D.3
- Proper element design in terms of dimensions of concrete elements for DE - B.1.5
- More use of PCE in contracts for DE - C.1
- More use of PCE in drawings for DE - C.2
- Knowledge transfer and consulting services for DE - D.3
- Education and training for personnel and subcontractors for CO - B.1.5.2
- Proper deals with purchasers such as accepting instalment payments for MF - A.1.4

7.3.4. The Most Effective Proposed Recommendations

At the end of the validation process for the framework, it was clear that using prefabricated elements to reduce concrete waste requires the attention of high-level managers and policymakers in order to prepare facilities or incentives to encourage its use in Iran.

Table 7.11. Refined proposed recommendations

<table>
<tr><th colspan="3">Recommendations for Policymakers</th></tr>
<tr><td>Recommendation code</td><td>Mean rating</td><td>Suggestions</td></tr>
<tr><td>PM - A.1.1</td><td>5</td><td></td></tr>
<tr><td>PM - A.1.4</td><td>4.57</td><td></td></tr>
<tr><td>PM - A.3.1</td><td>4.71</td><td></td></tr>
<tr><td>PM - A.4.1.1</td><td>4.86</td><td>Proposing a prior method for measuring site waste in Iran would be helpful</td></tr>
<tr><td>PM - B.1.2</td><td>4</td><td></td></tr>
<tr><td>PM - B.1.3</td><td>4.14</td><td>Collaborate with Iran's traffic police</td></tr>
<tr><td>PM - B.1.5.1</td><td>4.57</td><td></td></tr>
<tr><td>PM - B.1.5.2</td><td>4.71</td><td></td></tr>
<tr><td>PM - B.3.2</td><td>5</td><td></td></tr>
<tr><td>PM - C.1.1</td><td>5</td><td></td></tr>
<tr><td>PM - C.1.2</td><td>5</td><td></td></tr>
<tr><td>PM - C.2.1</td><td>5</td><td></td></tr>
<tr><td>PM - D.1.2</td><td>4.57</td><td>Establish a sustainability department with specified duties, responsibilities, and powers</td></tr>
<tr><td>PM - D.3</td><td>5</td><td>More legislation for reducing construction waste</td></tr>
<tr><th colspan="3">Recommendations for Clients</th></tr>
<tr><td>Recommendation code</td><td>Mean rating</td><td>Suggestions</td></tr>
<tr><td>CL - C.1</td><td>5</td><td>More requests for PCE execution in contracts</td></tr>
<tr><td>CL - C.2</td><td>5</td><td>More requests for use of PCE in drawings</td></tr>
<tr><td>CL - D.1</td><td>4.71</td><td>Give more consideration to companies' CSR policies in contracts</td></tr>
<tr><td>CL - D.3</td><td>4.86</td><td>Give more consideration to companies' CSR policies in contracts</td></tr>
<tr><th colspan="3">Recommendation for Designers and Engineers</th></tr>
<tr><td>Recommendation code</td><td>Mean rating</td><td>Suggestions</td></tr>
<tr><td>DE - B.1.5</td><td>3.43</td><td>Proper element design in terms of dimensions of concrete elements</td></tr>
<tr><td>DE - C.1</td><td>3.57</td><td>More use of PCE in contracts</td></tr>
<tr><td>DE - C.2</td><td>4.29</td><td>More use of PCE in drawings</td></tr>
<tr><td>DE - D.3</td><td>4.29</td><td>Knowledge transfer and consulting services</td></tr>
<tr><th colspan="3">Recommendations for Contractors</th></tr>
<tr><td>Recommendation code</td><td>Mean rating</td><td>Suggestions</td></tr>
<tr><td>CO - B.1.5.1</td><td>3.86</td><td></td></tr>
<tr><td>CO - B.1.5.2</td><td>3.86</td><td>Education and training for personnel and subcontractors</td></tr>
<tr><th colspan="3">Recommendations for Manufacturers</th></tr>
<tr><td>Recommendation code</td><td>Mean rating</td><td>Suggestions</td></tr>
<tr><td>MF - A.1.1.2</td><td>4.57</td><td></td></tr>
<tr><td>MF - A.1.4</td><td>4.14</td><td>Proper deals with purchasers such as accepting instalment payments</td></tr>
<tr><td>MF - B.4.1</td><td>3.57</td><td></td></tr>
<tr><td>MF - C.1.1</td><td>4.86</td><td></td></tr>
<tr><td>MF - C.1.2</td><td>4.71</td><td></td></tr>
<tr><td>MF - C.2.1</td><td>4.71</td><td></td></tr>
<tr><td>MF - C.2.2</td><td>4.71</td><td></td></tr>
<tr><th colspan="3">Recommendation for Suppliers</th></tr>
<tr><td>Recommendation code</td><td>Mean rating</td><td>Suggestions</td></tr>
<tr><td>SU - A.1.1</td><td>3.29</td><td></td></tr>
</table>

7.4. Concluding remarks

As discussed in Chapter 2, there is no clear evidence in the literature on on-site concrete waste minimisation framework (OCWMF) of previous models. This is essentially for that a few limited studies have focused on concrete waste minimisation. Moreover, the literature has neglected to present a framework that clearly articulates using the specific method of PCE for minimising concrete waste from construction projects. Furthermore, the proposed OCWMF maps collaborative efforts of various stakeholders in using PCE for minimising concrete waste which has been barely addressed in the literature. As such, the proposed OCWMF features an innovative model of using a specific method by stakeholders of construction projects for minimising a particular construction waste which has not been previously reported in the literature.

However, some attempts have been made towards developing construction waste minimisation frameworks. For instance, Gamage (2011) worked out to develop a Procurement Waste Minimisation Framework (PWMF) in order to enhance waste minimisation in large construction projects undertaken by the UK top 100 contractor organisations and quantity surveying organisations. In developing the PWMF, Gamage (2011) evaluated the relationship between construction procurement system and construction waste generation. He, indeed, focused on a particular stage that allowed exploring waste origins and waste minimisation measures specific to procurement systems. In this way, the major entities that Gamage (2011) was looking at were construction procurement systems used in large construction projects that are different from those looked within this research that were the OCWM methods used through the works executed at construction projects from the foundation upward (on-site or in situ).

In addition, there is a reflective gap in the PWMF developed by Gamage (2011) with regard to the importance of collective roles that various stakeholders could play within construction procurement systems; but the OCWMF presented in this chapter puts forward elements of a collaboration framework that could potentially motivate stakeholders to work together within a whole system towards minimising construction waste.

Furthermore, as Vilasini et al. (2014) argue, construction waste minimisation cannot be achieved without changes in the way in which real work at construction projects is performed. They believe that it is not sufficient to change procurement systems; robust operating systems are also required to minimise waste from construction projects successfully (Vilasini et al., 2014). Arguing so, Vilasini et al. (2014) developed a framework within which improvements in construction processes can be streamlined through a cyclic and repetitive process based on the so-called Look-Ask-Model-Discuss-Act (LAMDA) model. Accordingly, this framework introduces a 'waste walk', where site management walks through the construction site daily to observe any evidence of waste, to ask the site workers about causes of waste, to discuss with them to find possible remedies, and to get help from the site workers to implement the remedies (Vilasini, 2014). The LAMDA-based framework, in fact, promotes a culture of teamwork that was neglect in the PWMF developed by Gamage (2011).

Vilasini et al. (2014) also tried to verify the applicability of the framework to a real construction alliance project in New Zealand. As an outcome, they found out that the framework is equally suited to waste detection and improvements in construction processes leading to waste minimisation at the site level. They suggested this framework to project organisations with which the organisations should detect needs and opportunities for construction process change as well as transform processes accordingly (Vilasini et al., 2014).

In developing the CWM framework based on LAMDA model, Vilasini et al. (2014) indeed regarded that organisational conditions exist in project alliances, helping to minimise construction waste from alliance projects. But, they overlooked how broader contexts may affect organisational conditions as well as the activities executed at alliance projects. This was also an absence in the PWMF developed by Gamage (2011). In comparison, the OCWMF presented in this chapter recognises the importance of broader contexts, and considers that how the OCWMF might get distorted in the process of implementation as it interacts with broader contexts. With this regard, the proposed OCWMF further addressed a shortcoming in the construction waste minimisation literature as well as former CWMFs. It should be also mentioned that the major entities that Vilasini et al. (2014) were looking at were construction activities executed at alliance projects that are different from those looked within this research that were the OCWM methods used in construction projects (on-site or in situ).

In a further study, Liu et al. (2015) identified that there is insufficient design decision making tools to support effective construction waste minimisation evaluation and implementation. They made the first attempt to stablish a coordinated correlation between Building Information Modelling (BIM) and CWM decision making in developing a framework for improving CWM performance in the UK. The intention was to develop a framework that could guide to address waste causes throughout all design stages, articulated within a BIM-aided CWMF (Liu et al., 2015).

Nevertheless, the BIM-aided CWMF is silent on this argument from Vilasini et al. (2014) presented earlier that construction waste minimisation cannot be realised without changes to the way real work at construction projects is performed. In developing the BIM-aided CWMF, Liu et al. (2015) implicitly assume that robust design decision making tools are sufficient to change processes generating construction waste, and architects are able to make effective CWM decisions across design stages of their construction projects. Built upon this assumption, the BIM-aided CWMF ignores the importance of operating systems in minimising waste from construction projects as regarded when developing the OCWMF in this chapter, the PWMF by Gamage (2011), and the LAMDA-based framework by Vilasini et al. (2014).

Moreover, the major entities that Liu et al. (2015) were looking at were design decision making tools used throughout all design stages of construction projects that are obviously different from those looked within this research that were the OCWM methods used through the works executed at construction projects from the foundation upward (on-site or in situ).

In addition, the BIM-aided CWMF reflects specific circumstances and conditions of the UK that is different from those in Iran. As presented earlier, Iran is a country in which low landfill taxes, sufficient landfill sites, and lack of proper legislation to reduce and control construction waste are observable. Moreover, the finding of this research showed limited PCE manufacturers and limited product availability in Iran that are not found in the UK. Also, labour is inexpensive in Iran and inflation is unforeseen, as well as overhead costs and interest rates are high, further making the country different from the UK in which Gamage (2011) worked out to develop the PWMF and Liu et al. (2015) articulated the BIM-aided CWMF. Therefore, these frameworks were developed in context-specific way, reflecting circumstances and conditions of two different countries of Iran and UK. This is true in the case investigated by Vilasini et al. (2014) in New Zealand. As they argued, "New Zealand has its own rules, regulations and approaches, in terms of contractual arrangements, team structures, project management methods, and cultures involved" (Vilasini et al., 2014, p. 19). Table 7.12 compares the OCWMF developed in this chapter, the PWMF offered by Gamage (2011), the LAMDA-based framework developed by Vilasini et al. (2014), and the BIM-aided CWMF articulate by Liu et al. (2015).

