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Development of Implementation Strategies for Offsite Construction Techniques in the Kingdom of Saudi Arabia

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Declaration

I declare that the work contained in this thesis is my own original work. Where work and ideas or concepts have been taken or adapted from any source, they have been properly cited and referenced.

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Abstract

Offsite construction is considered a new method of building in Saudi Arabia in comparison to other developed countries. The aim of this research is to examine the main factors affecting offsite construction in Saudi Arabia in order to propose a feasible strategy for its wider implementation. The broad range of factors affecting the impact of its application, the reasons for its use, and the challenges it faces were extracted from the existing literature. As a result, each reflects a factor affecting offsite construction. To achieve the research aim, the researcher adopted a mixed method approach, combining Semi-Structured interviews and Questionnaires. The interviews were administered amongst 6 expert participants in the construction industry in Saudi Arabia, while 136 participants from this industry filled in the questionnaire. All of the data were gathered and analysed based on scientific methods of analysis. The interviews revealed many factors that affect the implementation of offsite construction in Saudi Arabia and highlighted that there are four main offsite construction techniques (Offsite preassembly, Hybrid system, Panelised system and Modular building); this was also confirmed by the questionnaire. The questionnaire revealed that an increase in labour productivity and product quality as well as an overall reduction in project schedule are the main attributes of offsite construction. However, there are many challenges facing offsite construction in Saudi Arabia, including inflexibility in making on-site changes, limited design options, associated costs and risks, low awareness and resistance to OCT. An ISM validation confirmed similar outcomes. All of these factors are discussed in relation to the literature review in the discussion chapter, based on which the researcher developed an OCT implementation strategy which he tested using the ISM methodology.

In its investigation of the viability of offsite construction in Saudi Arabia, this study extends its scope beyond standard considerations of time and cost in construction, to examine these and other factors in the context-bound circumstances in which they are applied. This approach sets the background for a detailed examination of offsite fabrication in Saudi Arabia. This study considers the individual factors of cost, quality, environmental impact, negative perceptions, etc., and some of the implementation-related drivers and barriers. It also includes an examination of the social and cultural factors which could hasten the successful implementation of OCT, such as Saudi society's capacity to collaborate by adopting an open-minded, questioning approach to sharing information and to innovate by anticipating and responding to change.

Chapter 1: Introduction

1.1 Overview

The construction industry plays a fundamental role in the physical and economic development of Saudi Arabia. The Offsite Construction Techniques (OCT) approach construction in a different way compared to the traditional building method. Arif and Egbu (2010) define offsite construction as the type of construction where the purpose is to transfer some of the effort that goes into construction from the construction site to the supervised setting of a manufacturing facility. Offsite construction has been considered in the recent construction research as a way of improving the somewhat wasteful and inefficient practices associated with the construction industry (Ashworth and Hogg, 2000; Gibb and Isack, 2003; Corner *et al*., 2005; Blismas e*t al*., 2006). The improvement in resource efficiency at all stages of the process of construction, namely design, manufacture and construction will enhance the sustainability credentials of the construction sector. Myers (2008) argued that an offsite construction method is likely to assist a company to achieve resource efficiency, improve the quality of its product and increase levels of profit. Ive and Gruneberg (2000) attributed the use OCT as a construction industry response to an increase in the wages of site labour related to site productivity.

Several terms and acronyms are used to refer to offsite construction: Offsite Prefabrication (OSP), Offsite Manufacturing (OSM), Modern Methods of Construction (MMC) and Offsite Construction Technique (OCT) (Goodier and Gibb, 2007; Build-off-site, 2008). From a historical point of view, the terms used to describe the process of building manufacture and the elements of construction involved in it have changed. Five key words are commonly used in the literature to describe this form of construction: Standardisation, Pre-fabrication, and Pre-assembly. This chapter presents an overview of the thesis, starting with the background to OCT. For consistency, the researcher will use the term Offsite Construction Technique (OCT) in this study.

Historically, all or some of the components of off-site building were usually built or put together in a factory; this has been the case for many centuries (Stirling, 2003). For instance, windows and doors are two of the many parts that are produced off-site, which have been designed in buildings since the beginning of the built environment. Modular frameworks were used and building parts like bricks and roofing slate were standardised (Gibb, 2001).

After providing brief background knowledge about offsite construction, this chapter will state the problem definition, before demonstrating the need for the study as part of the rationale for the research. Next, it will describe the aim and objectives of this study, followed by the research questions and hypotheses. After that, this chapter will provide a brief explanation of the research methodology and the structure of the PhD thesis.

1.2 Problem Definition

Before discussing offsite construction, it is essential to provide background information about the Saudi economy which has led to improvements in many sectors, especially the construction sector. When talking about the economy, special mention should be made of the oil sector and the discovery of oil in Saudi Arabia over 60 years ago. Following the discovery of oil in the 1950s, Saudi Arabia has generated great wealth; however, in recent times, Saudi Arabia has begun to develop industries unrelated to oil manufacturing, such as construction and real estate. In 2011, Saudi Arabia had the second highest real estate and construction project value in the GCC (Gulf Cooperation Council), worth £136.2 billion, constituting 35.0% of the total construction and real estate projects. Most of these projects are being executed by Saudi construction companies.

In the Kingdom of Saudi Arabia, off-site construction is a relatively new area of research that has the potential to offer a solution to the housing industry (Aburas, 2011). Arif and Egbu (2010) have identified OCT as a construction paradigm that could alleviate the housing shortage.

Aburas (2011) offers three main reasons as to why OCT has not been employed commonly or efficiently in Saudi Arabia's construction industry:

- There exist technical limitations specifically linked with modular and volumetric construction
- The material used in construction in Saudi Arabia is primarily brick and concrete
- Negative perceptions of OCT exist

Although there is no shortage of research on the topic of OCT in the developed world, there is a shortage of studies examining the impact of OCT on the construction industry in Saudi Arabia. The outcome of this study will provide the necessary findings on the development of an offsite construction strategy relevant to the demands and limitations/barriers in the country. This research is based on previous studies conducted by Lu (2009), which investigated OCT and the attitudes towards it in the USA. Though in a different context, this study will examine the use of offsite construction in Saudi Arabia and whether the participants are satisfied with it, while studying the factors related to its implementation.

1.3 Research Justification and Motivation

OCT has not been implemented on a large scale in the U.S construction industry, even if the current automation technology and modes of transportation provide considerable opportunities for implementing these techniques in order to optimise the overall project performance. The use of OCT in the UK is more widely implemented in the commercial sector than the residential and industrial sectors. The reluctance of clients to adopt innovative building techniques is because they have failed to ascertain the benefits that OCT can bring to their project. Also, for many of those who were involved in the construction process, the benefits of using OCT have not been fully grasped.

The rationale informing this research stems from the Saudi construction industry's acute managerial problems, which include planning inefficiency, low productivity, and cycles of mistakes and rework (MOP, 1997; Alsaqer, 2001). In many previous studies, schedules and delays have been identified as a major and costly problem (Assaf et al., 1995; Assaf and Hejji, 2006; Al-Kharashi and Skitmore, 2009).

The benefits of OCT have been widely studied and include reductions in time, defects, health and safety risks, environmental impact, and whole-life cost, with a consequent increase in predictability, productivity, whole-life performance and profitability (see e.g. Gibb and Isack, 2003; Venables et al., 2004; Pan et al., 2007; Tam et al., 2007; Eastman and Sacks, 2008).

Many researchers believe that, in the context of innovative digital technology, OCT technology is the “future of the construction industry” (Hampson and Brandon, 2004; Tam et al., 2007). Another study concludes that, in the Kingdom of Saudi Arabia, off-site construction is a relatively new area of research that has the potential to offer a solution to the housing industry (Aburas, 2011).

1.4 Aims and Objectives

The aim of this research is to develop implementation strategies for offsite construction techniques in Saudi Arabia.

This research sets out to achieve this aim by testing how OCT impacts upon the construction industry and by establishing the relationship between stakeholder satisfaction and the use of offsite construction techniques (OCT). The exploratory study sets out to answer the research questions and examine the hypotheses in order to develop an offsite construction strategy.

To achieve the above aim, the following main objectives are suggested this study:

1. To describe and analyse the drivers and barriers for using offsite construction techniques in the construction industry in a selection of developed countries and extrapolate the sets of conditions which contribute to its success.
2. To investigate and analyse the barriers and drivers to the use offsite techniques in the construction industry in Saudi Arabia.
3. To establish the relationships between the impact and satisfaction among practitioners with the current implementations of offsite construction technologies in Saudi Arabia.

4. To conceptualise a strategy(s) for the successful implementation of offsite construction in Saudi Arabia.

5. To validate an OCT implementation strategy and adoption process.

1.5 Research Questions

1. What are the factors and techniques affecting and enhancing offsite construction in the developed world?

2. What are the factors and techniques affecting and enhancing offsite construction in Saudi Arabia?

3. What main factors will contribute to a successful offsite construction implementation strategy in Saudi Arabia?

1.6 Scope of the Study

It a complex matter fully to investigate the construction industry in relation to OCT. Many variables, systems and practices are involved; hence, it is beyond the remit of the current study comprehensively to investigate the whole sector. The scope of this study is specifically tailored to explore the points below in an attempt to provide a context, based on which the research aim and objective can be met:

1. This study focuses on specific types of projects (residential/, civil engineering, building/industrial building) and not on infrastructure or motorways, highways etc.

2. The data used for strategy development were obtained from the questionnaire survey and interviews with construction engineers, architects, contractors and other professionals working in Saudi Arabia. A mix of respondents with different backgrounds is important to minimise bias (Ng et al. 2005).

3. Many factors contribute to offsite construction. However, this research is limited to management-related factors that are controllable internally by construction organisations. As it is impractical to address a large number of factors in a limited time, external factors such as those related to the environment will not be considered.

4. Since offsite construction consists of different stages, the research considers only the construction stage; other components of offsite construction, such as designing and manufacturing, will not be examined.

5. This research is limited to large construction projects owned by government departments in Saudi Arabia and a big private company. Medium and Small Private Sector projects are not considered.

1.7 Expected Research Contributions

The research is likely to make both academic and practical contributions, as explained below:

1. The research reviews, synthesises and critically evaluates previous studies on Offsite Construction. A simple analysis of the findings and recommendations of a number of such studies suggests several courses for Offsite Construction.

2. This study is the first academic initiative concerned with the application of OCT in Saudi Arabia. It could assist the implementation of more efficient managerial practices. This may contribute towards meeting the objectives of government plans in terms of enhancing the construction sector and making it more productive.

3. Overall, this study has provided the basis for the development of research in the area of Offsite Construction within Saudi Arabia.

1.8 Research Sample

The targeted population in this study were professionals involved in the construction sector (e.g. engineers, architects, project managers, academics and contractors). Following a mixed method approach, the participants were tested using questionnaires and semi-structured interviews. The questionnaire was sent to 174 participants and 136 responded by completing it. Semi-structured interviews were carried out using a sample of 6 experts in the construction industry. Further to the use of both of these methods of data collection, the researcher conducted a focus-group interview, using ISM (Interpretive Structural Modelling) to validate the results with four experts in the field of offsite construction.

1.9 Research Methods used

Table 1-1: Research methods

Objectives	Research Questions	Research Methods: Literature review	Interviews	Questionnaire	ISM
To describe and analyse the drivers and barriers regarding the use of OCT in the construction industry in a selection of developed countries and to extrapolate the sets of conditions which contribute to its success.	What are the factors and techniques affecting and enhancing OCT in the developed world?	**S**			
To investigate and analyse the barriers and drivers to the use OCT in the construction industry in Saudi Arabia.	What are the factors and techniques affecting and enhancing OCT in Saudi Arabia?	**S**	**P**	**P**	
To establish the relationships between the impact and the satisfaction among practitioners with the current implementations of OCT in Saudi Arabia.	What are the main factors that will contribute to a successful OCT implementation strategy in Saudi Arabia?	**S**	**P**	**P**	
To conceptualise a strategy (or strategies) for the successful implementation of OCT in Saudi Arabia.		**S**	**P**	**P**	**P**
To validate an implementation strategy and adoption process.					**P**

S=Secondary Data, P=Primary Data.

1.10 Structure of this research

The thesis consists of seven chapters; the composition of each chapter is highlighted as follows:

1. **Introduction to the research**: This chapter provides an overview of OCT, a statement of the research problem, the rationale for the research, the research aim and objectives, the research question, the scope of the study, the research sample and a definition of the terms.

2. **Literature review**: This chapter starts a section explaining the economy and construction industry in Saudi Arabia. The next section of this chapter discusses OCT and the various terms related to it, and draws a comparison between OCT and traditional construction techniques. The literature review considers the use of OCT by the construction industry in the United Kingdom, United States, Hong Kong and Saudi Arabia. The benefits, challenges and barriers related to OCT are identified in this chapter. The chapter ends by highlighting the application, benefits, barriers and challenges of OCT worldwide.

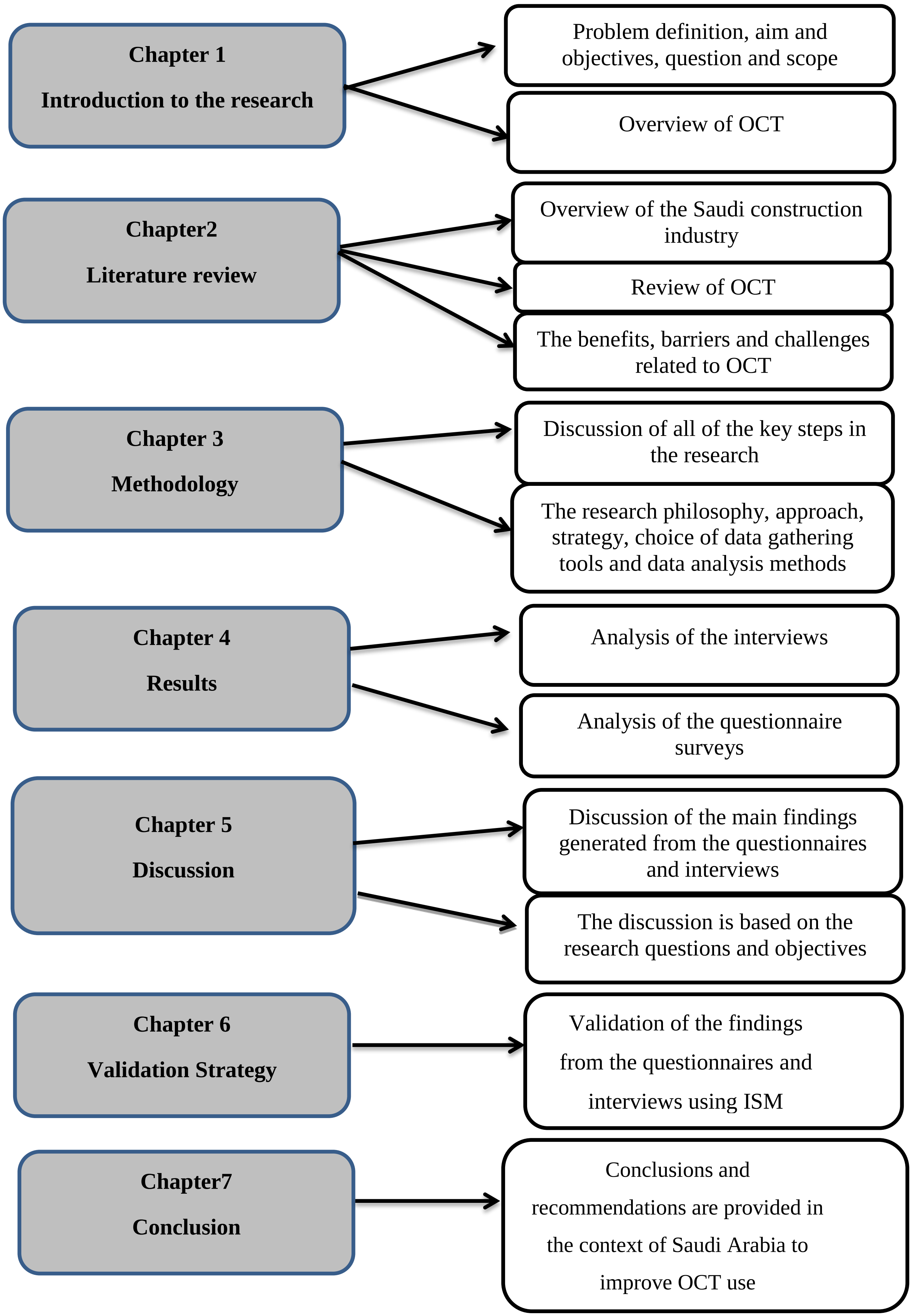
3. **Methodology**: This chapter discusses all of the key steps involved in the research, including the research philosophy, research approach, research strategy, choice of data gathering tools, procedure and data analysis methods.