Table 7.12. Comparison between the OCWMF, PWMF, LAMDA-based CWMF, and BIM-aided CWMF

CWMF	Focus	Context in which developed	Major Entity looked at	Methodology / Technique used	Contribution to existing knowledge	lack(s)
OCWMF (Author)	The OCWF focuses on using PCE for minimising concrete waste from construction projects.	Iran	OCWM methods used at construction projects	Construction Process Improvement Methodology and DRIVE technique	The OCWMF features an innovative model of using the specific method of PCE by stakeholders of construction projects for minimising particular concrete waste, which has not been previously reported in the literature.	The present case study is not enough for drawing robust conclusion about the potential of the OCWMF for motivating stakeholders to use PCE for minimising concrete waste from construction projects in various cases and contexts.
BIM-aided CWMF (Liu et al, 2015)	This framework focuses on waste causes throughout all design stages	UK	Design decision making tools used throughout all design stages of construction projects	Building Information Modelling (BIM)	This was the first attempt to stablish a coordinated correlation between BIM and CWM decision making in developing a framework that could guide to address waste causes throughout all design stages.	The BIM-aided CWMF is silent on that construction waste minimisation cannot be realised without changes to the way real work at construction projects is performed.

CWMF	Focus	Context in which developed	Major Entity looked at	Methodology / Technique used	Contribution to existing knowledge	lack(s)
LAMDA-based CWMF (Vilasini et al., 2014)	This framework focuses on the way in which real work at construction projects is performed.	New Zealand	Construction activities executed at alliance projects	Look-Ask-Model-Discuss-Act (LAMDA) model	This framework regards that organisational conditions exist in project alliances, helping to minimise construction waste from alliance projects.	This framework overlooks that how broader contexts may affect organisational conditions as well as the construction activities executed at alliance projects.
PWMF (Gamage, 2011)	The PWMF focuses on the relationship between construction procurement systems and construction waste generation.	UK	Construction procurement systems used in large construction projects	Construction Process Improvement Methodology	The PWMF allows exploring waste origins and waste minimisation measures specific to procurement systems.	The PWMF disregards the importance of collective roles that various stakeholders could play within construction procurement systems. It also ignores that construction waste minimisation cannot be achieved without changes in the way in which real work at construction projects is performed.

CWMF=Construction Waste Minimisation Framework; OCWMF=On-site Construction Waste Minimisation Framework PWMF= Procurement Waste Minimisation Framework; LAMDA= Look-Ask-Model-Discuss-Act; BIM= Building Information Modelling; DRIVE=Define-Review-Identify-Verify-Execute; PCE= prefabricated concrete elements

(Source: Author)

In a nut shell, the focus of what is considered the issue of construction waste production, as well as the challenge(s) against minimising construction waste are dissimilar in the CWMFs presented in Table 7.12. In developing these frameworks, the researchers were relying on their own academic knowledge and professional skills in understanding the problem pertaining to construction waste production, as well as working out in the specific circumstances and conditions of their own case studies to manage the problem.

In sum, different perspectives and methodologies were employed in developing the CWMFs presented in Table 7.12, implying that that there is no 'one' adequate diagnosis of construction waste problem, 'one' adequate problem framing, and 'one' best way to minimising construction waste.

7.5. Summary

This chapter discussed the proposed OCWMF development and validation and provided an account of the barriers for using PCE in Iran and related recommendations to enhance the chance of usage in order to reduce the amount of concrete waste.

Overall feedback on the OCWMF validation was positive in terms of clarity and information flow, and the validation results showed that the OCWMF has a clear structure and information flow. In the pre-validation questionnaire, respondents rated the consequences of not using PCE in the construction projects in terms of their impacts. The appropriateness and importance of proposed recommendations for each reason was explored as well. Top-ranked reasons and top-ranked proposed recommendations were allocated in the validation interview questions to refine the proposed recommendations.

The validation outcomes identify the most appropriate and efficient recommendations to help to increase the usage of PCE in the construction projects in Iran and subsequently generate less concrete waste on-site. The next chapter presents a discussion of the research findings.

8. Discussion

8.1. Introduction

This study was conducted to investigate on-site concrete waste minimization methods in the UK and Iran, explore any differences in the methods in these two counties, and examine the possible reasons for these differences, also to develop an On-site Concrete Waste Minimisation Framework (OCWMF). This chapter presents a discussion of topics developed from the outcomes of the research illustrated in the previous chapters, particularly Chapters 4, 5, 6 and 7.

The first two sections of this chapter compare questionnaire surveys from the UK and Iran, including aspects such as the number of participants and results in each country.

The following three sections discuss topics raised during examination of the research objectives. These topics are divided into: on-site concrete waste minimization highlights, waste minimization incentives, and barriers to concrete recycling. Subsequently, the last section of this chapter reviews the validation results of the developed OCWMF.

8.2. Participation in the UK and Iran

Participation in the questionnaire surveys in the UK and Iran were compared and the results are presented in Table 8.1. Table 8.1 and Figure 8.1 illustrate the percentage of respondents by their roles in the UK and in Iran.

Table 8.1. Role of respondents by percentage of total

Role	UK	Iran
Contractor's Project Manager	23.3%	29.10%
Site Superintendent	24.6%	33.60%
Project Consultant	20.5%	18.20%
Engineer	23.3%	19.10%
Unspecified	8.2%	None

Source: Author

As seen in the Table 7.1, the majority of participants in the UK were project consultants whereas the majority in Iran were site superintendents. Project consultants had the lowest participation in Iran, and contractors' project managers had the lowest participation in the UK. Figure 8.1 compares the proportion by role of participants in the UK and Iran.

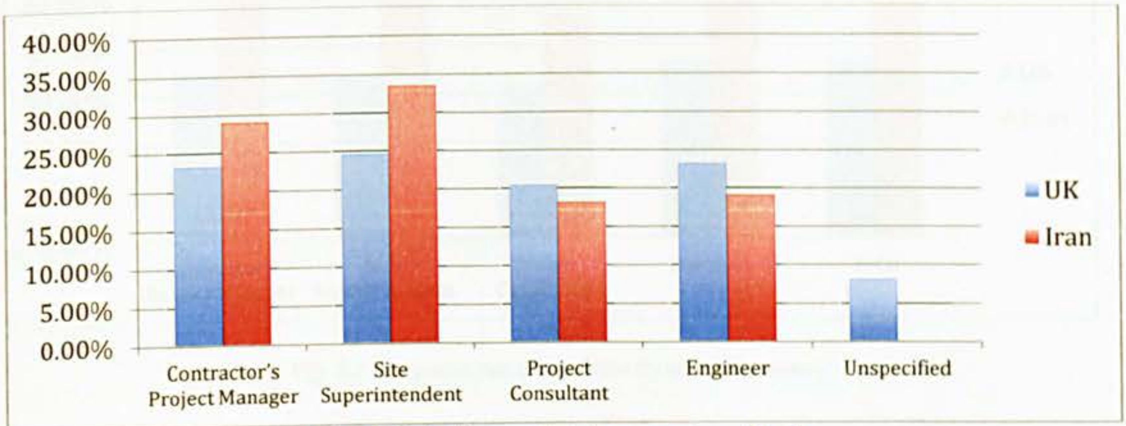


Fig.8.1. Role of respondents by percentage of total

As seen in Table 8.2, project consultants represented the greatest number of participants in the UK whereas site superintendents represented the greatest number in Iran. It should be noted that project consultants represented the lowest number of participants in Iran, the group with the fewest participants in the UK was contractors' project managers. In total, the response rate in the UK was 37.2 % and 56.1% in Iran.

Table 8.2. Respondent's participation (response rate)

	Respondent's participation by role	
Role	**UK**	**Iran**
Contractor's Project Manager	34.7%	58.10%
Site Superintendent	33.9%	63.80%
Project Consultant	31.2%	46.50%
Engineer	36.9%	52.20%
Total	37.2%	56.10%

It can be argued that the author has had connection with the stakeholders in construction industry in Iran. Therefore participation in Iran was more than the UK. It can be also argued that questionnaire survey took six weeks in the UK and ten weeks in Iran. However, the ten weeks duration of questionnaire data collection in Iran could be caused by the slower mailing system in Iran. Alternatively, it can be claimed that in Iran as a developing country there are more interest in participation in the waste minimization improvement studies than the developed counties. Figure 8.2 below compares the response rates in the UK and Iran in a diagram.

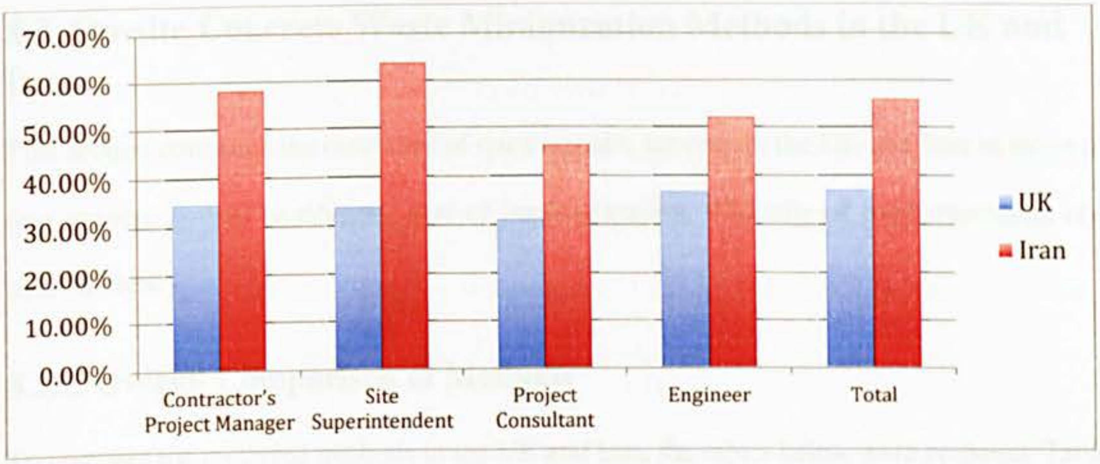


Fig. 8.2. Response rate comparison by role and country

Table 8.3 illustrates the experience of respondents in the UK and in Iran. As seen, the majority of participants in the UK had between 15 and 20 years of experience, and the majority of respondents in Iran had between 20 and 25 years of experience. Figure 8.3 compares respondents' experience in the UK and Iran in a diagram.

Table 8.3. Years of experience of respondents in the UK and Iran

Years	UK	Iran
Over 30	12.3%	26%
25 – 30	13.7%	28%
20 – 25	20.5%	45%
15 – 20	23.3%	1%
10- 15	16.4%	0
5 – 10	4.1%	0%
0 – 5	0	0%
Unspecified	8.2%	0%

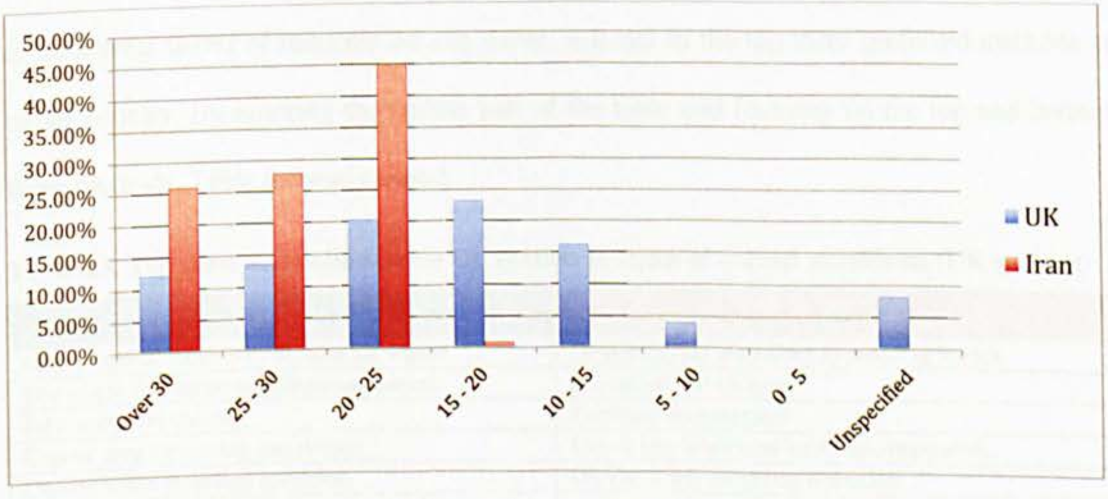


Fig. 8.3. Respondents experience by country

8.3. On-site Concrete Waste Minimization Methods in the UK and Iran

This section compares the outcomes of questionnaire surveys in the UK and Iran in terms of four aspects: overall worthiness, cost of implementation, difficulty of implementation, and cost efficiency.

8.3.1. Overall Comparison of Methods

To compare the preferred methods in the UK and Iran, the tables below were prepared. Table 8.4 compares the preferred on-site concrete waste minimization methods in the UK and Iran in terms of overall worthiness in ranked order.

Table 8.4. Comparison of OCWMMs in terms of overall worthiness (UK vs. Iran)

UK	Iran
Governmental incentives in reducing wastes	Governmental incentives in reducing wastes
Use of pre-fabricated building components	Education and training
Education and training	Purchase management
Purchase management	On-site inventory management
Onsite inventory management	Use of ready mixed concrete
Implementation of environmental management systems	Waste prevention in on-site transport
Waste prevention in onsite transport	Identification of available recycling facilities
Identification of available recycling facilities	Use of Information Technology on-site
Use of Information Technology onsite	On-site waste conservation
On site reuse	On-site reuse
Onsite waste conservation	Implementation of environmental management systems
Quality Management	Quality Management
Central area for cutting and storage	Use of pre-fabricated building components
Onsite waste recycling operation	On-site waste recycling operation
Proper site layout planning	Proper site layout planning

As seen in Table 8.4, while "Implementation of environmental management systems" seems to be a great driver of reducing on-site waste, it is not in the top three preferred methods in either country. By ignoring the middle part of the table and focusing on the top and bottom three methods, Table 8.5 was created.

Table 8.5. Top three and bottom three OCWMMs in terms of overall worthiness (UK vs. Iran)

UK	Iran
Governmental incentives in reducing wastes	Governmental incentives in reducing wastes
Use of pre-fabricated building components	Education and training
Education and training	Purchase management
Central area for cutting and storage	Use of pre-fabricated building components
On-site waste recycling operation	On-site waste recycling operation
Proper site layout planning	Proper site layout planning

Therefore, as discussed in Chapters 5 and 6, the most striking difference between the methods used in each country is in "Use of pre-fabricated building components", which is one of the top three methods in the UK and one of the bottom three in Iran. As discussed in Chapters 6 and 7, the main reason for this difference was in high cost involved in use of PCE in Iran. This is in line with recent research findings of several studies in other developing countries such as in Sri Lanka by De Silva and Vithana (2008).

8.3.2. Comparison of Methods in terms of Cost of Implementation

Table 8.6 compares the preferred on-site concrete waste minimization methods in the UK and in Iran in terms of cost of implementation in ranked order.

Table 8.6. Comparison of OCWMMs in terms of cost of implementation (UK vs. Iran)

UK	Iran
Government incentives to reduce waste	Government incentives to reduce waste
Purchase management	Purchase management
On-site inventory management	On-site inventory management
Waste prevention during on-site transport	Waste prevention during on-site transport
Identification of available recycling facilities	Identification of available recycling facilities
Education and training	On-site reuse
On-site waste conservation	On-site waste conservation
Use of information technology on-site	Central area for cutting and storage
Proper site layout planning	Proper site layout planning
On-site reuse	Implementation of environmental management systems
Use of pre-fabricated building components	Education and training
Quality management	Quality management
Implementation of environmental management systems	On-site waste recycling operation
Central area for cutting and storage	Use of information technology on-site
On-site waste recycling operation	Use of pre-fabricated building components

By ignoring the middle part of the table and focusing on the top three and bottom three methods, Table 8.7 was created.

Table 8.7. Comparison of OCWMMs in terms of cost of implementation (UK vs. Iran)

UK	Iran
Government incentives to reduce waste	Government incentives to reduce waste
Purchase management	Purchase management
On-site inventory management	On-site inventory management
Implementation of environmental management systems	On-site waste recycling operation
Central area for cutting and storage	Use of information technology on-site
On-site waste recycling operation	Use of pre-fabricated building components

As seen in Table 8.7, the three cheapest methods in both countries are the same. However, differences exist in the most expensive methods. "Use of information technology on-site" and "Use of pre-fabricated building components" are two most expensive methods in Iran while "Implementation of environmental management systems" and "Central area for cutting and storage" are the two most expensive methods in the UK. One reason for this could be that "Implementation of environmental management systems" is mandatory in the UK whereas there is requirement to implement an environmental management strategy in Iran.

8.3.3. Comparison of Methods in terms of Difficulty of Implementation

Table 8.8 compares the preferred on-site concrete waste minimization methods in the UK and Iran in term of difficulty of implementation in ranked order.

Table 8.8. Comparison between OCWMMs in terms of difficulty of implementation (UK vs. Iran)

UK	Iran
Education and training	Education and training
Purchase management	Purchase management
On-site inventory management	On-site inventory management
Identification of available recycling facilities	Identification of available recycling facilities
Use of pre-fabricated building components	Governmental incentives in reducing wastes
Quality management	Quality management
Government incentives to reduce wastes	Central area for cutting and storage
Use of information technology on-site	Use of information technology on-site
Implementation of environmental management systems	Implementation of environmental management systems
On-site reuse	On-site reuse
Proper site layout planning	Proper site layout planning
On-site waste conservation	On-site waste conservation
Waste prevention during on-site transport	Waste prevention during on-site transport
On-site waste recycling operation	Use of pre-fabricated building components
Central area for cutting and storage	On-site waste recycling operation

By ignoring the middle part of the table and focusing on the top three and bottom three methods, Table 8.9 was created.

Table 8.9. Comparison between OCWMMs in terms of difficulty of implementation (UK vs. Iran)

UK	Iran
Education and training	Education and training
Purchase management	Purchase management
On-site inventory management	On-site inventory management
Waste prevention during on-site transport	Waste prevention during on-site transport
On-site waste recycling operation	Use of pre-fabricated building components
Central area for cutting and storage	On-site waste recycling operation

As seen in Table 8.9, again, the top three easiest methods in both countries are the same. Differences exist in the most difficult methods to implement. "Use of pre-fabricated building components" is one of the most difficult methods in Iran while "Central area for cutting and storage" is one of the most difficult methods in the UK.

8.3.4. Comparison of Methods in terms of Cost Efficiency

Table 8.10 compares the preferred on-site concrete waste minimization methods in the UK and Iran in term of cost efficiency in ranked order.

Table 8.10. Comparison between OCWMMs in terms of cost efficiency (UK vs. Iran)

UK	Iran
On-site reuse	On-site reuse
Government incentives to reduce waste	Government incentives to reduce waste
Purchase management	Purchase management
Education and training	Education and training
Identification of available recycling facilities	Identification of available recycling facilities
Implementation of environmental management systems	Implementation of environmental management systems
Waste prevention during on-site transport	Waste prevention during on-site transport
On-site inventory management	On-site inventory management
Use of pre-fabricated building components	Use of pre-fabricated building components
Use of information technology on-site	Use of information technology on-site
On-site waste conservation	On-site waste conservation
Quality management	Quality management
Central area for cutting and storage	Central area for cutting and storage
On-site waste recycling operation	On-site waste recycling operation
Proper site layout planning	Proper site layout planning

By ignoring the middle part of the table and focusing on the top three and bottom three methods, the table 8.11 was created. As it can be seen in Table 8.11, cost efficient methods in both countries are ranked in the same order.

Table 8.11. Comparison between OCWMMs in terms of cost efficiency (UK vs. Iran)

UK	Iran
On-site reuse	On-site reuse
Government incentives to reduce waste	Government incentives to reduce waste
Purchase management	Purchase management
Central area for cutting and storage	Central area for cutting and storage
On-site waste recycling operation	On-site waste recycling operation
Proper site layout planning	Proper site layout planning

8.4. On-site Concrete Waste Minimization Highlights

Based on analysis of the results in Chapter 5, reasons for differences between on-site concrete waste minimization methods in the UK and Iran can be proposed, which mainly involve the high cost of pre-fabricated elements in Iran. In addition, use of ready-mix concrete was proposed as a method for minimizing concrete waste in Iran, and the results of the case study illustrated that concrete waste production associated with ready-mix concrete depends on proper execution of the work. For instance, concrete waste production during use of ready-mix concrete can significantly increase by improper purchase management such as over ordering of concrete, large quantities of concrete remaining in the pump car and pump pipe, or poor quality workmanship at the site level such as breaking of formwork.

8.5. Waste Minimization Incentives

In terms of the impact of government policies and regulations on using current waste minimization methods, it is obvious that legislation such as the Landfill Tax has had a greater impact on the use of waste minimization methods than policies such as the Sustainable Construction Strategy of 2008. This finding seems to be consistent with those of other studies such as Osmani et al. (2008) and Chen et al. (2002), who proposed that legislation and relevant penalty charges are major incentives that have impacted waste minimization efforts.

An additional issue that was mainly mentioned in the different stages of the research in Iran was lack of proper or sufficient government legislation and regulations regarding waste minimization. For example, international environmental standards such as ISO 14001 or EMAS require companies to investigate and effectively manage their waste to minimize its impact on the environment; however, such initiatives were not observed in Iran.