4. **Data Analysis:** This chapter includes an analysis (in light of the research objectives) of the data collected in the course of the administration of interviews and questionnaire surveys.

5. **Discussion:** This chapter discusses the main findings generated from the questionnaires, interviews and ISM. Particularly focusing on the drivers, impacts and barriers related to the use of OCT in Saudi Arabia, the discussion is based on the research questions and objectives.

6. **Validation Strategy:** The findings from the questionnaires and semi-structured interviews are validated in this chapter using ISM; this involves examining the drivers, impacts and challenges and their level of importance while assessing the relationship between the different factors.

7. **Conclusion:** In this chapter, conclusions are drawn from the study based on the main findings from the interviews and the questionnaire as well as from the ISM. Recommendations are provided in the context of Saudi Arabia in order to improve OCT use.


Chapter 1
Introduction to the research
Problem definition, aim and objectives, question and scope
Overview of OCT
Chapter2
Literature review
Overview of the Saudi construction industry
Review of OCT
The benefits, barriers and challenges related to OCT
Chapter 3
Methodology
Discussion of all of the key steps in the research
The research philosophy, approach, strategy, choice of data gathering tools and data analysis methods
Chapter 4
Results
Analysis of the interviews
Analysis of the questionnaire surveys
Chapter 5
Discussion
Discussion of the main findings generated from the questionnaires and interviews
The discussion is based on the research questions and objectives
Chapter 6
Validation Strategy
Validation of the findings from the questionnaires and interviews using ISM
Chapter7
Conclusion
Conclusions and recommendations are provided in the context of Saudi Arabia to improve OCT use

Chapter 2: Literature Review

2.1 Introduction

This chapter presents a Literature Review with a brief description of the Saudi economy and its construction industry. It defines the off-site construction technique (OCT) and compares it to the traditional construction methods. In particular, the question of whether OCT can take advantage of the systemic weaknesses within the traditional Saudi construction field is addressed.

In a manner that has permitted the extrapolation of basic principles common to its successful operation. These principles set the background for a more detailed examination of OCT in Saudi Arabia. Then, the individual factors of cost, quality, environmental impact and negative perceptions, etc. are considered, as are some of the drivers and barriers to its implementation. These include a detailed examination of Saudi society's capacity to absorb and adopt an open-minded questioning approach to sharing information, and an examination of the social and cultural factors which could slow the successful implementation of OCT in Saudi Arabia.

This study does not set out to produce a building manual as a guide to the details of OCT. It does set out to investigate the viability of OCT in Saudi Arabia. In doing so, it extends its scope beyond the standard considerations of time and cost in construction, to examine these and other factors in the context in which they are applied. A 2013 review of the housing market in England, which examined the potential for OCT methods playing a more significant role in future house building, concluded that cultural changes incorporating technology, the dynamics of delivery and business model innovation, would be necessary. This Literature Review takes a similarly broad-based view, arguing that if the future success of OCT in the UK requires cultural change, it is reasonable to argue that cultural change may be needed for the assimilation and application of OCT in Saudi Arabia.

2.2 Economy and construction in Saudi Arabia

The success of the economy is considered a major factor in the Saudi construction sector. It is important to understand how the Saudi economy enhances the construction industry; the following section discusses the Saudi economy, and is followed by a description of the construction industry, specifically with reference to OCT.

Oil is the major pillar of the Saudi economy and its primary source of income, representing roughly 90% of all export revenue and contributing 45% to GDP (MOP, 2008). Saudi Arabia is one of the world's oil-rich countries, with an economy larger than that of many countries in the Gulf region and the Arab world. The exploitation of oil commenced at the beginning of the 1950s and has considerably transformed the country, which at present continues to develop its infrastructure (Saudi Arabia Economy, 2009). Following recent years, in which oil revenues reached a peak, it became increasingly necessary to make a significant adjustment to the government's level of expenditure by increasing investment to support growth (MOP, 2009). Therefore, the country has taken various measures to improve its infrastructure, allocating budgets to a number of projects, especially those in the field of construction.

Much of the literature refers to the explosion in population growth over the past quarter of a century (Long, 2005. p.28). Historically, Saudi Arabia's high birth-rates compensated for its high death rates due to a lack of available health care. With modern health care in place, the death rate has fallen, but couples continue to have large families. Saudi Arabia now has one of the highest birth rates in the world (Long 2005 p.27). Despite its growing population, the Kingdom is estimated to host approximately ten million non-national immigrant workers, while the official unemployment rate is 10.7% The labour force is employed primarily in services (71.9%), followed by industry (21.4%) and agriculture (6.7%). The unemployment rate stood at only 11.8% for 2008; however, this is based on the employment of Saudi Arabian males, and unemployment is estimated at 25% in other sources (Zuhur, 2012, p.161). Strikes, collective bargaining, and unions are not allowed. The official policy aiming at employing more Saudi Arabians to substitute foreign workers is known as Saudisation. Saudisation creates some difficulties for employers, such as meeting higher salary demands, which may impact on their profit margins. It has been argued that Saudi Arabians are less qualified than some technically trained foreign workers. Generally, the effect of the policy is to increase costs for employers and therefore represents a barrier to the training of a specialised workforce. Zuhur’s contention that the policy is unlikely to impact on employment in less-skilled occupations such as construction goes to the heart of OCT’s dilemma (Zuhur, 2012, p.163). The skills of the traditional workforce are craft-based, so additional skilled labour will be needed, either sourced from overseas, or by training the indigenous workforce to meet the demands of OCT.

Reports in the Arab press indicate that 49% of those unemployed have never applied for a job. The challenge in the construction industry is partly caused by the fact that it is cheaper for firms to recruit more unskilled foreign workers than Saudi nationals. Foreign workers receive low wages and have few laws to protect them. Efforts to promote the hiring of Saudis have had little actual impact on the numbers of locals employed. One reason put forward for this high unemployment rate is the lack of a work ethic among the youth in the country (Sullivan, 2012).

The government, through its involvement in the public sector, plays a vital role in industrial activity, but the private sector, with the support of the government in recent years has contributed, to a growing but still limited extent, to industrial diversification and development within the Saudi system of free enterprise (Mo C&I, 2001).

Thesocial and economic development increased in the 1950s and 1960s, but the trigger for the greatest change was the 1970s' energy crisis, which led to extensive social and economic development projects. Saudi Arabia has experienced as much change in the past seventy years as European civilization has experienced since the beginning of the Industrial Revolution (Long, 2005, p.28).

The country became a member of the World Trade Organisation in December 2005 (MOP, 2009). In 2009, the World Bank ranked the Kingdom 13th among competitive countries in the world, making it well-placed to achieve its objective of becoming one of the top 10 competitive countries by 2010 (MOP, 2009). The recent reforms offer new business opportunities in Saudi Arabia by reducing the cost, time and complexity habitually required for a business to be established or construction permits to be obtained.

According to MOP (2009), this economic process is characterised by the relative ease with which both government and private sectors have agreed to adapt to the new circumstances. Even if the economic plans have not achieved all their objectives, rapid economic progress has been made. A key strategic objective of economic and social development has been to diversify the economic base by increasing non-oil public revenues. Reducing dependence on oil resources is important because, firstly, these resources are not inexhaustible and, secondly, the economic base is volatile, given the fluctuation in prices in the international markets (MOP, 2009).

The government plays a central role in industrial and economic development; it has set economic growth priorities in seven successive development plans. The Ministry of Economy and Planning sets out long-term economic and social development plans, aiming for continuity in development and concentrating on human development issues, such as education, health and the family, and more specifically, the infrastructure (MOP, 2009). Other sectors of the economy are under the control of separate ministries, such as those of finance, transport, energy, communication and agriculture. Development plans have determined the economy's infrastructural, industrial, commercial and agricultural needs, setting out strategies with the purpose of delivering clearly defined national objectives (MOP, 2002). The Western literature regards the private sector as the most appropriate driver of industrialisation. However, the notion that the private sector should play a primary role at the expense of the state, with its large public sectors, fails to take account of some of the social and cultural factors discussed in Section 2.6.1. A less controlling and powerful public sector might well, in the medium to long term, serve the interests of innovative construction companies. However, Saudi Arabia, still a "developing nation" operating under a set of circumstances different from those of Western countries, will continue to rely on state intervention for large construction projects (Zuhur, 2011, p.161).The implications of these structural arrangements for OCT are set out in the discussion chapter.

Oil revenues have been the engine driving the economy, enabling the government to build the basic infrastructure without which the free enterprise economy would not develop. For the period from 2005 to 2009, a significant number of large-scale public projects were planned; these include new economic and industrial mega-cities, roads, railways, airports universities, schools and other educational amenities, housing complexes, healthcare facilities, sewage and desalination projects, sports facilities, dams, agricultural and industrial complexes (MOP, 2009).

2.2.1 The Saudi construction industry

The construction industry is fundamental to the physical and economic development of Saudi Arabia. It contributes approximately 9% to the GDP, employs more workers (1.5 million) than any other sector, and is a big consumer of manufacturing and service commodities (MOP, 1997; NCB Economist, 2003). The huge infrastructure initiatives in the last decade have provided the construction industry with a number of large projects. Figure 2.1 shows the steadily increasing Government expenditure on construction, with a budget of 65 billion Saudi riyals (SR) being allocated and spent in 2009 alone (MOP, 2009).

Saudi Arabia, on account of its sheer size, the availability of investment funding and its demographic growth, has the largest construction industry in the Middle East, with multi-billion dollar projects in the process of being completed and several others at the planning stage. Perhaps previously over-reliant on public sector initiatives, its current construction boom now relies on a healthy mix of both the public and private sectors (Middle East Finance and Economy, 2005).

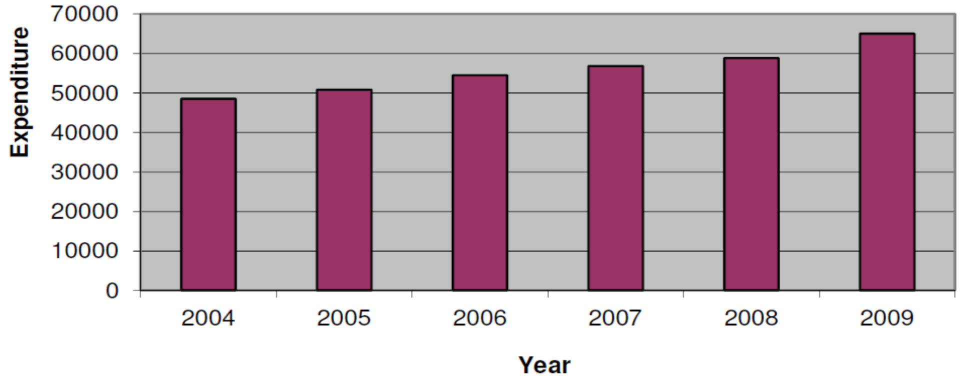


Figure 2-1: Saudi Government Expenditure on Construction (MOP, 2009).

A construction boom is presently in the process of being renewed in line with the increase in public and public-sponsored investments. Over the last decade, scores of universities have been built across the country (SAAB, 2007). The King Abdullah University for Science and Technology, the largest in the Kingdom, was opened in September 2009, and is dedicated to promoting research and innovation in the country (Alwatan, 2009).

2.3 Offsite Construction Technique (OCT)

OCT refers to the set of applications or processes where buildings, and most or all of their main components, are manufactured and assembled at a location separate and distinct from the construction site, prior to their assembly and installation on-site. OCT involves the manufacture and pre-installation assembly of building components, elements or modules at their final locations (Goodier and Gibb, 2007), which represents an innovative alternative to conventional, site-based, labour intensive construction. This process includes panelised building systems, hybrid building systems (PODS), modular buildings and a degree of off-site pre-assembly (Gibb and Pendlebury, 2005).

The process of pre-fabrication of the main building components or the assembly of building system at off-site locations is different from those commonly used in the field of construction, where most of the building components are manufactured on-site (Arif and Egbu, 2010; Azmanet al., 2010; Pan et al., 2007). Assuming that the project is coordinated and managed efficiently, OCT clearly enjoys several potential advantages; a reduction in the duration of projects, lower cost, improved quality control, the facility to anticipate and control on-site health and safety, reductions in on-site environmental disruption, and, consequently, less social and economic interruption in people's lives and their environment; the potential to reduce costs increases productivity and attracts investors to the construction industry (Gibb, 1999; Lu, 2009; Lusby-Taylor et al., 2004).

The benefits of OCT have been widely studied and include reductions in time, defects, health and safety risks, environmental impact, and whole-life cost, with a consequent increase in predictability, productivity, whole-life performance and profitability (see e.g. Gibb and Isack, 2003; Venables et al., 2004; Pan et al., 2007; Tam et al., 2007; Eastman and Sacks, 2008). The use of the technology is not limited to building houses; this technology has also been applied in the building of multi-storey buildings, particularly if located within a populated inner-city area, and in a variety of civil engineering projects. (Ngowiet al., 2005).

However, Tam et al (2007) argued that OCT technology had not developed to a standard sufficient to endorse a vote of confidence from the construction industry in general. This uncertainty does not deny the benefits of the technology, particularly its potential to improve productivity and optimise performance in the construction industry. Two years after Tan arrived at his conclusion, the Committee on Advancing the Competitiveness and Productivity of the U.S. Construction Industry (CACPUCI, 2009) recommended the implementation of the technology as one of the five key methods of enhancing both the efficiency and productivity of the U.S. construction industry.

Mbachu (2009) anticipates that, to capitalise on its initial achievements, OCT must integrate the processes of mechanisation and robot-isation, which have been successfully implemented in the aerospace and the motor vehicle industries. Many researchers believe that, in the context of innovative digital technology, OCT technology is the “future of the construction industry” (Hampson and Brandon, 2004; Tam et al., 2007).

2.3.1 OCT and Related Terms

Prefabrication is one of the terms used as a synonym for OCT in existing literature. Others are: Off-site Fabrication (OSF), Off-Site Production (OSP), pre-assembly, Off-site Manufacturing (OSM), and industrialised buildings. “Modern method of construction” (MMC) is another term used to refer to OCT. However, upon a moment of reflection, it should become clear that these terms are not synonyms; it is important to distinguish between MMC and OCT. OCT is a “sub-set of MMC” which places all OCT into the category of MMCs but all modern methods of construction (MMC) do not necessarily occur off-site (Goodier, 2007; Lusby-Taylor et al., 2004).

The primary aim of the use of OCT and related terminologies is to refer to the relocation of construction activities from the construction site to an off-site “factory-controlled environment”, with the aim of improving quality, and reducing cost and construction time

(Gibb and Isack, 2003; MBI, 2010a; Tatum et al., 1986). In this thesis, the researcher chooses the term OCT (OCT) to avoid confusion.

2.3.2 Levels of OCT

Offsite pre-assembly

Offsite pre-assembly is a process by which various building materials, pre-fabricated components, and/or equipment are joined together at a remote location for subsequent installation. It is generally focused on a system. Examples are: roof trusses; pre-assembled vessels, complete with insulation, platforms, piping and ladders (Tatum *et al*, 1986).

Hybrid Systems (Pod)

Hybrid systems consist of pre-fabricated, fully factory-finished building facilities, including completed bathrooms with all the furnishings installed, completed office washrooms and plant rooms, etc.

Panelised Systems

Panelised systems refer to the construction of the structural frame of the building by using panels manufactured in a factory. Such a system consists of factory-built structural components instead of completed modules, transported to the site, assembled and secured to a permanent foundation, typically including additional factory based fabrication, such as cladding, insulation, internal finishes, doors and windows (NAHB, 2004).

Modular Buildings

Modular buildings refer to factory-built homes of one or more units, completely assembled or fabricated in a manufacturing plant away from the jobsite, then transported and assembled on-site. Modular buildings normally have multi-rooms with three-dimensional units, which are constructed and pre-assembled, complete with trim work, electrical, mechanical, and plumbing systems installed (O'Brien, 2000).

2.3.3 Comparison of OCT with Traditional Construction Methods

Comparing one thing with another can be an inexact science because comparisons are often selective. Though distinctions are often not made clear, OCT is often compared to traditional options on the basis of both value and elemental costs. Goodier and Gibb (2007) point out that comparisons between the efficacy of OCT and that of traditional construction methods are often primarily based on development cost rather than on the longevity of the project's life cycle .

The fact that the speed of construction is the most frequently referenced and considered the most valued advantage of using OCT over other methods of construction is perhaps overshadowed by the general perception, in Europe, that it delivers poor quality (Pan et al, 2007). This belief, in common with stereotypical attitudes to innovative changes using new technologies, may constitute a general perception which lags several years behind the reality (Pan et al, 2007).

Another advantage may be the perception that OCT is more eco-friendly than conventional methods. In the course of their comparison of OCT to traditional construction methods, Barret and Weidmann (2007) argue that OCT outperforms the traditional construction approach when it comes to greenhouse gas emissions and environmental degradation. Poon and Jaillon argue that it provides a solution to reducing waste during the building design and construction processes (Poon and Jaillon 2010, p.1026). Several authors make claims for waste reduction on-site by using OCT (Tam et al., 2005, 2007a; Jaillon et al., 2009). Fong et al. (2003), through a case study analysis, demonstrated a reduction of 56% of construction waste through using OCT and recorded reductions in water consumption (41%) and construction time (20%), although this study was confined to only one building sample, using the innovative precast technique. This is a valid viewpoint but, to achieve a deeper and valid comparison, other aspects must be taken into account, such as the longevity and life-cycle of the project – is it temporary or permanent – and the attitudes of customers, who might consider modular construction as fragile and impermanent.

Can OCT take advantage of the systemic weaknesses within the traditional Saudi construction methods?

Multinational construction companies working in Saudi tend to experience systemic problems with regard to managing and completing their projects. For instance, culture shock is experienced by project managers when their clients fail to attend appointments on time; OCT's accommodation with Saudi cultural values is discussed at length in Section 2.6.1 of this Literature Review. The literature suggests that a raft of conditions - globalisation, improvements in software, higher educational levels, and increased demand for housing to accommodate demographic change – may lead to at least an increase in the use of targeted OCT. In the past, the evidence was that its application has often been a response to a specific need at a specific time.

However, it could be argued that the subject of time is culturally relative. Is it possible that delays in traditional Saudi construction could make OCT seem more attractive? The literature emphasises that both OCT and traditional construction methods prioritise time as an indicator for project success. Indeed, both processes share three important phases, i.e. project conception, project design and project construction, even if they adopt different strategies to implement them. If, historically, the application of OCT has often been a response to a specific need at a specific time, there may be grounds for the belief that OCT may hold a future advantage.

According to the literature referring to conventional building projects, delays occur during the ‘construction’ phase, “where many unforeseen factors are always involved”. The rapid expansion of Saudi Arabia's oil economy has also created a clash of commercial cultures. Economies of scale, the legally binding nature of written contracts, the transparency of business operations, the timely delivery of contracted goods and services, interest charges on capital loans, and other practices regarded as standard in the West have come into conflict with the traditional Saudi commercial practices emerging from an oral culture where a person's word is his bond (Long, 2005, p.31).

Completion beyond the date specified in a contract, and the consequent loss of revenue is a common problem in construction projects. To the owner, delay means loss of revenue through the opportunity-cost of the non-availability of production facilities (Ramanathan et al., 2012).

The traditional construction process is subject to many variables and unpredictable factors, which result from many sources. Some of these sources – the performance of the parties, the timely availability of resources, environmental conditions, the involvement of third parties, contractual uncertainty, and the too rare completion of a project within the specified time (Assaf 2006) – could, at least in theory, be ameliorated if not eradicated by an off-site factory based approach.

Although older studies report “frequent and lengthy delays”, pervious study records a reduction in delays in Saudi traditional construction methods from 70% (Zain Al-Abidien 1983) and 59% (Al-Khalil and Al-Ghafly, 1999: 101) to 40% (Kahlil, 2004), suggesting that some improvements have been achieved over the last decade. Faridi and Al-Sayegh (2006) reported that the financial cost of project delay is held to be “one of the most serious and frequent problems in the Saudi Arabian construction industry”. The delay of any construction project affects the direct costs of that project. In a case where the project is a public building or facility, the complications increase when the client is a government department. The consequences of these delays include the public’s uncertainty regarding development plans, disruption to the government’s budget, and public inconvenience resulting from the delay of the project. From the contractor’s viewpoint, delays cause higher overheads and the loss of output and revenues.

From the client’s viewpoint, the causes of the greatest delays are the client’s lack of finance to complete the work, slow decision-making by the owner, followed by suspension of work by the owner, and difficulties in obtaining work permits (Alkharashi&Skitmore 2009).

The contractor’s response cited the replacement of key personnel, slow decision making by the owner, the owner’s poor communication with the construction parties and government authorities and interference by the owner in the construction operations as the causes of the greatest delays (Alkharashi&Skitmore 2009). For consultants, the problems were the suspension of work by the owner, the owner's poor communication with the construction parties and government authorities, and the replacement of key personnel (Alkharashi&Skitmore 2009).

The booming demand in the Saudi Arabian construction industry has a knock-on effect on the unavailability of qualified and experienced manpower, materials and equipment, which in turn interferes with the scheduling upstream of other projects in the pipeline, thereby further extending delays. Alkharashi and Skitmore (2009) advise that the Saudi government should, through targeted education and selective subsidies, encourage specialised and centralised OCT factories which would address the problem of scheduling, which several sources have reported to be "a critical issue in the construction industry in Saudi Arabia"(Al-Ojaimi 1989), (Assaf et al. 1995),(Al-Khalil and Al-Ghafly1999) . If consultants and contractors have faith in the professional expertise of OCT centres of excellence, this should help avoid future confusion in the construction sector.

The government would have a vested interest in incentivising the private sector to develop such centres because, as Alkharashi and Skitmore (2009) point out, the government is very often the client yet, as the client, it is nevertheless often "unaware of technical issues and simply passes on its tasks to the consultant". Poor communication between the client and consultant and unfamiliarity with the personalities and abilities of the technical staff involved are additional complications which would be alleviated by government-backed but privately-owned centres of excellence.

If government investment were seen to assist the process of developing centres of OCT excellence, these could help to combat the "high level of uncertainty associated with construction projects" (Alkharashi and Skitmore 2009) by distributing large construction projects more evenly over a number of years to help to alleviate the situation. Aburas (2011) recommends more training for existing practitioners and new education courses for future graduates to increase the use of OCT.

Overall, the Saudi construction industry must overcome both the man-made and environmental hurdles that are commonly faced by any construction business. Three primary concerns are common to owners: the time necessary for completion, cost and quality. The traditional 'sequential' approach to construction is another compounding challenge. It should be clear that the industry encounters persistent problems, such as delay, waste, poor quality, low productivity, mistakes and later rework. Recurring delays of considerable length in the completion of projects are a very serious problem in the public sector (Zain Al-Abidien 1983; Al-Sultan, 1989; Al-Khalil and Al-Ghafly, 1999; Falqi, 2004; Assaf and Al-Hejji, 2006).

However, to better understand the development of OCT, it is worth examining its implementation in other western and Asian countries where this has long been in use. The following section will discuss OCT in the UK, and briefly examine its impact on the construction industries in the USA and Hong Kong. Following this, OCT will be discussed in the Saudi context to provide a rationale for the current study.

To summarise this section, the traditional construction process is subject to many variables and unpredictable factors, which result from many sources, including the performance of the parties, the timely availability of resources, environmental conditions, the involvement of third parties, contractual uncertainty, and the too rare completion of a project within the specified time. The financial cost of a project delay is held to be "one of the most serious and frequent problems in the Saudi Arabian construction industry". The delay of any construction project affects the direct costs of that project, and it should be clear that the industry encounters persistent problems, such as delays, waste, poor quality, low productivity, mistakes and later rework. Recurring delays of considerable length before the completion of projects are a very serious problem in the public sector.

That comparisons between the efficacy of OCT and that of traditional construction methods are often primarily based on development costs rather on the longevity of the project's life cycle, the fact that the speed of construction is the most frequently referenced and considered the most valued advantage of using OCT over other methods of construction , OCT is more eco-friendly than conventional methods, OCT outperforms the traditional construction approach when it comes to greenhouse gas emissions and environmental degradation, and the fact that OCT provides a solution to reducing waste during the building design and construction processes and waste reduction on site by using this techniques.

2.4 Overseas Applications

The reason for choosing OCT in the countries specified is that they have successfully implemented this technique through years of experience, OCT has not been implemented on a large scale in the U.S construction industry, even if the current automation technology and modes of transportation provide considerable opportunities for implementing these techniques in order to optimise the overall project performance. The use of OCT in the UK is more widely implemented in the commercial sector than the residential and industrial sectors. The implementation of OCT extends to other Asian countries, such as Singapore, Korea and Hong Kong construction that depend heavily on foreign labour.

2.4.1 OCT and its Application in the United Kingdom

Arguably, the use of OCT by people in the UK dates back to the 1620s when they brought with them to South Africa panelised wood, ready for use by the fishing fleet to construct temporary accommodation (Peterson, 1948). During the Crimean War in 1855, in response to a request by Florence Nightingale, the famous civil engineer Isambard Kingdom Brunel was commissioned to design a pre-fabricated modular hospital.

In the extremely demanding circumstances of 19th century Crimea, he designed within five months a 1,000 patient hospital, with innovations in sanitation and ventilation. The simple point here, developed in greater detail in this study, is that, historically, OCT has often been insufficiently planned and designed to meet an immediate need. Both the strength and weakness of OCT has been its strong connection with the type of project, the prevalent conditions, and the construction application required. The mass pre-fabrication of residential buildings in the United Kingdom in the 1920s and 30s encountered several factors: an urgent widespread market demand for new housing, a broad public acceptance that the lead time between the initiation and execution of the traditional process was unfit for purpose, and a shortage of skilled labour. Although Waskett is correct to refer to the failure of the traditional methods to meet the demands, innovative construction intervention following the destruction caused by war was less a case of entrepreneurial intervention and more a case of the means being suited to the required end (Waskett, 2001).

In the United Kingdom, OCT was not consistently developed into the 1930s, resulting in a lack of long-term innovative technological change in building design (Waskett 2001). Indeed, in the course of the 27 years that separated the World Wars, the extent of urban devastation reflected advances in the destructive power of armaments, while no corresponding development had been made in the techniques of off-site construction. Once again, there was pressure on the UK government to provide homes and employment opportunities for soldiers returning home.

In the UK, OCT is mainly used in the commercial rather than the residential and industrial sectors – because in England and Wales masonry systems are frequently used for most residential buildings – and when they are used, it is mainly for assembling heating and cooling equipment as well as other building services (Blismas 2006).

Although the benefits of using OCT are well-documented, the process is not applied on a large scale (Pasquire&Gibb, 2002). In 2004, OCT represented only 2.1% of the construction work in the UK, including new buildings, the refurbishment or repair of existing buildings, and civil engineering work (Pan et al., 2007).

Other sources record a slightly higher – but still low – percentage; the uptake of off-site in the UK industry remains low, with its market value to date estimated to be up to £6 billion, which is approximately less than a 6% share of the UK construction industry (Pan and Sidwell, 2011, p.1082; Goodier and Gibb, 2007). Innovation in the UK house building industry is conservative in comparison with that in other countries (Pan et al., 2007). The industry has been reluctant to adopt innovative building technologies.

Dr. Martin Edge conducted research in 2002 to identify resistance to the use of OCT, and how this might be overcome. Carried out over a period of 30 months, the research included interviews with representatives of 100 major construction companies and manufacturers, construction professionals, house buyers and developers. It concluded that home buyers are partially resistant to new building materials, but less resistant to new forms of OCT. The study also found that there was a strong market, offering innovative forms of housing which have the potential to be affordable, flexible and sustainable (Edge, 2002). Perhaps the repeated use of the word 'potential' is a hint to the reader that, located somewhere in the OCT process, is a bottleneck preventing its wider application. The market to which Edge refers is unlikely to include pre-fabricated high-rise blocks.