8.6. Sustainable Waste Management Policy

The results of this study revealed that most participants involved in the survey in Iran are conscious of waste minimisation policies. This may be a positive indication that current stakeholders in the construction industry are aware of pertinent policies regarding waste minimisation at a strategic level. However, surveys results showed that only a minority of companies have waste minimisation policies.

8.7. On-site Concrete Waste Minimisation Framework

Although there are various methods that can potentially help minimise concrete waste generation in Iran, the OCWMF in this research is focused on use of PCE as it is the most ignored concrete waste minimisation method in Iran.

Development of the OCWMF was based on key concepts of problem-solving methodology in addition to findings that emanated from the research. Framework validation results showed that the developed OCWMF has a clear structure and information flow and thus enables users to view and understand links between components of the framework. As a result, adoption of the concepts of problem-solving methodology to develop OCWMF was successful. Result of this study highlighted that policy makers in Iran are the most important stakeholders in improving use of PCE in Iran. The validation results also illustrated that the OCWMF is suitable to be proposes to high-level policy makers in Iran.

8.8. Barriers to Concrete Recycling

While investigating on-site concrete waste minimization methods in the UK and Iran, a number of barriers and difficulties were encountered regarding concrete recycling, which are identified and elaborated on in detail below.

- On-site waste sorting is costly.
- Waste transportation from site to recycling plant is expensive.
- Allocation recycling machinery on-site is rather difficult and creating a concrete recycling team and preparing scopes, goals, and objectives in addition to overall concrete recycling plans increase management costs.
- Concrete waste recycling during a project term is time consuming.

- Additional documents related to recycling on-site activities such as working documents, procedures and tools increase the documentation workload.
- Lack of participation of personnel in concrete recycling can cause problems.
- Applications for recycled concrete products are limited.
- Supply and demand of recycled products are still unbalanced.
- Current research investment for concrete recycling products is insufficient.
- The technologies to support concrete recycling such as resources, training, competent staff, and expertise as well as client support are still insufficient.
- Government financial support is lacking.
- The number of concrete recycling companies in limited.
- Attitudes of those in the construction industry and government are different regarding the subject.

8. 9. Post-rationalisation of the Findings from the Research

One can see the findings of this research from the lens of the so-called Lean Construction Philosophy. Essential to lean construction philosophy is minimising waste through construction project delivery processes (Howell, 1999). In relevant literature, the word 'lean' means minimising and eliminating waste from the activities and processes that absorb resources but create no value (Howell, 1999; Koskela and Howell, 2002; Ballard and Howell, 2004).

Originally, lean construction is an attitude or way of thinking about construction project delivery based on the concept of Lean Production Management. The original concept of lean production was developed by the Toyota Motor Company, where Eiji Toyoda and Taiichi Ohno pioneered the concept in the Japanese motor-vehicle industry after World War II. Then, the lean concept scientifically stepped into the spotlight through the publishing of the first academic paper published on the Toyota Production Systems (TPS) in 1977, followed by the Toyota Productions systems book published in 1978 (Holweg, 2007).

After years of collaborative research and learning, it was concluded that the fundamental principles of lean production thinking are universal, and this philosophy can be thus applied to any industries where minimising waste of materials, time and effort matter (Koskela and Howell, 2002). The evolution of the lean production concept into the construction industry began in the early 1990s through the studies conducted by Koskela (1992), and Howell and Ballard (1994). However, as commonly known, lean construction philosophy was introduced as an outcome from a research carried out by Glenn Ballard and Greg Howell that was published in a paper entitled, "What is Lean Construction" written by Greg Howell in 1999. According to Koskela and Howell (2002) and Ballard and Howell (2004), lean construction is a way to design construction project delivery systems in order to minimise waste of materials, time and effort in construction projects, and to generate the maximum possible amount of value from the projects. Through a recent theoretical review of lean construction concept, Alves et al. (2012) noted that "the understanding of lean construction as a synonym of waste elimination is still valid" (p. 521). As such, the fundamental principles of lean construction are elimination of non-value adding flow activities and making conversion activities more efficient (Howell, 1999; Koskela and Howell, 2002; Ballard and Howell, 2004). These principles reveal the waste generating from the disruption of activity flow, non-release of the 'right' work, and the misallocation of resources (Lehman and Reiser, 2000). Accordingly, the ideal of the lean construction philosophy is to minimise waste and maximise value of construction project by systematically applying a method to the project delivery system that fulfils the ideal above in a cost-effective and timely manners (Lehman and Reiser, 2000).

It can be seen that the premise underlying the proposed OCWMF is in line with the ideal of the lean construction philosophy. The proposed OCWMF builds upon the premise that minimising the amount of the on-site concrete waste production from construction projects in Iran could be achieved by motivating stakeholders of the projects to use the PCE. Built upon this premise, the proposed OCWMF offers recommendations for all stakeholders of the construction projects, including project managers, clients, consultants, contractors, PCE manufacturers and suppliers, and waste management companies in Iran. Through the validation process for the OCWMF, it was also recognised that using the PCE to reduce concrete waste requires particular attention of high-level managers and policymakers in order to prepare facilities or incentives encouraging the stakeholders of the projects to use PCE in Iran. It is expected that the recommendations formulated within the proposed OCWMF would result in to decrease non-value adding use of concrete in the construction sites, that is, the use of concrete for the purpose other than the intended purpose of the project.

The OCWMF was proposed to be implemented at project level. However, it can be understood that a collaborative effort by the stakeholders of the construction projects in Iran for implementing the OCWMF could add various values to the projects with effects at project, company, local, national and global levels. At the project level, reducing the amount of on-site construction waste leads to cleaner and safer sites, and improves health and safety issues (Ekanayake and Ofori, 2000). A well-stablished OCWMF can decrease the cost of construction projects as the true cost of waste, including the cost of materials purchase, transport and landfill taxes (Ekanayake and Ofori, 2000; Yahya and Boussabaine, 2006; RICS, 2006;WRAP, 2010a), is usually higher than it seems to be. This implies that implementing the proposed OCWMF at a construction project can increase profitability of the project. Waste minimisation can also improve construction companies' reputation, allowing them to meet environmental responsibilities. According to the NSCC (2007), minimising the amount of waste contributes to corporate social responsibility (CSR) agendas, and enables promotion of a respectable environmental image of construction companies, giving them an edge when tendering for new projects (NSCC, 2007).

Moreover, construction waste minimisation is one of the key factors of sustainability in construction, and impacts local, national and even global environment. For instance, a well-defined waste minimisation strategy can be a deal with limited landfill sites for construction waste disposal that are becoming a serious problem, especially in large cities (Sve, 2009). By minimising construction waste, environmental pollution can be also reduced in terms of the energy consumed during processing, delivery, and using materials in a project, and consequently reducing CO2 emissions to the atmosphere.

In a nutshell, the key impression of the proposed OCWMF is motivating the project stakeholders by removing the barriers to the use of PCE which would result in cleaner and safer worksites, more profitable projects, more socially and environmentally responsible companies, as well as more sustainable environment. This key impression of the proposed OCWMF well matches with the core idea behind the lean construction philosophy as stated by Koskela and Howell (2002) as: "when the strategies of lean construction are employed, it connects strategy of the management level to execution at the project level, resulting in a collaborative effort that encourages teamwork and removes many of the barriers and unknowns creating a safer, more efficient and effective worksites" (p. 297). As such, the OCWMF extracted from the findings of this research has the potential of a tool for implementing lean construction thinking at construction projects in Iran, and it can hence be considered as an addition to the existing lean construction tools.

One may argue that the finding from present research could be aligned with other branches of social science theories, such as Actor-Network Theory (ANT) and the theory of Social Construction of Technology (SCOT), which have been widely used in construction studies. Nevertheless, the OCWMF was developed from a perspective that is different from philosophical perspective of ANT and SCOT theory.

Both ANT and SCOT theory focus on the interaction between society and technology (Bijker et al., 1987; Law and Callon, 1992), but they conceptualise the interaction in different ways. ANT builds upon the hypothesis of technological determinism, and theorises that technology is the driving factor in shaping society (Callon et al., 1986; latour, 1997; Latour, 2005). Conversely, the SCOT theory is based on social determinism, and conceptualises that "technologies emerge from social interactions among social groups and actors" (Pinch and Bijker, 1986, p. 352).

In theorising the interaction between society and technology, ANT sees these two entities as equals, and considers both as actors within a network (Latour, 2005). From this point of view, ANT does not make distinction between human and non-human aspects of a particular community, realising that both entities of society and technology exist in a fractal symbiotic relationship (Latour, 1997, 2005).

Although the proposed OCWMF resembles a network of stakeholders and recommends roles for them to play in minimising waste from construction projects in Iran, it emphasises on mapping collaborative efforts of human actors and considers technology as a dimension of broader contexts within which stakeholders are motivated to collaborate. For the proposed OCWMF, the term actor is used as in conventional sociology as defined by Wasserman and Faust (1994) as "discrete individual, corporate, or collective social units." (p.17).

That is, according to the proposed OCWMF, key actors of construction projects and technology operate at different levels (stakeholders and context), whereas ANT describes technology as an actor playing a role equal to other (human and non-human) actors which are tied together into a network built and maintained in order to achieve a specific goal, for example minimising waste from construction projects. There is, therefore, a difference between the particular human implication of the notion of actor for the OCWMF and the meaning of actor in ANT that implies both human and non-human actors. This marks a clear difference between philosophical perspective on developing OCWMF and the philosophical tradition of ANT.

ANT is one stream within the SCOT theory. The SCOT approach can be used for sociological and historical studies of technology (Bijker, 1994), and its basic premise is that technologies emerge and develop from interactions among social groups and actors (Bijker et al., 1987). SCOT theory, in fact, criticises technological determinism underlying ANT, comprising two elements: first, technology develops autonomously; and secondly, technology determines an important degree of societal development (Klein & Kleinman, 2002). In this way, the SCOT theory considerably emphasises on the social groups. In the words of Pinch (1996): "The particular way in which society is conceptualised and linked to artefacts is via the notion of relevant social groups" (p. 23).

With this emphasise, the SCOT theory focuses on how the problem being studied (for example, minimising waste from construction projects in Iran) determines choice of technology by relevant social groups (for example, use of PCE by construction projects' stakeholders), but it neglects the origins of the choice of technology by social groups (for example, the reasons for using PCE in the UK and not using PCE in Iran).

The implication of this argument for the proposed OCWMF is that SCOT theory could serve as conceptual framework for guiding to find the missing OCWM method in Iran that could potentially result in minimising waste from construction projects in the country. However, it is overly narrow to conceptualise a framework within which one can explain the barriers to using PCE in Iranian construction projects, as well as describe the broader contexts influencing the use of PCE by projects' stakeholders.