Edge et al. (2002) found that house buyers are so strongly influenced by negative perceptions of the post-war 'prefab' that they will resist modernist box designs that change the appearance of a 'traditional' house. The human perception barrier, grounded in the historical failure of off-site practices, also exists among architects and other designers (Pan et al., 2004). Warren states that pre-fabricated architecture has long been associated with the failed mass housing attempts of the post-war reconstruction period (2010, p.9).

One such failure was the collapse of the Ronan Point tower block in east London in 1968. Ronan Point was part of a construction wave of affordable pre-fabricated housing. Its collapse was caused by a gas explosion. This critical event changed the way in which UK engineers considered robustness. The tower had been part of the UK's response to the general housing shortage previously mentioned. It was built from pre-fabricated concrete panels, a cheap building method commonly used in all European countries during the 1950s and 60s (Jones Bussell 2010).

A shortage of skilled labour, aggravated by periodic shortages of essential materials, the housing shortage and widespread market demand for new housing, encouraged the notion of system building which, through OCT, was anticipated would achieve improvements in quality and faster production times. At the time, it seemed to offer the perfect means to an end in solving the post-war housing crisis (Jones Bussell 2010). Lack of quality control led to unacceptable short-cuts in construction. The weakness was in the joints connecting the vertical walls to the floor slabs.

At the time of Ronan Point, the UK government, perhaps unwisely in retrospect, subsidised every floor built over five storeys high, and as a consequence the increased production resulted in a related downfall in construction quality. The literature contains several references to the advisability of government commitment, or government promotion, as an aid to consolidating OCT. Indeed, the Saudi government currently offers subsidies to certain building contractors. Although this is a legitimate recommendation, it comes with its own historical health warning. Subsequent studies of attitudes of UK house builders to OCT have suggested that the government "should subsidize the use of off-site MMC to make them cost effective" (Pan et al., 2007, p.188;Miles and Whitehouse, 2013, p.32).

Even though the estate was rebuilt, Ronan Point became synonymous with failed architecture. The taint of corrupt practice was linked to ties between subsidising agencies and construction companies and between subsidies and large public contracts. It is worth pointing out that an indirect barrier to OCT in Saudi could arise out of the “traditional, personalised, and informal Saudi norms for public and private commercial and financial transactions” (Long, 2005, p.32). From a Western viewpoint, these are judged to be illegal, thus contributing the popular notion of some in the West that Saudi society is basically corrupt (Long, 2005, p.32).

From a procedural perspective, Ronan Point begs the question of whether OCT is really safe. Does quick production time mask instability, making pre-fabricated buildings more likely to collapse? There is no simple or immediate answer to this question. Context, experience, demand, culture and environment will all play a part in preparing the ground for OCT. In the UK context, the positive outcome was the development and enforcement of robust laws and a change from British to European standards relating to OCT. The disaster also led to a standardisation of OCT, known as disproportionate collapse, which states that the building shall be constructed in such a way that, in the event of an accident, the building will not suffer collapse to an extent disproportionate to the cause (Jones and Bussell, 2010). It is difficult to conclude that OCT can be successful in Saudi Arabia without strict enforcement along similar lines. To achieve this, a lax or unlimited interpretation of the regulations would have to be unacceptable. Instead, the interpretation of regulations would need to be based on risk management principles, and each application would have to be considered on its merits.

In the architectural world, the partial collapse of Ronan Point symbolised, for many, the collapse of the ideals of 'modernity' and 'progress' and the association of OCT with shoddy work, suitable only for those who could not afford anything better (Newland, 2008). Although architects were hardly involved in the building process, the public blamed their modernist planning principles for the Ronan Point disaster (ibid.). Its impact on future OCT projects, though not easily measurable, was certainly negative.

Each project is unique and thus it is difficult to develop a comprehensive evaluation system that compares the use of inchoate and innovative OCT with conventional approaches. A research report by the Robert Gordon University, UK (Edge, 2002), noted that the resistance to innovation largely came from the construction companies themselves rather than from the clients. The uncertain impact of construction costs is another impediment to the use of OCT in the UK. A shortage of skilled assembly workers is another obstacle in the UK. Compared to conventional techniques, OCT requires highly qualified and skilled labour for the precise on-site assembly of building components manufactured in a factory environment(Goodier and Gibb, 2004; Venables et al., 2004; Clarke, 2002; Palmer et al., 2003). If the limited skills of on-site assembly workers 'are cited as a problem in the UK, along with the industry's limited capacity to produce building modules, this does not bode well for OCT's chances in less industrialised societies(Gibb, 2004).

2.4.2 OCT in the United States' Construction Industry

In common with the UK, the situation in the US, according to a Construction Industry Institute (CII) study in 1997, admittedly now out of date, states that the shortage of skilled craft workers represents a challenge for the United States' construction industry.

Several other studies have also emphasised that a shortage of skilled labour is a problem in the United States' construction industry (Liska and Piper, 1999; CII, 1998 & 2000, 2002; Hass, 2000; Eickman, 1999). On the other hand, demands from construction company owners that projects be completed more rapidly, be less expensive, and be completed without sacrificing quality and safety performance were reported.

Therefore, to overcome the shortage of skilled craft workers and to meet owners' expectations, construction companies must implement more efficient ways to deliver projects. The OCT adopted includes off-site preassembly, hybrid building systems, panelised systems and modular buildings.

These OCT approaches have not been implemented on a large scale in the United States' construction industry, even though the current automation technology and modes of transportation provide opportunities for implementing techniques to optimise overall project performance (Hass, 2000; O'Brien, 2000). Many reasons are put forward to explain why OCT has not been widely accepted in the US construction industry. Some of them are: limited design options, on-site change flexibility, transportation restraints of building systems and construction error tolerance (Gibb, 1999). One of the most significant challenges, in both the United States and the United Kingdom, are the perceptions of those using OCT (Barlow, 1999; Gibb, 2002; Hass, 2000; Sawyer, 2006). With the backing of the city administration, an apartment block made from pre-fabricated "micro-units" has been erected in Upper Manhattan by a New York firm of architects (Merlan Village Voice 2013). Once again, we have a niche application which exploits the advantages of OCT. Land is in short supply, it is appealing to younger tenants to live in refurbished inner city areas and owners are motivated by rising rents. In the digital age, downsizing in the form of mini-apartments has become feasible, economical, fashionable and eco-friendly. Under these conditions, OCT offers a solution.

A video illustrates the speed and efficiency of the final months of the construction process, although no actual "construction" takes place. Workers can be seen speedily fitting the pre-fabricated pieces together like a “jigsaw puzzle”. OCT, in this case, removes uncertainty from on-site construction (Merlan Village Voice, 2013).

2.4.3 OCT Applications in Hong Kong

Writing specifically about conditions in Hong Kong, a “dense and compact urban environment” with limited space for construction, Jaillon and Poon (2010) conclude that OCT, when combined with modular design and standard components, has the capacity to save time and costs involved in design and construction, providing that buildings systems are used across projects. However, we cannot extrapolate a wider general principle because their finding is site or context-specific. They explain that, in some projects, “specific site conditions restricted the use of similar pre-fabricated building systems across projects” (Jaillon and Poon, 2010, p.1025). Also, even though it is widely believed that flexible pre-fabricated building systems would result in efficient use of resources, Jaillon and Poon state that it “is seldom practised in Hong Kong” (Jaillon and Poon, 2010).

In Hong Kong, high-rise construction is the standard, so that the “repetition of pre-fabricated components at every floor is easily achieved” and quantity is, therefore, a major issue when using OCT to achieve economies of scale. The greater the need for numerous steel moulds, the more costly the production process becomes (Jaillon and

Poon, 2010)

It seems clear that circumstances in Hong Kong meet several conditions for the use of OCT. Since it provides a solution to reduce waste during the building design and construction processes (Poon and Jaillon 2010 p.1026), it addresses the limited space available for waste disposal and the increased use, on a small overcrowded island, of finite resources such as wood, metal and natural gravel for manufacturing. It also minimises the chance of construction materials and emissions being released into the environment, and allows for deconstructed materials to be re redirected into the material flow. To achieve this aim, the building industry will require a fundamental modification in the way in which buildings are designed, constructed and used. The design of a building would significantly influence the amount of potentially reusable/recyclable materials at the end of the useful life of a building (Jaillon and Poon, 2010 p.1026).

Yet, even in the Hong Kong public sector, most of the construction activities still rely on traditional on-site construction methods (Jaillon and Poon, 2010, p.1026), but the existence of incentive schemes in Hong Kong has spread OCT beyond public housing projects and introduced it to the private sector. The government's construction policy, as stated in Joint Practice Notes, sanctions such aims as the protection and improvement of the built and natural environment, promotes the construction of green and innovative buildings and encourages the adoption of a "holistic life cycle approach to planning, design, construction and maintenance" and the maximisation of the use of "natural renewable resources and recycled/green building material"(Joint Practice Notes, 2001).The private construction sector in Hong Kong has responded to environmental necessity and financial inducements as set out in the government backed Joint Practice

Notes, established in 2001, so that pre-fabricated components such as precast facades and semi-precast balconies are the most frequently used. The Joint Practice Notes have planned for success; that is, they have chosen processes which, by modern construction standards, are not the most difficult to replicate. Indeed, through repeated use, the quality is enhanced and guaranteed, and it becomes possible to exploit economies of scale which offset the fixed capital cost involved. Repetition of pre-fabricated components is central to making pre-fabrication cost effective.

It would appear from the Hong Kong perspective that the private sector will cooperate to make use of green features, but only up to a point. Although different types of pre-fabricated components are employed in both sectors, the link between perceived quality, market forces and cost is not easily broken. Therefore, semi-precast balconies, which are "frequently used in the private sector", are "non-existent" in public housing projects (Jaillon and Poon 2009, p.240). In contrast, units associated with functionality in smaller sized flats and not associated with a more flamboyant style, such as "precast cooking bench unit(s), precast internal partition wall(s) and precast beam(s)", were adopted in public housing projects but absent in the private sector (Jaillon and Poon, 2009, p.241). The long-standing government backed bias, first promoted in the 1990s, and formalised in 2001, towards the use of green features which "achieve higher product quality and finishing" in public housing projects, such as the use of precast facades and staircases, illustrates that experience and exposure to a learning curve is essential for the medium term success of OCT. This early development of OCT in public housing projects and Hong Kong's "extensive experience in pre-fabrication" has, to a limited extent, spread to and influenced pre-casting innovations in the private sector (Jaillon and Poon, 2009, p.241).

Under these conditions – long experience, government backing, limited access to resources on a small island, very high educational standards, a compact urban environment, a high demand for affordable housing and a shortage of building land – the adoption of OCT, as opposed to traditional construction techniques, holds clear advantages, such as improved quality control, reduced construction time (20%), reducedconstruction waste (56%), less dust and noise on-site, and fewer labour requirements on-site (9.5%).

To summarise, in Hong Kong, high-rise construction is the standard, so that the "repetition of prefabricated components at every floor is easily achieved" and quantity is, therefore, a major issue when using OCT to achieve economies of scale. The greater the need for numerous steel moulds, the more costly the production process becomes. It seems clear that the circumstances in Hong Kong meet several conditions for the use of OCT, since it provides a solution to reducing waste during the building design and construction processes.

Even in the Hong Kong public sector, most of the construction activities still rely on traditional on-site construction methods, but the existence of incentive schemes in Hong Kong has spread OCT beyond public housing projects and introduced it to the private sector. The government's construction policy sanctions such aims as the protection and improvement of the built and natural environment, promotes the construction of green and innovative buildings and encourages the adoption of a "holistic life cycle approach to planning, design, construction and maintenance" and the maximisation of the use of "natural renewable resources and recycled/green building material". The private construction sector in Hong Kong has responded to environmental necessity and financial inducements.

Through repeated use, the quality is enhanced and guaranteed, and it becomes possible to exploit economies of scale which offset the fixed capital cost involved. Repetition of pre-fabricated components is central to making pre-fabrication cost effective.

2.4.4 The Application of OCT in Saudi Arabia

Saudi Arabia's sustained economic growth has created a platform for economic and infrastructural expansion in the Kingdom. Nevertheless, as we have seen, construction projects were marked with delay and inefficiency (Alkharashi and Skitmore, 2009).

In 2011, Aburas asserted that OCT is increasingly used in Saudi Arabia, specifically in the construction of highways, bridges and stadia, although no statistics were provided. When asked about their perception of off-site construction in Saudi Arabia, many of the participants in a forum on the topic declared their involvement in its techniques for building bridges and overpasses, parts of roads or highways, wall panels and other facade panels. Some said that they were involved in the construction of high buildings and temporary structures like site offices and portable toilets (Aburas, 2011).

The use of OCT is not a new phenomenon in such projects. It has been in use for the past couple of decades in the construction of highways and bridges. The participants claimed that OCT added value by accelerating the speed of the construction process compared to traditional building methods. Reductions in wastage and the amount of labour required were also considered notable. When asked to identify its benefits and what would help to add to the uptake of OCT, the delegates listed the main benefits as speed, quality, increased health and safety, and cost savings (Aburas, 2011).

The delegates identified several barriers to off-site construction. One barrier identified was the technical restriction concerning volumetric and modular construction. Saudi Arabian construction uses mainly brick and concrete. In Japan and the US, the principal material used to build modular houses is wood (Aburas, 2011). The advantage of wood is that it is light and easy to transport from the factory to the construction site. The disadvantage associated with the use of concrete and bricks are the difficulty in lifting and transporting them. This assumes the availability of appropriate means of transport, infrastructure and lifting equipment off-site. It also assumes the availability of accurate cutting and measuring equipment to correct small errors. In addition, Aburas (2011) reports the need for further research into the topic of mixing heavy-weight concrete that is capable of resisting the heat and humidity of the desert climate. Until such research is carried out, it will be almost impossible to use modular and volumetric construction in Saudi Arabia.

A further impediment to the implementation of OCT would be the possible absence of a permanent factory for the manufacture of pre-fabricated wall panels. They are generally cast on the construction site itself and then lifted and fitted in place. Also, more training and new education programmes for existing practitioners and future graduates is needed to permit the increased use of OCT. Delegates in the forum also raised the issue of the lack of the kind of legislation that exists in countries such as Malaysia, which encourages construction companies to implement off-site construction. Attitudes within and outside the construction industry to off-site construction regarding issues of safety, durability and aesthetics, also remain a barrier. In the UK, where the process has been in use in its modern application since the end of World War II, the prevailing perception is that OCT delivers poor quality products (Pan *et al*, 2007).

An additional barrier relates to the difficulty of transporting over-sized loads containing modules, which requires wide roads and modern infrastructure. This could be difficult (although, on the evidence of inner-city pre-fabricated constructions in New York and elsewhere, not impossible) in some densely populated areas in Saudi Arabian cities where narrow roads and the lack of manoeuvrable and up to date lifting cranes would restrict the manoeuvring of these loads.

Aburas (2011) recommended educating consumers and the construction sector about the advantages of off-site construction, to help to modify the prevailing perception that modular construction is synonymous with temporary construction techniques. Without improved training and education programmes for professionals in the construction industry, off-site construction in Saudi Arabia is unlikely to keep pace with technological developments in more developed countries. The promotion of inter-disciplinary research would incorporate elements of both construction and manufacturing. If this is to become more widely used, the training of architects and designers is essential.

2.4.5 Summary of OCT application worldwide:

The reason for choosing OCT in the countries specified earlier is that they have successfully implemented this technique through years of experience. For example, OCT has been implemented mainly by large UK construction companies. The use of OCT is more widely implemented in the commercial sector than the residential and industrial sectors. The reluctance of clients to adopt innovative building techniques is because they have failed to ascertain the benefits that OCT can bring to their project. Also, for many of those who were involved in the construction process, the benefits of using OCT have not been fully grasped. Furthermore, the unclear impact of the construction costs was another big challenge to the use of OCT in the UK. The shortage of skilled assembly workers is another contributing obstacle, and research has found that home buyers are partially resistant to new building materials but not to new forms of OCT. In the context of the U.S.A., OCT has been implemented for many years; however, there are demands on the part of the owners (the buyers of construction) that projects should be completed faster, be less expensive, and be completed without sacrificing quality and safety performance. The aspects of OCT adopted include offsite pre-assembly, hybrid building systems, panelised systems and modular buildings. OCT has not been implemented on a large scale in the U.S construction industry, even if the current automation technology and modes of transportation provide considerable opportunities for implementing these techniques in order to optimise overall project performance.

The implementation of OCT extends to other Asian countries, such as Singapore, Korea and Hong Kong construction that depend heavily on foreign labour. In the system of HDB's semi-precast reinforced concrete, the principal building components, beams and columns, among others, are all cast-in-place. All other reinforced concrete components are pre-cast in a factory environment; these include staircases, parapets, as well as internal, non-load-bearing partition walls. The context of Hong Kong Construction typically has set up a pre-fabricating facility on the project site. Given that the preassembly process is carried out on-site, the construction company does not deal with the transportation issues. All of the pre-cast concrete modules are manufactured on-site and a crane lifts them into position at the rate of one floor per day. As in most Asian countries, the large population offers a great opportunity for using OCT which has been widely implemented in constructing high-rise buildings with more than fifteen floors.

Now that we have provided a summary of the use of OCT in different countries, it is essential to understand how it is used in the context of Saudi Arabia. As explained earlier, Saudi Arabia has adopted OCT in recent times and research has suggested (Aburas, 2011) that this approach is being employed increasingly frequently nowadays, more specifically within types of construction, like highways, bridges and stadia (Aburas, 2011). While stating the use of OCT worldwide, it is important to highlight the factors relating to OCT and its success in Saudi Arabia has not yet been fully examined. Hence, the purpose of this research is to examine such factors, people's satisfaction with OCT and the possible barriers to its usage.

The original intention of this research was to examine the application of OCT in several countries. However, it was concluded that a cursory investigation of the application and success of OCT in a range of several countries would not achieve the required descriptive depth to give validity to identifiable trends. The primary focus is on Saudi Arabia. The purpose of investigating OCT in other countries is to set a benchmark, a point of reference against which progress in Saudi construction's use of OCT could be compared. The purpose was not to construct an evidential compilation of countries and present them as representative of contemporary OCT practice. There is too much variation across the needs and capabilities of any construction environment to establish uniformity of practice. Given the restrictions of time and space, and the necessity of remaining relevant to the stated objectives, the choice of the United Kingdom, the United States and Hong Kong as countries worthy of investigation was informed by several fundamentals.

Saudi Arabia and Hong Kong share several construction conditions; for example, in Hong Kong and Saudi, most construction activities still rely on traditional on-site construction methods. The demanding physical site conditions experienced by Saudi workers are cited as a factor influencing the use of OCT. Hong Kong and Saudi are separated by only 1.14 degrees of latitude. The sharing of similar climatic conditions means that their construction industries share the motivation of alleviating onerous on-site working conditions by using an off-site factory-controlled environment that is more conducive to improving the quality and working conditions. Also, the government uses financial incentives to induce contractors to adopt sustainable policies, redirect the application of OCT beyond its customary association with public housing projects and encourage its use in the private sector. The policy of government-sponsored intervention to achieve desirable social aims would be worth considering in Saudi Arabia.

In Hong Kong, the use of OCT is driven by the necessity of making the best use of the limited resources in terms of land and water. The US construction industry is too big to hold in common more than a few specific traits that can be said to be characteristic of its off-site industry. However, its size permits genuine competition in the construction market, based on the exploitation of economies of scale. Culturally, it is associated with unfettered free market competition so, in the US, the utility of OCT should be exposed by the operation of market forces. The important qualification in the US context is that the International Building Code requirements are uniformly applied and high standards of quality and safety enforced. The US construction market should therefore be a crucible element in revealing how OCT responds to the demands of market forces and the stringent enforcement of building standards through quality inspections. The next section will look at the main benefits of OCT and the worldwide challenges it faces.

2.5 Benefits of OCT:

OCT can no longer be regarded as new. OCT is perceived as efficient, cost effective, and sustainable, or as expensive – according to its designated purpose, climate and location – and of inconsistent quality, depending on the skill levels and manufacturers' adherence to enforceable codes. Gibb (1999) provides a long list of the various benefits associated with the OCT of building components. Some of these OCT benefits are discussed below:

• OCT allows prototype testing, which is of particular significance for buildings planned to be erected in seismic zones. This makes possible the prediction of project outcomes, and results in the reduction of defects and the post-construction defect liability period. According to the *The Independent* newspaper, a 30-storey hotel, just outside Changsha, India, was built in a fortnight and tested on the second largest earthquake-testing platform for Magnitude 9 earthquake resistance (Beanland 2013).

- OCT improves the supervision of the manufacturing and preparation of materials and workmanship in a factory-controlled environment, thus enabling the manufacture of high quality building components which should result in a high quality end product.

- Activities taking place on-site parallel to off-site ones reduce the completion time required for the entire construction project.

- Components manufactured in the factory environment, ready to be installed on-site, contribute towards shortening of the duration of the site activities.
- The wastage on the construction site is reduced, thereby reducing to a minimum the carbon footprint of the construction.
- Components are manufactured in distant areas and hence far less material is handled on-site; the result is the better management of the construction site.
- OCT can considerably reduce the cost of the project.

In addition, Jaillon and Poon (2010), referring to oft-replicated process of manufacturing volumetric pre-assembled units for public housing, argue that OCT products generally suffer from few structural or quality defects, which is actually rare in the case of on-site construction projects. The reason is that it is more difficult to achieve an efficient quality control system on-site than in the factory environment.

Other benefits of OCT are as follows:

- Manufacturing building components in factory controlled settings benefits the environment as less waste, noise and dust are generated during the construction activities. Moreover, OCT does not consume a large amount of energy (Luo, 2008).
- The on-site construction of components provides an effective solution to the problems associated with a shortage of skilled labour; meanwhile, it also meets the market demands (MBI, 2010a; Nadim and Goulding, 2009).

- OCT is completely independent of weather conditions and the use of this approach curtails the delays caused by inclement weather (Bell, 2009).

- OCT is known for its efficient use of resources and environment-friendliness (MBI, 2010a).

2.5.1 Cost

In Pan et al.'s UK study (2004, p.188), the respondents named the primary barriers as the higher capital cost (68%) and difficulty in achieving economies of scale (43%). Even though Lusby-Taylor et al. (2004) believed that off-site costs should be more predictable than those of traditional construction, in 2004, they concluded that it was unlikely that costs would be reduced by using off-site methods. They argued from the designers' perspective that limited cost data contribute to the low level of usage of complete modular buildings and volumetric pre-assembly systems (Lusby-Taylor et al. 2004).

The variety of its applications in different locations, each with their own specific demands, has clouded the issue of the cost barrier of OCT, which is "seldom clearly defined" (Pan and Sidwell, 2011, p.1082). Subtle differences in the way in which it is referred to in the literature, as 'high initial costs', 'higher immediate costs', or 'higher capital costs', reflect and also contribute to the ambiguity and uncertainty of the cost barrier (Pan and Sidwell, 2011 p.1082). High costs (especially if economies of scale are impossible) and the fragmented structure of the supply chain inhibits designers' acceptance of off-site technologies (Pan et al., 2007, p.188)

Pan and Sidwell (2011, p.1082) cite innovative technology's association with a higher capital cost than its conventional counterpart, as a reason for the limited adoption of

OCT. Because the cost of the project is always a major consideration – the lowest bid usually wins the contract – there is a bias in the construction industry towards well-proven methods and materials. In an examination of medium to high rise residential buildings in the UK, Pan and Sidwell (2011. P.1082) rated the cost performance of four types of construction methods and found that cross-wall, by a ratio of 11% to 32%, was consistently cheaper than a reinforced concrete frame or a steel frame. Once developed, the innovative process of cross-wall technology delivered cost savings of up to 25% from its first use. The ways of achieving cost reductions included “efficiency learning, technological innovation, multinational partnering, and ‘in-house’ build management”. The results prove the logical reasoning that the experience curve improves the cost efficiency of OCT, a finding that should encourage OCT in the future (Pan and Sidwell, 2011, p.1081).

However, unless fixed costs are absorbed by economies of scale, or niche applications are found, the construction industry’s aversion to risk, the lack of information and public awareness of new technologies, the purchasing public’s perception of their inferior quality and the costs involved in using a new technology appear to be the principal barriers. Meanwhile, innovation will probably remain a cost-intensive investment, paying uncertain dividends.

2.5.2 Schedule

As with the issue of cost, the literature is inconsistent in its treatment of how OCT affects the duration of a project. While Goodier and Gibb’s 2004 study linked the benefits of OCT methods to shorter on-site duration and increased quality, it listed the main barriers as real or perceived additional costs and long lead-in times.

Pan et al’s (2007) study of the perspective of UK house builders on the use of off-site modern methods of construction states that the “traditional drivers of time, cost, quality and productivity are still driving the industry. Even in the UK, Pan et al. (2004, 188) concluded, the second most important driver for growth in OCT was dealing with time and cost uncertainty (54%). In Pan et al’s UK study (2004, p.188), when the respondents were asked to choose the most significant barriers, they named the third barrier as the higher capital cost (68%), and the difficulty in achieving economies of scale (43%) as well as an inability to freeze the design from an early stage (29%).

The literature suggests that, taken together, the traditional drivers of time, cost, quality and productivity remain the main drivers in the construction industry for making more use of off-site technologies (Pan et al., 2004, p.192). This may be so, but their limited uptake suggests that OCT has difficulties in capitalising on its perceived advantages. Goodier and Gibb (2004) and Venables et al. (2004) concluded that, compared to traditional construction methods, OCT is associated with longer lead-in times, making it more expensive, and that this is the main barrier to its increased use.

Another factor complicating any generalised non-context specific judgment about the utility of OCT is the perspective and role of whoever is expressing an opinion. For instance, while contractors and engineers believe that it achieves a higher quality in the end product, architects believe that pre-fabrication increases the programme and design time (Jaillon and Poon, 2010, p.1040).

2.5.3 Product Quality

The use of pre-fabricated components for high quality products can be achieved through accurate design and close supervision on-site; this reduces the amount and scope of change. The more precise profiles and standardised dimensions of components result in better quality control of the project. Currently, the construction IT software helps to guarantee that the alignment and precision of a given project are maintained both on-site and in the factory. Computer-assisted manufacturing technology allows products in the line to be different from each other. Software creates an integration of design practice and manufacturing to provide mass customised production (Russell, 1981). The lack of unanimity on the issue of quality suggests that, because the OCT industry is driven by time and cost, the lowest cost for a given quality often wins the contract. Achieving consistency and predictability in quality remains an elusive objective.

2.5.4 Onsite Safety Performance

OCT can enhance the on-site safety record by limiting the exposure of workers to inclement weather, hazardous operations, and extended on-site working time. Workers in a fabrication factory are unaffected by inclement weather. Pre-fabricated components also provide more working space to minimise the possibilities of accidents occurring on-site (Ball, 1998).

2.5.5 Environmental Impact

The manufacturing process, if carried out with care, enables construction waste to be controlled and reduced to a minimum through convenient design and recycling opportunities. Negative environmental impacts can be alleviated by reduced on-site construction time, less noise, and less waste produced on-site. Moreover, industrialised construction processes can considerably reduce costs and increase material inputs. One specific scheme developed with European Community (EC) funding has been quoted as having the following anticipated benefits (Blismas, 2006):

- The amount of water used for the construction of a typical house was reduced by 50%.
- The use of quarried materials in the construction was reduced by 50%.
- The energy consumption was reduced by at least 50%.

To summarise the above sections, it is evident that OCT offers many advantages and benefits; mainly, it reduces the cost, schedule, environmental impact and need for skilled, craft workers, and increases product quality and safety. Therefore it is hypothesised that:

1. The use of OCT reduces the overall project schedule.
2. The use of OCT reduces the need for skilled craft workers on-site.
3. The use of OCT increases project product quality.
4. The use of OCT increases safety performance.
5. The use of OCT increases design efficiency
6. The use of OCT reduces the negative environmental impact of construction operations.

2.6 Challenges Facing OCT

As OCT is a newly emerging technology, it faces several challenges. These challenges must be addressed to overcome the barriers to its uptake and encourage its wider implementation in the construction industry. The literature refers to many challenges of

OCT use, which can be summarised as follows:

2.6.1 Project Planning and Coordination

Increased pre-project planning is a disadvantage when pre-fabrication, preassembly, and modularisation are opted for in construction. There is a need for greater engineering efforts to be made beforehand (CII, 2002). Therefore, extensive planning preceded by design work must be precisely conducted before fabrication begins. The implementation of OCT in construction work increases the lead time engineering. Related to this is the need for a detailed understanding of all aspects of the construction work. The planning and design should be conducted with precision to incorporate the construction work needs. This is one of the challenges that must be overcome in order to decrease the reluctance of the industry to implement OCT. The standardisation of components and their repetitive use can serve as a potential solution to this problem. Improved IT integration of construction processes is also likely to overcome this challenge. Moreover, the coordination of design, transportation, and on-site installation are critical components for its successful implementation.