After all, regarding the main concern of the present research (minimising waste from construction projects in Iran), the major entities that the research was looking at (OCWM methods), its aim (motivating stakeholders to use a recommended OCWM method for minimising waste from construction projects in Iran), the methods used to achieve the research aim (interviews and questionnaire surveys exploring stakeholders' points of view on OCWM methods) as well as the outcomes from the research (barriers to using PCE in Iran and recommendations for motivating stakeholders to use PCE), it was realised that this research could be best embedded within the lean construction philosophy, compared to other branches of social science theories, as presented and argued earlier.

8.10. Summary

This chapter provided a discussion of topics developed during the research that were illustrated in previous chapters. This chapter compared the participants and results of the study in the UK and in Iran. Moreover, the presented topics raised during examination of the research objectives.

In terms of participants, it was determined that the majority of participants in the UK were project consultants whereas had the majority between participants in Iran were site superintendents. The majority of participants in the UK had between 15 and 20 years of experience, and the majority of respondents in Iran had between 20 and 25 years of experience. In terms of results, it was shown that while "Implementation of environmental management systems" seems to be a great driver of reducing on-site waste, it is not in the top three preferred methods in both countries. Moreover, the main difference between the methods used in each country is in "Use of pre-fabricated building components", which is one of the top three methods in the UK and one of the bottom three in Iran. In contrast, the top three cheapest methods the top three easiest methods in both countries are the same. Differences exist between the most difficult methods to implement in each country. "Use of pre-fabricated building components" is one of the most difficult methods in Iran, while "Central area for cutting and storage" is one of the most difficult methods in the UK.

A number of topics were raised when addressing the research objectives. For instance, the interviews illustrated that concrete waste production during use of ready-mix concrete depends on proper execution of the work. Furthermore, it was determined that legislation such as the Landfill Tax has had a greater impact on using waste minimization methods than policies such as the Sustainable Construction Strategy of 2008. It was also concluded that in Iran, there is a lack of proper and sufficient government legislation and regulations addressing waste minimization. Result of this study highlighted that policy makers in Iran are the most important stakeholders in increasing the use of PCE in Iran. The validation results also illustrated that the OCWMF is suitable to be proposed to high-level policy makers in Iran. Also, a number of barriers and difficulties encountered in concrete recycling were presented.

Finally, the findings of this research were seen from through the lens of the so-called Lean Construction Philosophy essential to which is minimising waste through construction project delivery processes. In doing so, it was understood that the premise underlying the proposed OCWMF is in line with the ideal of the lean construction philosophy. It was also argued that the finding from present research could be best aligned with the Lean Construction Philosophy, compared to other branches of social science theories such as Actor-Network Theory (ANT) and the theory of Social Construction of Technology (SCOT), which have been widely used in construction studies.

9. Conclusions and Recommendations

9.1. Introduction

The previous chapters presented the findings of the empirical study. This chapter provides conclusions and recommendations based on the results of this study. The first section of the chapter illustrates how the aim and objectives of the research were achieved. The next section presents key contributions of the research.

Then, research limitations are explained.

Lastly, the final section proposes recommendations for industry, policy makers and provides suggestions for further research.

9.2. Achievement of the Research Aim and Objectives

The main concern of this research was minimising waste generating from construction projects in Iran. With this concern, a classification of construction wastes offered by Alwi et al. (2002) was adopted that categorises construction wastes into material, labour, and machinery wastes. This research focused on material waste, in particular, on concrete waste generated from construction projects. Furthermore, following Cox and Clamp (2003), three major stages in construction projects were recognised, including design, tendering and contract, and construction. The focus of this research was only on concrete waste generated from construction stage (on-site or in situ).

In the words of Ekanayake and Ofori, (2000), this research focused on any concrete material that is required to be transported away from the construction site or used in the construction site for the purpose other than the intended purpose of the project (such as recycling, reuse, etc.), because of material damage, excess, specification change or non-compliance with specifications, or because it is a by-product of construction processes and activities (on-site or in situ). In other words, the focus was on on-site concrete waste generated as "a consequence of the works executed at buildings or any construction project from the foundation upward" (Llatas, 2011, p. 1266).

With the above-mentioned concern and focus, this research aimed to illustrate the recommendation that can potentially be used to improve on-site concrete waste minimisation in Iran. In this regards, the determined steps were: to identify the preferred on-site concrete waste minimization methods in the UK and Iran, using the UK as a model of success, explore any possible differences between the preferred methods in both countries, and examine the reasons for these differences, finally, to propose a framework to improve on-site concrete waste minimisation in Iran. The first three objectives of the research were specified to identify the preferred on-site concrete waste minimization methods and objectives 4 and 5 were determined to explore the differences. Sixth objective was to propose a framework for Iranian construction projects. Table 9.1 illustrates the research objectives.

Table 9.1. Adopted research approaches for achieving the research objectives

Research Objective	Research Approach	Research Method	Rationale
(1): To identify the common methods of on-site concrete waste minimization in the UK.	Qualitative	Semi-structured face-to-face interviews	Most on-site concrete waste minimization methods were identified through the literature review and previous studies. However, the purpose of this objective was to explore all existing methods, which were confirmed by the professionals in construction projects. Therefore, a purposeful sample and an approach based on individual interpretation rather than quantification was employed.
(2): To rank the on-site concrete waste minimization methods in the UK. (3): To rank the on-site concrete waste minimization methods in Iran.	Quantitative	Questionnaires	The purpose was to determine the most suitable and preferred methods in each country. A quantification approach was required to create valid and replicable results.
(4): To identify differences between common methods of on-site concrete waste minimization in the UK and in Iran and explore the possible causes of these differences.	Qualitative	Semi-structured face-to-face interviews	The purpose was to compare the methods in the UK and in Iran and to determine the reasons for differences between common methods.
(5) To investigate the causes of differences between the best methods in the UK and best methods in Iran.	Case study	Observation	Case study was chosen as the best way to conduct an in-depth study to confirm or refute the points interviewees mentioned.
(6) To propose a framework for Iran	Quantitative Qualitative	Validation questionnaire Validation interviews	The purpose was to determine the best way to propose the possible recommendations for improving on-site concrete waste minimisation in Iran.

Source: Author

9.2.1. Fulfilment of the First Objective

The first objective was to identify the existing methods of on-site concrete waste minimization in the UK in order to have updated information about the current methods being used in construction projects and create the most reliable and complete questionnaire for the subsequent phase of the research. Although most of on-site concrete waste minimization methods were identified in literature reviews and recent studies, in order to be confident that the most updated information had been gathered, semi-structured face-to-face interviews were conducted. Purposive non-random sampling was used to select interview participants. Five interviews were conducted with professionals in the construction projects that included senior managers or executives of companies who had sufficient, reliable knowledge, experience, and success in the construction projects. The companies were chosen from lists of the 100 leading construction companies, 100 leading homebuilders, and 100 leading consulting firms in the UK. Data was recorded through note taking with a focus on writing down key points. Interviews were conducted within 45-minute periods. The five interviews were conducted over approximately five weeks from November 2012 to December 2012. While the participants mentioned different possible and common methods, most referred to "Use of pre-fabricated components", “Education and training", and “Purchase management” as the most effective waste reduction methods. Almost all interviewees mentioned that legislation and regulations in the UK are the main drivers for construction waste reduction, for instance, increasing the Landfill Tax, increasing costs for waste disposal, and compliance with requirements of the Site Waste Management Regulations of 2008.

9.2.2. Fulfilment of the Second Objective

The second objective was to rank the on-site concrete waste minimization methods used in the UK in order to identify the preferred ones. After the literature review and evaluation of current and previous studies on waste minimization, a list of possible on-site concrete waste minimization methods was prepared. This list was used to create a questionnaire administered to professionals in construction projects. Participants were asked to rate on-site concrete waste minimization methods in terms of:

a) Cost of implementation

b) Difficulty of implementation

c) Cost efficiency

d) The overall worthiness of spending on them to create savings or minimize waste.

A total of 196 questionnaires were sent to the participants that included consultants, contractors' project managers, and site superintendents. Participants were chosen from the top 100 UK construction contractor companies and top 100 UK consultant companies. The probability sampling method was adopted for conducting this part of the research, and the technique used was stratified random sampling. Questionnaires were sent to participants by mail, accompanied with a pre-paid, addressed envelope to return completed questionnaires to the researcher. To improve the questionnaire, fill in gaps, and determine the time required for and ease of completing the exercise, five pilot questionnaires were conducted. The response rate was based on the total number of questionnaires sent and the total number of respondents. A total of 196 questionnaires were sent, and 101 participants responded to the survey. Therefore, the active response rate for the survey was 51.5%.

Outcomes were determined by quantitative data analysis methods. The results indicated that "Government incentives to reduce waste", "Purchase management", and "On-site inventory management" are the cheapest methods. "On-site waste recycling operation", "Use of pre-fabricated building components", and "Proper site layout planning" were indicated as the most expensive methods. "Education and training", "Purchase management", and "On-site inventory management" are the easiest methods for implementation. "Waste prevention during on-site transport", "On-site waste recycling operation", and "Central area for cutting and storage" are the most difficult methods. "On site reuse", "Government incentives to reduce waste", and "Purchase management" are the most cost efficient methods. "Central area for cutting and storage", "On-site waste recycling operation", and "Proper site layout planning" are the least cost efficient methods. "Use of pre-fabricated building components", "Education and Training" and "Purchase Management" were the most recommended methods in the UK among current practices. "Central area for cutting and storage", "On-site waste recycling operation", and "Proper site layout planning" were the least recommended methods.

9.2.3. Fulfilment of the Third Objective

The third objective was to rank on-site concrete waste minimization methods in Iran and identify the most preferred ones. The same questionnaire survey as the one used in the UK was administered in Iran with the same sample size and sample frame. Therefore, a total of 196 questionnaires were sent to potential respondents that included consultants, contractors' project managers, and site superintendents. Participants were chosen from the top 100 construction contractor companies and top 100 consultant companies in Iran. Most questionnaires were sent to participants by mail, accompanied by a pre-paid, addressed address envelope so completed questionnaires could be sent to the researcher. However, other delivery and collection methods for the questionnaires were used as well. Again, to check the suitability of the questionnaire for the industry in Iran, five pilot questionnaires were conducted. The response rate, based on 196 sent questionnaires and 115 received responses, was 58.7%.