2.6.2 Transportation Restraints and Logistic Challenges

These are timely developments because the benefit of on-site cost reductions is perceived in the developed world as dependent on the location of the supplier. This influences the decision to choose OCT. Also, one solitary centrally located supplier is insufficient. There is a need for multiple suppliers to avoid a market "monopoly"(Tan 2001). Transportation plays a fundamental role in making OCT possible. The method and route of transportation impose restrictions in terms of size, weight, width and weight during transit (CII, 2002). Road transport, as the most widely used method, usually limits the size of modular buildings or preassembled building components to 12-14 feet in width, and 50-55 feet in length. Their weight is also restricted by the capacity of lifting equipment which should usually be between 10 to 30 tons. In the US, there exist highway restraints to add to the lifting capacity limitations of the crane. Manufactured building components must be overly designed to minimise possible damage during transit, which is likely to increase the design and construction costs (Pendlebury, 2004).

Whether using OCT is feasible or not largely depends on the transportation and other logistical issues related to large sized components and modules. Dynamic impacts during transportation sometimes require special arrangements to be made during design and construction. Transportation and logistics are critical due to constraints such as the weight limits and dimensions of roads, bridges and tunnels, etc. Special care needs to be taken during loading and offloading the components and special lifting machines are required for this purpose. Likewise, the installation of modules requires specialised cranes and qualified operators to handle and place the heavy components.

2.6.3 Design challenges

One of the important challenges facing OCT is the lack of flexibility which makes any design modifications at a later stage problematic. OCT is usually carried out with structural or non-structural elements that are built in environments other than the construction site. This makes it almost impossible to make any changes during the process of on-site erection, resulting in an industry-wide reluctance to implement the construction technique. OCT may be used more if it develops the flexibility to make changes during the critical phases of the construction process. It is commonly believed that using OCT always means continuously using similar components and having similar structures all the time. Commonly, the predetermined element of modular construction which forces architects to make all design decisions ahead of time – requiring the building blocks to be shipped to the site with all their features and interior partitions preconfigured – is presented as a cost saving element. This cuts down on on-site operations and the many mistakes that inevitably arise from them.

However, this no longer represents an insurmountable obstacle because, in high-tech societies, Computer Aided Design (CAD) and high tech digital manufacturing machines have made it possible for OCT to deliver buildings with variable designs (Yau, 2006).

2.6.4 Negative Perceptions

Based on the literature, negative perceptions of OCT represent one of the most important impediments to OCT in most countries, with the possible exception of Germany and Japan. In the US, confusion has arisen regarding the public perception of the difference between pre-fabricated buildings and manufactured "mobile homes", even though there is a huge difference between these two types of buildings (Hass, 2000; O'Brien, 2000).

Although many benefits are claimed for OCT, this technology faces negative perceptions related to its use. These perceptions are based in particular on the housing supplies built after World War II, at a time when the high demand for housing was met through the construction of pre-fabricated houses. Unfortunately, the poor quality of these houses resulted in the blame being directed at the whole concept of OCT since that time. The negative perceptions associated with the use of OCT have not been eased by a failure to distinguish between mobile homes, holiday homes and pre-fabricated homes. Certainly, from the viewpoint of many inhabitants, pre-fabricated buildings retain a negative image;

many consider them to be unattractive, made from poor quality materials, with poor acoustics and insufficient thermal insulation. Most pre-fabricated architectural components seem ordered from a common stock, with the issue of cost effectiveness prevailing over aesthetics and creativity. Customers of buildings might consider modular construction as fragile and impermanent; these attitudes are perhaps a legacy of incidents such as the collapse of a part of Ronan Point in the 1960s, when OCT was too often an adaptation to insufficient planning, rather than an integrated and integral element of a well-managed construction plan.

2.6.5 Flexibility to make changes on-site

OCT, particularly for modular buildings, requires a well-defined scope in the early stages of the project planning (CII, 2002).

To summarise, based on the conclusions arrived at regarding the challenges facing OCT, the researcher is committed to examining each of these challenges: Transportation Restraints and Logistic Challenges; Design challenges; Negative Perceptions and Flexibility to make changes on-site.

1. The use of OCT limits the number of design options available.
2. Transportation restraints (i.e. size constraints, transportation costs, impact on building structures) limit the use of off-site construction techniques.
3. The owner’s negative perception of off-site construction techniques limits the use of those techniques.
4. The use of OCT limits the ability to make changes to work on-site.
5. The use of OCT requires the high use of IT.

2.7 Barriers to the uptake of OCT

Despite its well-documented benefits, the literature contains numerous references to the limited uptake of OCT (Egan, 1998). There is a need, therefore, to identify and address the barriers constraining its adoption. Several studies have been conducted to identify these barriers. For example, Chiang et al.(2006) and Tam et al. (2007) report a number of barriers to the use of OCT in the Hong Kong construction industry. Hindrances relevant to the UK industry were reported by Goodier and Gibb (2007) and Pasquire et al. (2004). Constraints to the application of OCT in the U.S. construction industry were identified by an MBI (2010a) report. Likewise, a CRC (2007b) Report pointed out the barriers to the uptake of pre-fabricated construction in Australia. It is believed that, even if many barriers exist to the uptake of OCT, the construction industry still has the potential to benefit from this technology (Tam et al., 2007).

The barriers to the uptake of OCT technology identified in the Australian report (CRC, 2007b) were taken as the starting point for the present study. The feedback received from industry members during the pilot interviews revealed that these constraints are relevant to the New Zealand context, with a few minor adjustments. The nine main constraint groups identified in the case study about Australia were reduced to seven in the New Zealand study:

2.7.1 Barriers to the Process and Programme

The use of OCT is a process which requires the integration of planning, design, manufacturing, supply and installation. Previous studies identified barriers relating to the process and programme of OCT.

OCT projects finalise design at an early stage, so that the manufacturing of components can start earlier and components are ready as soon as construction activities are launched on-site. OCT design takes longer than usual and is dependent on the proper management of interfaces during design. Kelly (2009) argues that time delays on OCT projects relate to the precise design information which is required before the commencement of the project. Extensive coordination on the part of clients, architects, management consultants and contractors is required.

All of these activities increase the lead time of the project. Longer lead times are seen as a main barrier to the adoption of OCT technology (CRC, 2007b). Goodier and Gibb (2007) also consider longer lead times as a key constraint to the adoption of OCT. Murray *et al.* (2003) observe that the construction industry has realised the need to improve the current practice which demands the skilled use of IT and OCT as tools to improve quality and efficiency issues. Rivard (2000) mentions the need for computer-integrated design and construction. The limited use of information technology, especially among small and medium sized construction firms, is one of the concerns (Love and Irani, 2004). The demand to keep pace with the ever-changing software and employing skilled operatives capable of exploiting IT are also barriers to the use of OCT (CRC, 2007b; Blismas et al, 2005; JohnssonMeiling, 2009, p.679). Saudi OCT faces the challenge of ensuring that computer engineers, subcontractors and architects can develop component knowledge, and openly share that knowledge, in a way that is mutually beneficial. This topic is set out in detail in the discussion chapter.

The CRC (2007b) report stresses that the advantages of using OCT can only be reaped if the project is designed as an OCT project from the outset. The reason is clear: the manufacture of components commences far earlier than the start of construction activities (Jaillon and Poon, 2010). One of the conditions of using OCT in construction is to freeze the project design at an early stage. If the project design cannot be frozen at an early stage, this can be seen as a barrier to the adoption of OCT (CRC, 2007b; Jaillon and Poon, 2010).

The OCT components which are manufactured in factories or yards are designed to create a match between the interfaces during the installation on the construction site. Haas and Fagerlund (2002) emphasise the need for engineering care in the interface management. This mismatch of interfaces can result in large scale problems. This is due to the inflexible nature of factory built components; they cannot be modified on the spot. This inflexibility limits the implementation of OCT (CRC, 2007b; Scofield*et al.*, 2009a).

2.7.2 Barriers relating to cost, value and productivity

One of the barriers, mentioned several times under the broad category of cost, value and productivity, is the perception that OCT projects are more expensive than traditional site-built projects (Blismas and Wakefield, 2007; CRC, 2007b; Phillipson, 2003). Gibb and Isack (2003) and Jaillon and Poon (2010) affirm that OCT construction methods are costlier than the conventional site-built methods when steel moulds are used for OCT, because they are more expensive than the traditional timber formworks used on-site. Likewise, the CRC (2007b) report confirms that the design fees can also be higher. However, Haas et al. (2000) believe that, “under specific conditions”, the use of OCT can save costs compared to conventional construction methods. When the life cycle value of the project is taken into account and the standardisation of components is adopted, the repetitive use of these components can increase the cost benefits of using OCT (Haaset al., 2000; Jaillon and Poon, 2010). There appears to be some inconsistency in the literature regarding the issue of cost. The most unambiguous assessment is that, whilst modular construction can be more cost effective, it is unlikely to be cheaper. After all, why would a system specified with the same high-quality components as a traditionally-built project and designed for the same longevity be cheaper? The reality is that construction is simply moving into a factory, while the materials remain the same – from the steel frame to the plasterboard. It seems more appropriate to locate cost benefits within the time-advantages which accrue to OCT in comparison with site-based construction. When contractors are successful in reducing the programme time by up to 50%, the building is occupied at an earlier stage for a faster return on investment.

Pan et al's (2007) study of the perspective of UK house builders on the use of OCT suggest that the "traditional drivers of time, cost, quality and productivity are still driving the industry". Nearly two-thirds of the firms wished to see an increase in the adoption of such technologies. However, the current barriers relate to a "perceived higher capital cost, complex interfacing, long lead-in times and delayed planning process". Interestingly, rather than highlight the technical shortcomings of one construction procedure or another, Pan et al. (2007) base their critical analysis on perceptions, and the need for accurate data. A widely reported critical barrier is the higher capital cost, either real or perceived, associated with off-site solutions, coupled with a lack of publicly available cost data and other information (Pan and Sidwell, 2011, p.1082; Goodier and Gibb, 2007).

Given the different accounts of OCT-related costs in the literature, and evidence that financial and social factors are the drivers of innovative approaches to building, this broader analysis seems well-informed. The authors recommend changing peoples' perceptions, providing better cost data, tackling issues of planning and regulation, using the lever of political influence and improving the practical guidance and procurement (Pan et al., 2007).

They base their judgement on what they refer to as the 'potential' offered by off-site technologies for reducing costs, time, the poor quality of construction work, and, to a lesser extent, health and safety risks and environmental impact (Pan et al., 2007).

Although they make no clear distinction between the private or public sector, Pan and Sidwell (2011, p.1097) conclude that the OCT of UK apartment buildings does not necessarily involve higher construction costs, but they also mention that savings would be dependent on reducing the capital cost by developing cross-wall technology, and that the "high capital cost or cost intensive investment associated with offsite construction is a myth". They conclude that construction cost savings are possible "through effective management", which would involve "efficiency learning, technological innovation, partnering, and 'in-house' build management". However, Pan and Sidwell qualify their conclusion by adding that "cost reduction and effectiveness is not automatically achieved by using off-site techniques".

However, by adding that "further investigation in a new context would be merited", they help validate this research's finding that, despite the many references to OCT's future potential, its successful application remains conditional on a range of technical, social, geographical, market-led and cultural factors, which must come together to provide a solid foundation for its success. Their analysis implicitly takes into account OCT's ‘potential ‘and underlines its sensitivity to context, geography, market demands and culture. Based on this, only future practice will confirm whether or not Pan and Sidwell’s argument that the higher capital cost of OCT is a ‘myth’ will prove to be an accurate assessment.

Pan et al.’s 2004 study of UK house builders indicated that traditional construction methods achieved a satisfaction rate of over 80%, while traditional building methods attracted a satisfaction rate of 59%. However, house builders recorded a dissatisfaction rate of 47% with off-site techniques within the industry. Pan et al. describe these findings as “somewhat disappointing”. Reflecting on the Hong Kong experience, kitchens and bathrooms were regarded as the most promising opportunity for growth in off-site solutions (44%), followed by external walls (41%), timber frame structures (37%) and roofs (33%). It is reasonable to conclude that, while UK house builders will be both well informed and motivated to take advantage of the optimum procedures available to them, they did not see any great potential for investing in complete modular buildings (Pan et al. 2004, p.187)

The establishment of factory units or production yards is necessary for the application of OCT and the related manufacturing process; the cost of such an operation is very high. This high initial setup cost is reported to be responsible for hindering the widespread application of OCT (Blismas and Wakefield, 2007; CRC, 2007b; Pan *et al.*, 2005).

The components built in a factory environment also require the use of cranes to lift and install them in their positions on-site; sometimes this calls for the need of specialised cranes because of site constraints, the heavy weight of the component and the unusual dimensions of the components or modules. The widespread use of cranes while carrying out an OCT project is costly and is more likely to be a barrier to the use of OCT. The transportation of OCT components of large size from factory to construction site is another barrier identified under this broad category of constraint (CRC, 2007b; Pasquire*et al.*, 2004). This cost is dependent on the distance between the factory's location and the construction site; accordingly, long journeys are likely to be more expensive, thereby increasing the entire cost of the project.

2.7.3 Barriers relating to regulations

One of the main issues with the legal frameworks is that they are not structured to encourage the use of OCT. Designers find it difficult to consider using OCT, given the lack of knowledge about this technology in the construction industry's policies and code of practice. An MBI (2010a) Report indicates that building codes are among the main constraints which discourage the use of OCT technology.

A CRC (2007b) Report highlights the fact that there are very few OCT codes and standards available. All in all, these regulations are constraining, costly and onerous. Likewise, there are safety compliance issues related to the use of cranes to handle heavy pre-fabricated components. It is not only expensive to achieve such compliance, but also time-consuming and discouraging for contractors.

2.7.4 Barriers relating to the industry and market culture

The industry and market culture plays a role by encouraging or discouraging innovation. The New Zealand construction industry is described as not very innovative and the industry and market culture as responsible for hindering the application of OCT

(Scofield*et al.*, 2009a). The risk associated with innovation is an important reason preventing the industry from trying something new.

The construction industry is labour-intensive, and labour has its own stakes against the newly-emerging technologies. Resistance of the labour market towards the acceptance of OCT technology is likely to hold back its uptake (CRC, 2007b). Clients also have a stake based on their vested interests and perceptions. The preferences of the client are often paramount in the process of deciding which method of construction to adopt (Gibb and Isack, 2003). Becker (2005) believes that New Zealand clients prefer the tried and tested traditional designs; they are not always in support of new and innovative ideas such as OCT. Consequently, this hinders the application of OCT.

Another constraint to the uptake of OCT is the conservative approach of the industry towards the adoption of the technology (CRC, 2007b). Designers prefer to continue using the traditional design methods based on a number of specifications. They are reluctant to opt for new design approaches. Similarly, contractors appear reluctant to adopt a different supply chain procedure.

The pessimism which surrounds the quality of building materials and poor craftsmanship associated with the previous use of OCT is an additional factor (POST, 2003). Pan *et al.* (2005) report important concerns about the adoption of OCT by clients who feel that it must be tested to ensure that it offers better quality outputs compared to the conventional construction methods. The impression that OCT offers poor quality dates to the post-World War II period, when the demand for housing during the re-construction phase was met by the use of pre-fabricated buildings. These building were of poor quality and the industry did not always meet the safety and quality standards.