The results indicated that "Government incentives to reduce waste", "Purchase management", and "On-site inventory management" are the cheapest methods. "On-site waste recycling operation", "Use of pre-fabricated building components", and "Proper site layout planning" are the most expensive methods. "Education and training", "Purchase management", and "On-site inventory management" are the easiest methods to implement. "Waste prevention during on-site transport", "On-site waste recycling operation", and "Central area for cutting and storage" are the most difficult methods to implement. "On site reuse", "Governmental incentives for practices in reducing wastes", and "Purchase management" are the most cost efficient methods. "Central area for cutting and storage", "On-site waste recycling operation", and "Proper site layout planning" are the least cost efficient methods. "Use of pre- fabricated building components", "Education and Training" and "Purchase Management" were the most recommended methods in Iran among current ones. "Central area for cutting and storage", "On-site waste recycling operation", and "Proper site layout planning" were the least recommended methods.

9.2.4. Fulfilment of the Fourth Objective

The fourth objective was to identify the differences between common on-site concrete waste minimization methods in the UK and in Iran and explore the possible reasons for these differences. The result of comparison between popular methods in the UK and Iran revealed that differences exist in "Use of pre-fabricated elements" and "Use of ready-mix concrete" in Iran. A qualitative approach was adopted to collect data about differences between top ranked on-site concrete waste minimization methods in the UK and Iran using semi-structured face-to-face interviews. Purposive heterogeneous sampling was used to select interviewees. Ten interviews were conducted with professionals in construction projects that included senior managers and executives of companies who had recently been involved in at least one project involving a multiple-story, concrete structure building, had more than 20 years of experience in construction industry, were graduates of UK or US universities or had proper up-dated knowledge about global waste management methods in order to compare the methods. The companies were chosen from lists of the 100 leading construction companies, 100 leading homebuilders, and 100 leading consulting firm in Iran. The sample frame was the same as that used for the questionnaire survey. During the interviews, participants were asked to express their points of view about possible reasons for differences between methods in the UK and Iran in accordance with their understanding of and experiences with minimizing concrete waste on-site. The responses provided in-depth understanding about the possible reasons for differences. Through clarifying and coding the responses, possible reasons were recognized. Results are shown in Table 9.2.

Table 9.2. Reasons for differences between on-site concrete waste minimization methods in the UK and Iran

Causes	Number of repeated responses
Use of pre-fabricated building components is far more expensive than other concrete works	5
Differences between proportion of manpower costs and machinery costs in Iran and the UK	5
Lack of concern about waste minimization in Iran	5
Low charge for landfill tax	4
Few pre-fabricated concrete manufacturers	4
Difficulty of execution of pre-fabricated concrete elements on-site due to lack of proper equipment	4
Difficulty of transportation of pre-fabricated elements due to congested traffic in Tehran and night time regulations for lorry transport	4
Limited pre-fabricated concrete products produced in Iran	4
High transportation costs for pre-fabricated elements	3
On-site execution mistakes	3

Source: Author

By focusing on the answers, it is clear that most of the responses were about the cost of using pre-fabricated concrete elements. Therefore, the next stage was to observe a case study that included three different methods of concrete works (use of pre-fabricated concrete elements, use of ready-mix concrete, and traditional in situ concrete).

9.2.5. Fulfilment of the Fifth Objective

The fifth objective was to investigate the reasons for differences in best methods in the UK and best methods in Iran. As the main reason of differences was cost related to the use of pre-fabricated concrete elements and use of ready-mix concrete, the case study approach allowed examined of the cost and concrete waste production of three different methods of making and pouring concrete in a construction project in Tehran. These three methods were: in situ concrete, ready-mix concrete, and use of pre-fabricated concrete elements. Before making observations, the researcher communicated with the contractor of the project by email and phone. The contractor and client had agreed on using the three methods of concrete work. The selected project was a seven-story building with a concrete frame structure in North Tehran, Iran. The contractor used three methods for casting concrete elements:

- In situ concrete (making and pouring) for floors 5 and 6;
- Ready-mix concrete for floors 3 and 4;
- Pre-fabricated concrete elements for floors 1 and 2.

Data collection methods were interviews accompanied by the collection of hard documentary data. Semi-structured interviews and audits of cost and waste were conducted. The results of the case study indicated that use of pre-fabricated concrete elements is the most costly (£170 per cubic metre of concrete) and produces the least on-site concrete waste (0.01% waste production). In situ concrete is the least costly (£72 per cubic metre of concrete) and produces the most concrete waste (0.96% waste production). Furthermore, although there is a significant reduction in material waste when pre-fabricated elements are used, consultants and contractors were still not interested in using this method in their projects due to the high costs involved.

9.2.6. Fulfilment of the Sixth Objective

The sixth objective was to propose a framework for construction projects in Iran. The outcomes of interviews and case study in Iran revealed that using PCE was the main difference between OCWMM in the UK and Iran. In addition, several barriers to using PCE in Iran were identified. Therefore, during the study several suggestions for increasing use of PCE in Iran were proposed. Based on these findings, the OCWMF was developed. The proposed framework was validated through a process that included pilot study discussions with two construction management researchers, completion of six pre-validation questionnaires, and seven validation interviews. The validation process was aimed at determining the clarity, information flow, and appropriateness of the content of the framework, and, finally, refining the framework. The overall feedback on the framework was positive and included several suggestions for its improvement.

9.3. Contributions of the Research

Coming back to the critical remarks on the construction waste minimisation literature presented in Chapter 2, it can be claimed that the OCWMF extracted from the outcomes of this research (literature review, questionnaire surveys, interviews, case study findings) could address some blind spots in the literature, and work out to overcome them. As critically discussed before, there is no clear evidence in the literature on on-site concrete waste minimisation framework (OCWMF) of previous models. That is, the literature have neglected to clearly articulate a framework within which collaborative efforts of various stakeholders in using a specific method for minimising a particular waste from construction projects could be elaborated. Developing the OCWMF, in fact, contributed to address this shortcoming, serving as a heuristic instrument for mapping collective efforts of projects' stakeholders within a whole system of minimising concrete waste (on-site or in situ).

Further, this research regarded that how broader contexts may affect the efforts of stakeholders or the acceptability of the proposed OCWMF by them, and how the OCWMF might get distorted in the process of implementation as it interacts with broader contexts. With this regard, the proposed OCWMF helped to create a clearer picture of how minimising concrete waste from construction projects in Iran is embedded in, intertwined with and shaped by broader technological, socio-economic, legal and political contexts. Putting these dimensions of broader context together into OCWMF resulted in to sketch out the interplay amongst them, and to gain a comprehensive image of the contexts that need to be considered if minimising concrete waste from construction projects is to be achieved in Iran.

To put it in more precise terms, using the Construction Process Improvement Methodology (CPIM) (Serpell and Alarcon, 1998) and the DRIVE technique (Gamage, 2011) in developing the OCWMF could contribute to produce an instrument for depicting structure of broader contexts influencing collaborative efforts of stakeholders in minimising concrete waste (on-site or in situ) from construction projects. Although the OCWMF represents specific circumstances and conditions of this case study conducted in the context of Iran, the

CPIM and the DRIVE technique can also be applied to systematically unveiling the aforementioned blind spots of literature in other contexts and case studies as they helped to arrange the outcomes from this case study in a logical order.

In other words, one can suppose that the logic underlying the OCWMF could potentially be used to undertake a systematic mapping of efforts by stakeholders in other cases, and to build a framework that systematically accounts for several dimensions of new contexts. However, it is recognised that this case study is not enough for drawing robust conclusion about the potential of the logic derived from the CPIM and the DRIVE technique in underlying such a framework for application to other cases and contexts. Therefore, more empirical work is needed to explore strengths and weaknesses of the logic in developing further models of OCWMF for a number of case studies and contexts in a range of efforts for construction waste minimisation.

After all, it should be acknowledged that the proposed OCWMF provided overall design principles for a framework to map collective efforts of projects' stakeholders within a whole system, as well as to depict schematic structure of broader contexts influencing the efforts. As such, the OCWMF extracted from the outcomes of this research entails a differentiated conceptual repertoire for guiding construction waste minimisation efforts, embracing an understanding of multiplicity of distributed efforts of projects' stakeholders, and retaining multi-dimensionality of broader contexts influencing the efforts. It can then be concluded that developing OCWMF from the findings of this research and its validation contributed to the conceptual and empirical work with construction waste minimisation.

In previous section, it was also argued that the OCWMF has potential of a tool for implementing lean construction thinking at construction projects in Iran, and it can hence be considered as an addition to the existing lean construction tools. Although this research did not intend to conduct a critical review of lean construction literature, and a major contribution to the lean construction philosophy was not a purpose, the findings arising from this research provided empirical evidence to do so briefly.

By mapping collaborative efforts of various stakeholders for minimising concrete waste from construction projects, the proposed OCWMF, indeed, addressed a limitation in lean construction literature. In the words of Koskela and Howell (2002): "when the strategies of lean construction are employed, it connects strategy of the management level to execution at the project level, resulting in a collaborative effort that encourages teamwork and removes many of the barriers and unknowns creating a safer, more efficient and effective worksites" (p.297). It seems that diverse perceptions, expectations, and strategies of various stakeholders are neglected in construction management based on lean thinking, and this philosophy of construction management places large parts of the stakeholders' efforts outside the realm of developing strategies for minimising waste from construction projects.

That is, from a top-down perspective, lean construction thinking promotes an understanding of collaboration that recognises the role of high-level managers in developing waste minimisation strategies, and thus pays little attention to the roles that other stakeholders of construction projects could take in doing so. There is, therefore, a conceptual gap in reflecting implications of diverse perceptions, expectations, and strategies of various stakeholders in construction management based on lean thinking.

However, from a bottom-up perspective, the OCWMF was extracted from the perceptions, expectations, and strategies offered by diverse stakeholders of construction project through the surveys in which they participated. The proposed OCWMF, in fact, eliminates the position of top managers as external supervisor and/or navigator of construction management and construction waste minimisation efforts. From this fresh perspective, there is no longer an outside from where high-level managers and policymakers can proceed sovereign intervention in construction projects in order to manage the projects and to minimise waste from the projects; but they are seen as insiders respecting the knowledge and experience of diverse stakeholders of construction project, as well as considering the strategies offered by the stakeholders in collaborating with them within a whole system.

Last but not least, it should be known that lean construction philosophy is in its early stage of development, and the OCWMF proposed in this research employed an innovative methodology (CPIM) and (DRIVE) technique in developing a tool towards applying lean construction thinking to construction projects. As such, the proposed OCWMF was an addition to the existing lean construction tools.

Again, one can suppose that the logic underlying the OCWMF could potentially be used to develop further tool(s) for applying lean construction thinking to other cases of construction projects in different contexts from a fresh perspective that is different from those have been reported in the lean construction literature to date. However, it is understood that this case study is not enough for drawing robust conclusion about the potential of the logic to do so, and more empirical work is needed to explore strengths and weaknesses of the logic in developing further lean tools for a number of case studies and contexts in a range of construction projects.

9.4. Research Limitations

There were limitations in each stage of the research. This section discusses these limitations in terms of each of the five research steps as below.