Lusby-Taylor et al. (2004) indicate that clients reject houses which are made using OCT techniques. Things are made worse by the fact that it is sometimes difficult to obtain funding and insurance for OCT projects, as financial service providers, including insurers and credit lenders, require sufficient guarantees which correspond to the perceived financial risk associated with the projects based on OCT (Barker, 2003). This situation can be regarded as a hindrance for developers' adoption of OCT.

2.7.5 Barriers relating to Saudi culture

Saudi Arabia has, in the past fifty years, experienced a transition from a traditional desert based society to one which is sceptical of modernity. Although its infrastructure has been refurbished to form a modern, largely urban society, other aspects of society are proving less easy to change. For example, the unforgiving desert climate and the heat that goes with it tend to make Saudis more nocturnal in their habits than most other peoples. The traditions and cultural attitudes have been shaped by Islamic and Bedouin culture. Family ties take priority, and must be taken into account, even in the business world. For social and cultural reasons, the details of which are not relevant here, there is a tendency towards a high rate of absence among students and workers. European standards of "time management and accountability are invalid in Saudi Arabia" (Morris 2011). From the outsider's perspective, it is a society that is more comfortable "passively receiving information from the television than actively seeking information from books" (Morris 2011).

The preceding discussions on social and cultural values are not intended as a general critique of the society. They are written for the purpose of highlighting certain social and cultural factors which could slow the successful implementation of OCT in Saudi Arabia. Most of the literature (particularly works authored by Arab writers) on traditional Saudi construction methods, both conventional and off-site, treat the topic as if construction takes place in a vacuum as regards values; in other words, even the research interpreting the causes of delays in the industry explains itself in transactional terms rather than by referencing social and cultural factors. Topography, climate, and infrastructure are factors which are considered to the exclusion of less visible, more intrinsic ones. However, differences between countries must be considered by looking at several factors, including culture, as these play a central role in all marketing environments (Ben Mansur, 2013, p.24).

Cultural behaviour is commonly held to depend on a set of values determined by an underlying structure of interacting belief systems. Research shows that the way in which individuals perceive their social environment is directly related to their cultural background (Ben Mansur, 2013, p.23).

Arabic culture places a high premium on the face to face resolution of conflict, and the avoidance of embarrassment or discomfort to others; therefore, preventing loss of face is essential for business success in Saudi Arabia. Hofstede, who developed a framework to describe the effects of a society's culture on the values of its members, argued in 1991 that Western and Middle Eastern countries stand at opposite ends of the spectrum when it comes to cultural values. European countries are inclined to focus on the deal as the key element in business, whereas Saudi culture has long been based on the relationship aspect of business (Ben Mansur, 2013, p.25).

Two factors suggest that a skills deficit could affect the application of OCT in Saudi Arabia. One of these factors is the unpreparedness of the Saudi academic curriculum, which is focused on religion rather than on problem solving and critical thinking approaches. The other is the 'rentier state' of mind induced by the over reliance on foreign labour (Whitaker, 2009).

Which social and cultural factors might slow the successful implementation of OCT in Saudi Arabia? According to Long (2005), one characteristic is the pre-Islamic tradition of "legitimizing group decisions by consultation and consensus". The Arabic saying, *Insha'allah*, or "God willing" – whether in a government, business, or family context – is taken literally (Long 2005, p.24). The Western mind-set could be inclined to associate fate with passivity; it no longer identifies fate with the notion of total faith in God's will. In relation to the construction industry, a belief in Fate, or God's will, could have the effect of inducing decision makers to wait longer than others might for a desired outcome. Arguably, the need to make key decisions early in the procurement process is incompatible with the slow moving Saudi decision making, which prioritises patience as a "watchword of traditional Saudi behaviour" (Long, 2005, p.25). In support of the view taken by this research, Long argues that an understanding of Saudi behaviour requires an understanding not simply of the substance of a situation, but also the context in which it is being viewed. For example, such contexts could be the "differences of expression of situational behaviour" and "absolute Islamic moral values".

Saudi verbal communication at face value often does not convey what the speaker/writer either intends or actually thinks about a subject. It could be argued that possible misunderstandings arising from this trait must be overcome in all business contexts.

However, outside agencies involved in Saudi OCT– this usually means Western subcontractors – must submerge themselves in collaborative models with Saudi nationals which require participation in technological development. Uncertainty is the enemy of this process.

Another relevant characteristic – not unique, but prevalent in Saudi culture – is that behaviour is highly personalised. Trust is the foundation of all social transactions, and without personal rapport, successful social, business, and governmental relations will not develop. Within Saudi companies, the negotiation process is a part of relationship building and, unlike Western practice, the contract itself plays a minor role in lowering the level of uncertainty at the beginning of the relationship (Ben Mansur, 2013, p.12).

The components of trust mainly arise from the expectations of business partners. Trust is cemented when partners keep their promises. Huang and Dastmalchian(2006, p.363) define trust as “the willingness of one party to be vulnerable to the actions of another party based on the assumption that the other will perform a particular action”. In its early stages, expectations of trust drive the business relationship (Ben Mansur, 2013, p.14). Because “empathy, and politeness” have a greater impact on trust when the parties first become familiar with each other, compatibility in a relationship improves when the two collaborating parties “share values, beliefs, goals, status, lifestyles and personality traits”(Ben Mansur, 2013, p.15). Organisational trust refers to the belief that the necessary structures are in place in a firm to justify the expectation of a successful collaboration. The key characteristic of trust is the extent to which a customer believes that the seller’s intentions and motives will benefit the customer and that the seller is concerned with creating positive customer outcomes. Trust is also linked to other components, namely bonding, reciprocity and empathy, which lead to cooperation (Ben Mansur, 2013, p.18).

These points are relevant to this research because trust is a significant determinant of problem-solving effectiveness. It remains to be seen, if, for example, a more open exchange of collaborative ideas bringing greater clarification of the goals and problems, and an increased motivation to implement conclusions, is possible in a Saudi context (Ben Mansur, 2013, p.20). Ben Mansur's conclusions are hesitantly expressed, but he acknowledges that Saudi Arabian culture enters into the trust equation when trying to build commercial relationships, and that there is room for improvement in the areas of "commitment and punctual delivery" (Ben Mansur, 2013, p.120).

There is arguably a causal connection between poor punctual delivery and the rhythms of daily life in Saudi. These rhythms are different from most other places and are embedded, to a large extent, in the traditional working day, which is geared to the five times a day prayer cycle. Writing in 2005, Long noted that the prayer cycle is still observed by individuals and the self-employed, but that it "creates difficulties for large government offices, major banks, and large corporations" (Long, 2005, p.30). There is no reason to think that time sensitive OCT schedules would not be similarly interrupted.

There has been an evolution towards Western office hours, but not to the extent of totally abandoning the traditional daily rhythms around the prayer cycle, despite the innovative ways in which Saudis have modified modern business and public financial practices to conform to Islamic law. Another cultural difficulty impeding the medium term application of OCT could be Saudi educational standards. Saudis do not have a strong tradition of reading and writing in Arabic. Some Saudi students complain that the curriculum is irrelevant to their career needs. Others observe a disconnection between the traditional values of the patrimonial state and the demands of the market and civil society (Niblock, 2006). Writing of Al Yamamah University, which specialises in Business Administration and Information Technology courses (and might be expected to provide the pool of skilled labour which OCT demands), Morris (2011) states that most students have limited "experience with researching and writing in Arabic" and no experience of writing a "situation-problem-solution" essay in Arabic, while the habit of academic reading was "wholly foreign" to them (Morris, 2011). Changes in the school and university curriculum have aimed at placing greater emphasis on leadership, teamwork and problem solving abilities, but such change is often slow to show results. Some may argue that these reflections on Saudi Arabian education are out of place in a study of OCT. However, a review of the literature shows that many research articles discuss its application as a method separate from a social – as well as a geographical and a technical – context. Smith is an exception to this practice. One of the purposes of education is to encourage problem solving and the sharing of knowledge. However, the competitive adversarial demands of the traditional construction industry are unsympathetic to the principle of integration associated with OCT. Smith (2011), in reference to Western educational institutions, suggests that, to absorb this principle, a revision of the curriculum and the promotion of goals that prioritise cross disciplinary learning should be encouraged in schools' teaching architecture and engineering. Solving complex problems in a collaborative style requires a questioning mind-set that is accustomed to, and unafraid of, asking difficult questions (Smith, 2011, p.337). There is no reason to believe that this aspiration to collaborate in a construction environment would not aid a growth in expertise in a Saudi context.

The continued training abroad and at home of young Saudis as professionals is slowly changing the religious culture, and many young Saudis take a more contemporary view of Islam than does the conservative approach of previous generations. With religious studies being prioritised over marketable skills and foreign labourers being offered much lower wages than the native workforce, the outcome in the construction industry is a ratio of nine to one between average Saudi and expatriate salaries. Despite laws stipulating quotas for Saudi employees, and despite a near-doubling in the number of non-government workers, the Saudi proportion of the private-sector workforce in construction fell from 17% in 2000 to just 10% in 2010 (Economist, 23.06.12).

It is easier to describe the areas in which modern Western business ethics and traditional Saudi business ethics clash, than it is to try to analyse the underlying cultural sources of this clash. Perhaps the two most fundamental cultural sources of conflict are linked with concepts of law and honour. From a Western cultural perspective, legality is the guiding principle by which all business decisions involving risk must be made. From a Saudi cultural perspective, *Sharaf*– an ancient code of personal and collective honour – is the principle which guides relationships, including commercial relations. From the Saudi perspective, the strict legality of a transaction will not be the primary determinant of whether it is considered dishonourable and therefore "morally corrupt", and Western business practices, that are deemed dishonourable by *Sharaf* values, have reinforced the popular belief among many Saudis that "secular Western culture is basically corrupt" (Long, 2005, p.32). Personalised and informal Saudi norms for completing commercial and financial transactions sometimes lead to the payment of ‘commissions’ which, from a Western perspective, may be judged illegal, thus contributing to the popular notion of some in the West that Saudi society is “basically corrupt” (Long, 2005, p.32).

The clash between traditional Islamic culture and Western technological modernisation has been accommodated, with some success, by a blending of modernisation with tradition to the exclusion of secular values. Despite, or perhaps because of, their acceptance of the outward trappings of modernisation in the form of information technology, communications and health care, and their building of a modern social and economic infrastructure, not even the most modernised Western-educated Saudis want to abandon their Islamic cultural heritage for the secular humanism of the West. Sustaining the equilibrium between modernisation and a society based on Islamic values will continue to constitute the country's most pressing challenge in the twenty-first century (Long, 2005, p.33).

One of the distinctive features of the Saudi construction industry is its reliance on low skilled foreign workers. Several contractors employ workers who, in many cases, have little or no experience of modern methods of construction. Although they have skills in construction, the standards practised in Saudi Arabia are unfamiliar to them, as these standards are different to some extent from those in their home countries (Saudi Council of Chambers of Commerce and Industry, 1998). Besides this, in Arab countries including Saudi Arabia, people are not usually committed to punctuality, which means that their time-keeping is sometimes poor and could impact on the time-sensitive performance of the industry.

Like any (new) technology which involves change, OCT often attracts resistance. The inherent "protectionism and conservatism" of the industry culture is no exception. A Western viewpoint states that those familiar with the Kingdom know that, when tendering construction contracts, the Saudis move slowly but steadily forward (Stephens, 2013). The Kingdom has to some extent been able to 'featherbed' its citizens without the need for unwelcome taxation. This largesse is a real barrier to reform (Whitaker, 2009). If wealthy governments have no need to petition their citizens to fund spending through taxation, it becomes more difficult to build a civil contract of trust between the state and its citizens. The world of global competition and technological change demands a well-educated, technically skilled workforce with the managerial capacity to adapt to and apply the ever changing technologies (Whitaker, 2009). However, it would be unfair to suggest that the Kingdom is unaware or unresponsive to these issues.

2.7.6 Barriers relating to supply chain procurement

A supply chain and procurement system is important for any civil engineering project; it is far more critical for OCT projects. The CRC (2007b) report mentions that supply chain obstacles limit the capacity of suppliers to adopt OCT. This report states that markets are controlled by traditional suppliers and that any loss of project control during activities on-site obstructs the adoption of OCT.

There is a difference between OCT cash flows and the cash flows of routine construction projects. In a traditionally-built project, payments to the suppliers are made based on the delivery of the product; in the case of OCT, however, the suppliers have to wait until the final installation of product following the completion of on-site interface compliance issues. Wilson (2006) emphasises that the gap between the procurement of raw materials and the final payment may constitute a source of frustration for the suppliers.

Another supply chain related-issue is that the importation of OCT products is related to logistic and building code compliance issues (CRC, 2007b).

2.7.7 Barriers relating to skill and knowledge

The range of specific skills required for the development of OCT will help to determine its levels of supply and demand. Compared to traditional construction methods, the shortage of skills required to design and maintain OCT projects is frequently discussed or referred to in developed and developing countries. Scofield *et al.* (2009a) observe that the shortage of skills is an obstacle to the application of OCT. CRC (2007b) also points to a general lack of skills, particularly design and manufacturing skills, required to handle OCT projects. Planning and design require precision engineering and accurate interfacing of the components (Yau, 2006). The low tolerance of OCT interfaces as well as OCT's inflexibility around problems arising during the construction phase also represent a barrier to the adoption of OCT (Becker, 2005; CRC, 2007b; Scofield *et al.*, 2009a).

Another barrier which hinders the use of OCT is that, firstly, the workforce does not have the required skills and, secondly, the qualification of manufacturers and contractors is inadequate (CRC, 2007b; Gibb and Isack, 2003). CRC (2007b) further notes that due attention has not been paid to the need to improve skills and provide training on innovative methods of construction. Training focuses instead on traditional methods of construction. There is also little awareness of OCT products, practices and success stories.

More research and development are needed for continuous improvement and for handling the emerging problems related to OCT. Lack of research and development in the field of OCT has also been mentioned as a barrier to its adoption (Bell, 2009; CRC, 2007b).

2.7.8 Barriers relating to logistics and site operations

OCT involves the transportation of large sized components from the factory environment to the site; these components, sometimes as large as complete modules, must be fitted into ready-to-install buildings. Size makes transportation difficult. Haas *et al*. (2000) state that, in OCT, transportation logistics are constrained by the size and weight of the components, route selection issues and the need for resources to lift heavy components.

Site constraints like access to the site, restricted site movement due to the layout or available space, and the storage of OCT components on the site, could also limit the application of OCT (CRC, 2007b; Pasquire*et al.*, 2004; Scofield *et al.*, 2009a). The low tolerance of OCT components, more specifically in relation to on-site interfaces, combined with the availability of skilled labour to handle these components, constitute further barriers to the adoption of the technology (CRC, 2007b; Pasquire*et al.*, 2004).