Interviews in the UK

As discussed earlier, five interviews were appropriate for achieving the objective of this stage of the research. By conducting more interviews, new ideas may be added to the list of on-site concrete waste minimization methods. However, due to time limitations and difficulty in making appointments with senior executives of construction projects in the UK, only five interviews were conducted.

Questionnaires in the UK

The sample of potential respondents was selected from the top 100 construction contractor companies and top 100 construction consultant companies in the UK. The same sample size was used in both the UK and Iran in order to have the same number of participants. This research attempted to draw the most appropriate and best possible sample for the study. However, results might have been slightly different with a larger sample size and a different sample frame.

Questionnaires in Iran

The sample frame was determined by doing research in Iran. However, due to limited availability of information at the final stage, the number was estimated. Therefore, the sample frame size might have been slightly greater, but this should not affect the results considerably.

Interviews in Iran

The interviews were sequentially conducted with mixed methods and thus there may be an issue of one method directly affecting results from the other. For instance, interviews in Iran were conducted after the questionnaire survey in Iran, and the sample frames were the same; therefore, some responses to the interview questions might have been influenced by the respondent's earlier participation in the questionnaire survey.

Case study

Time limitation was a limitation in this stage of the research. Although the reason for choosing one project to observe the three concrete methods was to have the same site environment, same contractor management policy and experience, including more case studies would increase the reliability and generalizability of the research.

OCWMF

For this stage of research, the limited time frame was also a limitation.

9.5. Recommendations for Iran

Considering the outcomes and conclusions of this research, recommendations can be made for the construction industry and policy makers and for further research in order to improve current practices.

9.5.1. Recommendations for the Construction Industry

This study reports on the issue of integrated on-site concrete waste minimization methods and provides information that can be used to create opportunities for waste minimization in Iran. However, the recommendation that contractors merely choose to use pre-fabricated concrete elements in order to minimize waste production is not made. Instead, the recommendation is that they consider use of pre-fabricated concrete elements as an opportunity for waste minimization in Iran. This study also reports a complete list of methods for on-site concrete waste minimization, which can be used by contractors for decision-making about these approaches. Moreover, as discussed in the content, the three main stages of building projects in which waste minimization can be incorporated are:

- Design stage: Although this project stage was not directly involved in the research, clear specifications, proper high quality design and minimizing errors, and low wastage of materials can minimize concrete waste.
- Tender and contractual agreement stages: In this stage, the client, contractor, and architect can play important roles in reducing waste by incorporating waste minimization activities in contract tender processes and contractual clauses. One example of this is considering the sustainability strategy of companies in the bidding process.
- Construction stage: Effective on-site measures can be based on results of this research. In this regard, short-term strategies can provide frameworks that are supported by current skills and technologies while longer-term solutions can be incorporated into initiatives such as design for deconstruction and innovative solutions. For example, the performance of formwork and false work is a factor that can cause concrete waste so a careful design and good communication with sub-contractors might be useful in this respect.

Furthermore, more investment in pre-fabrication by industry stakeholders can be directed to decrease the actual cost of pre-fabricated elements, consequently reducing the amount of waste production.

9.5.2. Recommendations for Policymakers

Recommendations can accomplish two goals:

- To increase the cost of waste generation.
- To reduce the cost of pre-fabrication (for instance, power subsidies for pre-fabrication manufacturers)

Policy, legislation, and guidelines

A range of legislative, fiscal and policy frameworks is required to affect concrete waste generation. Detailed legislation on construction waste minimization needs to be prepared and publicized to ensure effective waste minimization and compliance with waste management strategies. Legislation should discourage the waste of resources and, illegal dumping and promote construction and demolition waste minimization and secondary material use. Policy and legislation should motivate the construction sector by tactics such as funding, tipping reduction, tax reduction, and faster granting of construction licenses. The pre-fabricated concrete industry can be promoted by applying simple methods that increase the possibility of usage of pre-fabricated elements such as promoting the private sector and universities to investigate innovative methods of reducing the cost of using pre-fabricated components in construction ND encouraging contractors and designers to use pre-fabrication to reduce waste production. High penalty charges for illegal dumping and waste generation is mentioned in the literature as a general recommendation. However, according to similar experiences, this context increases illegal disposal as an attractive option from an economic point of view. Furthermore, these types of taxes directly affect the property market and increase the prices.

Government support and incentives

The government in Iran is undoubtedly one of the main stakeholders in the establishment of the construction materials market. The government should visibly support this target by promoting the use of pre-fabrication and discouraging traditional in situ concrete methods. Governments in some countries such as China have already banned the use of in situ concrete for construction projects due to environmental problems.

Increasing public awareness

Although financial support must be given to the pre-fabrication construction materials market, more importantly, the level of public awareness or even the construction sector's awareness needs to be raised. Increasing public awareness about the benefits of pre-fabrication in construction can motivate the public to participate and invest in this market. For instance, the effectiveness of public television (which is regulated by the government in Iran) in promoting public awareness in other areas (e.g., reducing energy consumption) indicates its importance in promoting public awareness of pre-fabrication advantages.

9.5.3. Recommendations for Further Research

- As this study reveals, there is a significant lack of studies and publications on a wide range of construction waste minimization or management methods in Iran at the moment. Therefore, research in any area of construction waste minimization can add value to the existing knowledge and improve the environmental performance of construction companies in Iran, which will help to reduce environmental issues in the future.
- As this study reports, concrete is one of the main construction materials and will be a considerable issue in the near future in Iran in terms of waste and waste production. Therefore, more studies about concrete waste minimization are recommended.
- This study reports the ranking and mean ratings of on-site concrete waste minimization methods in the UK and Iran. Further studies about the differences in mean ratings of cost and difficulty of the methods is recommended as the results of this research illustrated that there are considerable differences among the mean ratings of different methods. Therefore, additional in-depth studies to compare these differences are recommended.

- It is recommended that similar studies be conducted in other regions. The present research is mostly focused on current knowledge and practices in the UK and Iran so it is recommended that other researchers conduct similar studies in other countries.
- This study revealed that waste could be significantly reduced by use of pre-fabricated concrete elements in a project. Therefore, to motivate the industry to use pre-fabrication, further investigation about drivers that can reduce its price in Iran is recommended.
- Finally, this research acknowledged that the logic underlying the OCWMF – adopted from Construction Process Improvement Methodology (CPIM) and the DRIVE technique – could potentially be used to undertake a systematic mapping of efforts by stakeholders in other cases of construction waste minimisation, to build a framework that systematically accounts for several dimensions of new contexts, and to apply lean construction thinking to other cases of construction projects in different contexts. However, this research recognises that the present case study is not enough for drawing robust conclusion about the potential of the logic to do so, and more empirical work is needed to explore strengths and weaknesses of the logic in developing further frameworks for a number of case studies and contexts in a range of attempts for construction waste minimisation and lean construction efforts.

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Appendix 1: Interview Survey Documents for the UK

Kingston University London

On-site Concrete Waste Minimisation Methods
INFORMED CONSENT FORM
(to be completed after Participant Information Sheet has been read)

- I confirm that I have read and understood the information sheet/letter of invitation for this study. I have been informed of the purpose, risks, and benefits of taking part.
- I understand what my involvement will entail and any questions have been answered to my satisfaction.
- I understand that my participation is entirely voluntary, and that I can withdraw at any time without prejudice.
- I understand that all information obtained will be confidential.
- I agree that research data gathered for the study may be published provided that I cannot be identified as a subject.
- Contact information has been provided should I (a) wish to seek further information from the investigator at any time for purposes of clarification (b) wish to make a complaint.

Participant:

Name of Participant	Signature	Date

Investigator Researcher:

Name of Researcher	Signature	Date

Kingston University London

The interview questions:

1- Background questions

Name:
Company:
Position in the company:
Experience in the field (Years):
Email address:
Number of employees in the company:

2- What is your opinion about sentences bellow:

- Governmental regulations and legislations have the most impact on waste management.
- Waste management strategy itself is cost saving for The Contractors.
- The Clients would like to be environmental responsible.
- The Engineers would like to be environmental responsible.

3- Does your company have any of the following policies in place?

- Sustainable policy:
- Sustainable waste management policy:
- Any other related policy:

4-Which of the following policies and legislations has more Impact on the current waste management practices.

Site Waste Management Plans (SWMPs):

- Landfill Tax:
- The Strategy for Sustainable Construction 2008:
- Other, please specify below:

Kingston University London

5-What do you consider as on-site concrete waste minimisation method. Please add to the following methods.

Use of pre-fabricated building components
Education and training
Waste prevention during on-site transport (include use of volumetric trucks to determine the exact quantities needed)
Identification of available recycling facilities
Use of information technology on-site (e.g., BIM in order to avoid mistakes and misfit of designs)
Implementation of environmental management systems
On-site waste conservation
On-site reuse
Governmental incentives for waste reduction practices
Central area for cutting and storage
On-site waste recycling operation
Proper site layout planning

Other (Any suggestions or advised please specify)

6-Any other comments:

Kingston University London

On-site Concrete Waste Minimisation Methods

Participant Information Sheet

The following interview is a part of a doctoral research study, which has been designed to illustrate the existing methods of Onsite Concrete Waste Minimising, and to find out most common and favorite current methods. The final aim of the research is to develop some improved OCWM methods. Your responses are important to clarify the information about each method from real experience.

You are being invited to take part in this study, as a specialist in construction industry. You have been selected randomly from one of the 100 leading construction or consultant companies in the UK.

The interview consists of 6 questions, and has been designed to take approximately 30-45 minutes to be completed, and interview will be arranged at a time and place that convenient for you. The interview would be note recorded, and later transcribed into a clear text form. You would be very welcome to have a copy of the final report.

There are no trick questions in this survey. There are no right or wrong answers.

Please note that all information we gain from you will be maintained in a strictly confidential manner. After 10 years of the project all raw data that can identify individuals will be destroyed. In the reporting of the project, no information will be released which will enable to reader to identify who the respondent was. You can withdraw your information at any point of the research and the data collected would be immediately destroyed.

The findings of these interviews would be used as one of the data sources for my PhD research at the Kingston University London.

May you have any questions please do not hesitate to contact me.

Yours Sincerely

Investigator Research Student: Amir B. Meibodi
Email: K0938193@kingston.ac.uk
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Kingston University London

Appendix 2: Questionnaire Survey Documents

Kingston University London

Amir B. Meibodi
School of Civil Engineering
Kingston University London

Dear Sir/Madam

Questionnaire: Onsite Concrete Waste Minimisation Methods

The following questionnaire is a part of a doctoral research study, which has been designed to illustrate the existing methods of Onsite Waste Minimising of Concrete and rank them. The final aim of the research is to develop some improved methods. Your responses are important to clarify the information about each methods and their ranking from real experience.

The questionnaire consists of just 8 multiple-choice questions, and has been designed to take approximately 10-15 minutes to be completed.

I would be very grateful if you could complete the questionnaire by one week after receiving it.

Many thanks in advance for your help in conducting this research and looking forward to receiving the completed questionnaire.

Please note that all information provided will be treated completely confidential. Data will not be stored and will be destroyed after the questionnaire result. Information about any individual respondents or organizations will not be made public. The findings of these questionnaires will be used as one of the data sources for my PhD research at the Kingston University London.

Yours Sincerely

Amir Meibodi

Kingston University London

Amir Meibodi
School of Civil Engineering
and Construction

Questionnaire

The aim of this questionnaire is to illustrate the existing methods of Onsite Waste Minimising of Concrete and rank them.

All information provided will be treated completely confidential. Data will not be stored and will be destroyed after the questionnaire result. Information about individual respondents or organizations will not be made public.

Background questions

Q1- what is the category of your company?
Registered General Building Contractor
Registered Specialist Contractor
Developer
Consultant
Quantity Surveyor
Other

Q2- what is the total numbers of your company's employees?
Less than 50 people
Between 51 to 300 people
Between 301 to 500 people
Between 501 to 1000 people
More than 1000 people

Q3- what is your position in the company?
Contractor's Project Manager
Site Superintendent
Project consultant
Engineer
Other

Q4- How much experience do you have in construction Industry? For instance: please 5 years of experience for group less than 5, and 5 years and 1 day of experience for group 5 to 10 years.
Less than 5 years
Between 5 to 10 years
Between 10 to 15 years
Between 15 to 20 years
Between 20 to 25 years
Between 25 to 30 years
More than 30 years

Kingston University London

Main questions

Q5-Please rate the following on-site concrete waste minimizing methods in terms of cost of implementation. Please consider 1 for very expensive, and 5 for very cheap.

On-site Concrete Waste Minimisation	**1**	**2**	**3**	**4**	**5**
Use of pre-fabricated building components					
Education and training					
Purchase management (e.g., better estimation of total concrete requirements, on-time ordering, etc.)					
On-site inventory management (including on-site sorting of construction and demolition materials)					
Waste prevention during on-site transport (include use of volumetric trucks to determine the exact quantities needed)					
Identification of available recycling facilities					
Use of information technology on-site (e.g., BIM in order to avoid mistakes and misfit of designs)					
Implementation of environmental management systems					
On-site waste conservation					
On-site reuse					
Governmental incentives for waste reduction practices					
Quality management (e.g., use of concrete with proper characteristics such as slump, etc.)					
Central area for cutting and storage					
On-site waste recycling operation					
Proper site layout planning					

Other (Any suggestions or advised please specify):

Q6- Please rate the following on-site concrete waste minimizing methods in terms of difficulty of implementation. Please consider 1 for very difficult to be implemented and 5 for very easy.

On-site Concrete Waste Minimisation	**1**	**2**	**3**	**4**	**5**
Use of pre-fabricated building components					
Education and training					
Purchase management (e.g., better estimation of total concrete requirements, on-time ordering, etc.)					
On-site inventory management (including on-site sorting of construction and demolition materials)					
Waste prevention during on-site transport (include use of volumetric trucks to determine the exact quantities needed)					
Identification of available recycling facilities					
Use of information technology on-site (e.g., BIM in order to avoid mistakes and misfit of designs)					
Implementation of environmental management systems					
On-site waste conservation					
On-site reuse					
Governmental incentives for waste reduction practices					
Quality management (e.g., use of concrete with proper characteristics such as slump, etc.)					
Central area for cutting and storage					
On-site waste recycling operation					
Proper site layout planning					

Other (Any suggestions or advised please specify)

Q7- Please rate the following on-site concrete waste minimizing methods in terms of cost efficiency. Please consider 1 for not efficient at all, and 5 for very efficient.

On-site Concrete Waste Minimisation	**1**	**2**	**3**	**4**	**5**
Use of pre-fabricated building components					
Education and training					
Purchase management (e.g., better estimation of total concrete requirements, on-time ordering, etc.)					
On-site inventory management (including on-site sorting of construction and demolition materials)					
Waste prevention during on-site transport (include use of volumetric trucks to determine the exact quantities needed)					
Identification of available recycling facilities					
Use of information technology on-site (e.g., BIM in order to avoid mistakes and misfit of designs)					
Implementation of environmental management systems					
On-site waste conservation					
On-site reuse					
Governmental incentives for waste reduction practices					
Quality management (e.g., use of concrete with proper characteristics such as slump, etc.)					
Central area for cutting and storage					
On-site waste recycling operation					
Proper site layout planning					

Other (Any suggestions or advised please specify)

Q8- Please rate the following on-site concrete waste minimizing methods in overall, or their worthiness of spending on them to make savings or minimise waste. Please consider 1 for the very bad and 5 for the excellent.

On-site Concrete Waste Minimisation	**1**	**2**	**3**	**4**	**5**
Use of pre-fabricated building components					
Education and training					
Purchase management (e.g., better estimation of total concrete requirements, on-time ordering, etc.)					
On-site inventory management (including on-site sorting of construction and demolition materials)					
Waste prevention during on-site transport (include use of volumetric trucks to determine the exact quantities needed)					
Identification of available recycling facilities					
Use of information technology on-site (e.g., BIM in order to avoid mistakes and misfit of designs)					
Implementation of environmental management systems					
On-site waste conservation					
On-site reuse					
Governmental incentives for waste reduction practices					
Quality management (e.g., use of concrete with proper characteristics such as slump, etc.)					
Central area for cutting and storage					
On-site waste recycling operation					
Proper site layout planning					

Other (Any suggestions or advised please specify)

Kingston University London

Participant information sheet

This questionnaire survey is a part of a Doctoral research study to develop an On-site Concrete Waste Minimisation Method.

Your responses are important to find out the most common and favorite current methods of On-site Concrete Waste Minimisation.

The questionnaire consists of just 8 multiple-choice questions, and has been designed to take approximately 10-15 minutes to be completed.

You are being invited to take part in this study, as a specialist in construction industry. You have been selected randomly from one of the 100 leading construction or consultant companies in the UK.

Research Background and Aim

Increasing government environmental legislations and regulations consequence a serious impact on current waste management practices in construction projects.

This research focuses on On-site concrete waste minimization methods. The primary stage of this research methodology is to find out the most common and favorite current methods of Concrete Waste Minimisation in construction sites in the UK. Therefore, opinions from the top construction companies in the UK and top UK consultant companies are gathered through this postal questionnaire survey.

The findings of these questionnaires would be used as one of the data sources for my PhD research at the Kingston University London.

There are no trick questions in this survey. There are no right or wrong answers.

Please note that all information we gain from you will be maintained in a strictly confidential manner. After 10 years of the project all raw data that can identify individuals will be destroyed. In the reporting of the project, no information will be released which will enable to reader to identify who the respondent was.

Please not that participation is always voluntary and you can withdraw your information at any point of the research and the data collected will immediately be destroyed.

May you have any questions please do not hesitate to contact me.

Yours Sincerely

Research Student: Amir B. Meibodi
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Kingston University London

Kingston University London

Participant Consent

By responding to this questionnaire you are agree data provided being used in this research, and confirm the statements below.

- I confirm that I have read and understood the information sheet/letter of invitation for this study.
- I understand what my involvement will entail and any questions have been answered to my satisfaction.
- I understand that my participation is entirely voluntary, and that I can withdraw at any time without prejudice.
- I understand that all information obtained will be confidential.
- I agree that research data gathered for the study may be published provided that I cannot be identified as a subject.

Yours Sincerely

Amir B. Meibodi
PhD Student
School of Civil Engineering and construction
Kingston University

Appendix 3: Interview Survey Documents for Iran

Kingston University London

On-site Concrete Waste Minimisation Methods

INFORMED CONSENT FORM

(to be completed after Participant Information Sheet has been read)

- I confirm that I have read and understood the information sheet/letter of invitation for this study. I have been informed of the purpose, risks, and benefits of taking part.
- I understand what my involvement will entail and any questions have been answered to my satisfaction.
- I understand that my participation is entirely voluntary, and that I can withdraw at any time without prejudice.
- I understand that all information obtained will be confidential.
- I agree that research data gathered for the study may be published provided that I cannot be identified as a subject.
- Contact information has been provided should I (a) wish to seek further information from the investigator at any time for purposes of clarification (b) wish to make a complaint.

Participant:

Name of Participant	Signature	Date

Investigator Researcher:

Name of Researcher	Signature	Date

Kingston University London

The interview questions:

1- Background questions

Name:
Company:
Position in the company:
Experience in the field (Years):
Email address:
Number of employees in the company:

2- What is your opinion about sentences bellow:

- Governmental regulations and legislations have the most impact on waste management.
- Waste management strategy itself is cost saving for The Contractors.
- The Clients would like to be environmental responsible.
- The Engineers would like to be environmental responsible.

3- Does your company have any of the following policies in place?

- Sustainable policy:
- Sustainable waste management policy:
- Any other related policy:

4-Which of the following policies and legislations has more Impact on the current waste management practices.

Site Waste Management Plans (SWMPs):

- Landfill Tax:
- The Strategy for Sustainable Construction 2008:
- Other, please specify below:

5- What do you consider as the main differences between preferred on-site concrete waste minimization in the UK and Iran? and why?

6- What do you consider as the main barriers for using pre-fabricated concrete elements (PCE) in Iran?

7- Please give your suggestions and recommendations to improve usage of PCE in Iran.

8-Any other comments:

Kingston University London

On-site Concrete Waste Minimisation Methods
Participant Information Sheet

The following interview is a part of a doctoral research study, which has been designed to illustrate the existing methods of Onsite Concrete Waste Minimising, and to find out most common and favorite current methods. The final aim of the research is to develop some improved OCWM methods. Your responses are important to clarify the information about each method from real experience.

You are being invited to take part in this study, as a specialist in construction industry. You have been selected randomly from one of the 100 leading construction or consultant companies in the UK.

The interview consists of 8 questions, and has been designed to take approximately 30-45 minutes to be completed, and interview will be arranged at a time and place that convenient for you. The interview would be note recorded, and later transcribed into a clear text form. You would be very welcome to have a copy of the final report.

There are no trick questions in this survey. There are no right or wrong answers.

Please note that all information we gain from you will be maintained in a strictly confidential manner. After 10 years of the project all raw data that can identify individuals will be destroyed. In the reporting of the project, no information will be released which will enable to reader to identify who the respondent was. You can withdraw your information at any point of the research and the data collected would be immediately destroyed.

The findings of these interviews would be used as one of the data sources for my PhD research at the Kingston University London.

May you have any questions please do not hesitate to contact me.

Yours Sincerely

Investigator Research Student: Amir B. Meibodi
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