In summary, a number of significant barriers were identified by the earlier research regarding the implementation or adoption of OCT; namely, Process and programme; Cost, value and productivity; Regulations; Industry and market culture; Supply chain and procurement; Skills and knowledge; and Logistics and site operations. Based on earlier research, this study hypothesises that:

1. The use of OCT increases overall the degree of on-site labour productivity.
2. The use of OCT reduces the on-site disruption of other adjacent operations.
3. The use of OCT decreases the overall project cost.

4. The use of OCT increases initial costs.
5. The use of OCT increases the property marketing value.
6. There exists a lack of available OCT codes and standards.

2.8 Conclusion

The evidence demonstrates that the building industry is responsive to the use of OCT solutions where there is a commercial imperative. In the period covering the last thirty or forty years, the literature has made no compelling argument for the sustained success of OCT. The research has shown it to serve a variety of functions – speed, adaptability, ease of transport etc. In the past ten years, several researchers have expressed the view that OCT is the "future of the construction industry" (Hampson and Brandon, 2004; Tam et al., 2007). Although this unqualified optimism is no longer prevalent, there is a sense, in an energy conscious age, that issues of sustainability, energy efficiency and waste reduction will complement the high demand for high volumes of low cost building. From this point of view, the tone of the literature generally reflects a process with a positive application for the future.

Instead, the tone of the literature is either open-minded or optimistic in describing a process whose day may soon come. In other words, a combination of free-market values, a concern for profit as the bottom line, a concern for the environment and sustainability and the ever-developing potential of computer software and the internet, may combine to make OCT the ideal producer of niche construction needs. Also, depending on a range of conditions related to geography, history, culture and the environment, OCT could move closer to the centre of a growing construction model. Consequently, decisions regarding the use of OCT are complex and unclear, because of the unclear interdependencies between construction resources and trades. Such complexities make unambiguous evaluations difficult. The challenge for OCT product suppliers is to address the actions that need to be taken to create the project and make an economic case for a step-change increase in the use of OCT solutions of all types. This study will proceed to examine the extent to which the Saudi construction industry can rise to this challenge. The next chapter will discuss the research methodology and methods adopted in order to meet the research aim and objectives.

Chapter 3: Research Methodology

3.1 Introduction

After reviewing the literature and generating the research hypotheses in the previous chapters, the methodological approaches adopted in this thesis will be discussed in this chapter. The chapter starts with an explanation of the research design, after which it describes the different research phases to meet the key steps in the research processes (see Figure 3.1). It highlights the common characteristics of the research methodology, introduces the processes of the empirical research used in this project study, and describes the research design based on the research questions and hypotheses employed in this study, before outlining the selection of the research methods and techniques, and the quantitative and qualitative approaches which were employed as the key methods in this research. In this chapter, the pilot study used to pre-test the questions and refine the questionnaire is also described. The analysis techniques are also discussed and the questionnaire survey and interviews described.

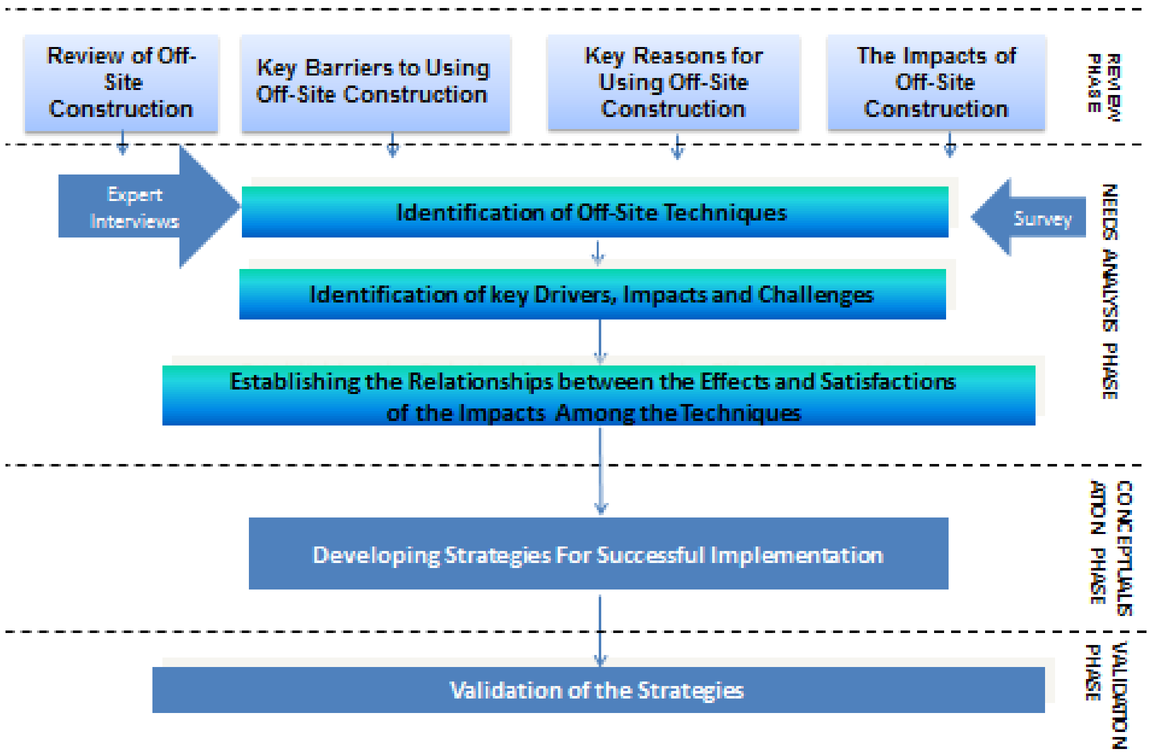


Figure 3-1: Research process

3.2 Introduction to Research

At the beginning, we must explain the purpose of the relevant research-related methodologies. The Oxford Dictionary defines research as “the systematic investigation into and study of materials and sources in order to establish facts and reach a new conclusion”. Howard and Sharp (1996) define research as “seeking, through methodical process, to add to one's body of knowledge and, hopefully to that of others, by the discovery of nontrivial facts and insights” (p.7). Saunders et al. (2009) describe it as the “understanding of a problem" (p.96).

Research methodology can also be described as the “systematic, formal, rigorous and precise process employed to gain solutions to problems and/or to discover and interpret new facts and relationships" (Waltz and Bausell, 1981, p.1); its design should be understood as "... the architectural blueprint of a research project, linking data collection and analysis activities to the research questions, and ensuring that the complete research agenda will be addressed" (Bickman and Rog, 2009, p.11). In this regard, the researcher considered a number of research designs and models such as the Nested Model, and the Research Onion.

The Nested Model is a research framework in which the outer layer represents the research philosophy and the inner layer represents the research approaches and research techniques (Kagioglou et al., 2000). For this research, the researcher chose the Research Onion (Figure 3.2), which comprises several layers, each of which refers to an aspect of the research process which aids the organisation, definition and development of the research, and provides an appropriate structure within which to frame the research inquiry. It has multiple layers, with the layers closer to the core becoming more comprehensive. The research design model proposed by Saunders et al. (2009) introduced three additional layers to the nested research model. The first layer represents the research philosophy, the second the approach, the third the strategy, the fourth the choices, the fifth the time horizon and the sixth the methods of data collection and analysis. This chapter examines the research process adopted in this study from the 'research onion' perspective of Saunders et al. (2012).

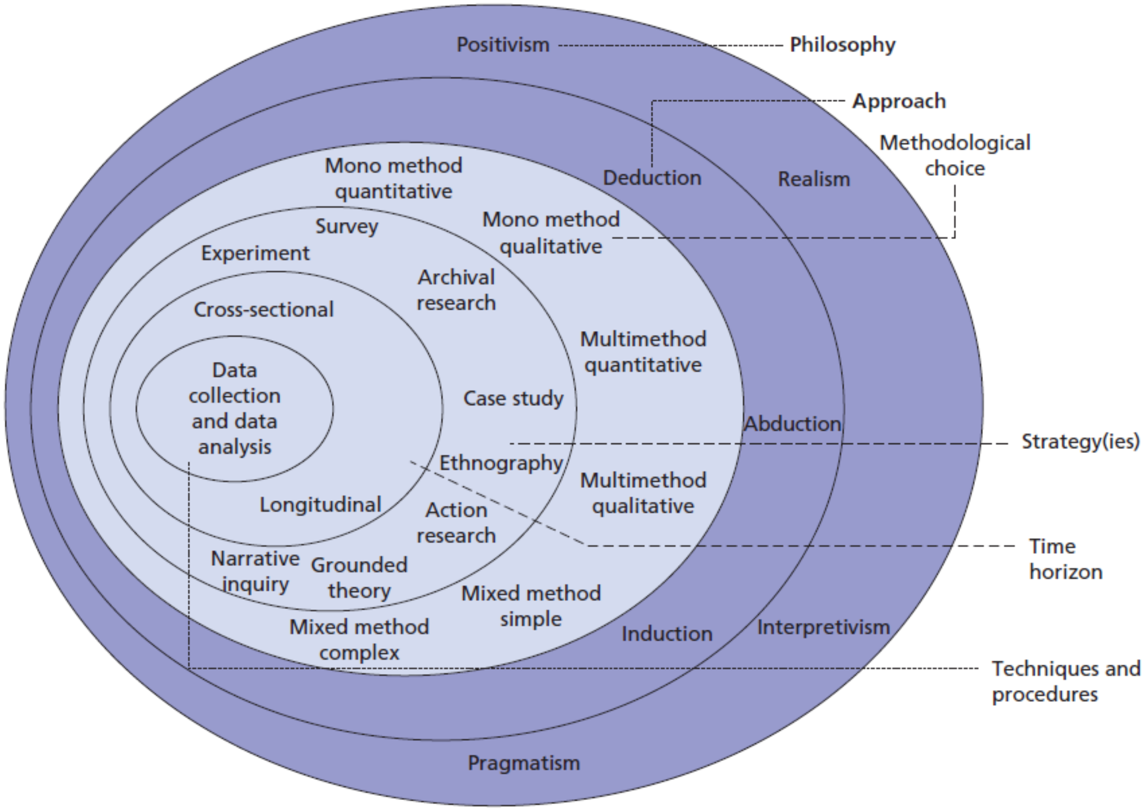


Figure 3-2: Research Onion Saunders et al. (2012)

3.3. Research philosophy

The research philosophy is the first layer of the model of Saunders *et al*. The philosophical considerations for designing research have been widely explored in the literature. The particular philosophical approach chosen by the researcher will be influenced by their view of the relationship between knowledge and the process through which it is developed (Saunders et al., 2012). This choice will be based on certain pre-suppositions and beliefs about how knowledge in their chosen field is derived. For example, a positivist researcher will hold the belief that discoverable general patterns of cause-and-effect can be used as a basis for predicting and controlling natural phenomena, and that, through measurement or observation, we can achieve empirical verification of accurate data.

These philosophies are categorised under the themes of epistemology and ontology (Crotty, 1998; Fitzgerald and Howcroft, 1998; Saunders, 2012). In the simplest terms, ontology is concerned with what constitutes reality and how we can understand it. Epistemology is concerned with what constitutes valid knowledge and how we arrive at it. Creswell (1994) indicated that ontology and epistemology are both branches of philosophy that try to explain the existence of an entity.

3.3.1 Epistemological Considerations

Epistemology is the philosophy of knowledge, of "how we came to know" or "how we find out about the topic being investigated" (Saunders et al., 2009). The two conflicting views on how social science research should be conducted are positivism and social constructivism or interpretivism. Positivism is informed by the view that the social world exists externally and its properties should be measured objectively through scientific methods rather than inferred subjectively through reflection or intuition. The positivist philosophical stance assumes that the researcher is independent of, and neither affects nor is affected by, the subject of the research (Easterby-Smith et al., 2008).

In contrast, social constructivism or the interpretive method holds that reality is socially constructed and determined by people rather than by objective external factors. Unlike the positivist, the social constructivist does not consider the world to consist of an objective reality, and focuses instead on subjective consciousness (Easterby-Smith et al., 2008). Thus social constructivism assumes that reality is not made of objective laws or immutable facts, but is socially constructed and given meaning by the people involved.

Positivism has its roots in the late 19th century triumph of science and rationalism. It holds that interpretations should be derived from observed data and that data collection and analysis methods should, as far as possible, be systematic and transparent (Patton, 2002, p. 93). Its strength is a focus on precision and clarity of thought, measured by a rigorous methodology. Its weakness is its association with the dubious concept "that a truly objective reality can be assessed and represented", particularly for complex social and behavioural phenomena. Using a mixed method approach, the transition from a Positivist to Interpretive values was stimulated by a need to analyse and integrate complex attitudinal phenomena into the text. The researcher initiated an Interpretivist phase by identifying specific quantitative results that needed additional explanation and used these results to guide the development of the qualitative aspect. The transition reflects the progression from determining the universal conditions that apply to off-site construction in general, towards a discussion of the particular conditions and attitudes affecting Saudi construction to analyse how construction professionals interpret activities.

One of the objectives of this research is to review the factors critical to the success of OCT and the potential barriers to its use in the Saudi Arabian construction industry. Many of these factors are based on an understanding of the science and technical knowledge put into practice by the contractors and professionals in the Saudi construction industry. Also, according to Chen and Hirschheim (2004), a positivist approach is represented through the formulation of hypotheses, models, or causal relationships among constructs, the use of quantitative methods and the researcher's objective, value-free interpretations. In this context, it could be said that the research as a whole takes a stance that needs to look into the philosophy of positivism.

The early use of a quantitative methodology inclined the researcher towards a positivist perspective to measure variables and assess statistical results. When the researcher moves to the qualitative phase, emphasising multiple perspectives and in-depth description, there is a shift towards the assumptions of constructivism. The shift in the underlying philosophical assumptions from a positivist towards a constructivist position has matched the transition from the questionnaire to the interview method, and the separate analysis of both data sources. The use of a mixed methods study begins with a quantitative survey phase, reflecting an initial methodological approach informed by positivist thinking but, in the qualitative phase of interviews, the researcher shifts to a constructivist paradigm.

The fact that data are collected and analysed to test hypotheses emphasises the confirmatory element of the positivist approach. This element of the research aims to explain and predict; at this stage, the researcher is interested in determining general laws that apply to whole populations rather than localised groups, isolating the effect of single variables to achieve a deeper understanding of statistical relationships. If different observers can agree on what is being observed, objectivity has been achieved. The qualitative methodological approach is less structured, with aspects of the research process subject to change in response to information or events. The qualitative methodology is more concerned with describing experiences, emphasising meaning and exploring the nature of an issue.

3.3.2. Ontological Considerations

Ontology is concerned with "whether social phenomena can be considered objective entities with a reality external to social actors, or whether they can and should be considered social constructions, built up from the perceptions and actions of social actors" (Bryman, 2004). Saunders (2009) explains that Ontology is concerned with the nature of reality and relates to the assumptions researchers make about the way in which the world operates.

In the case of this research, it would be relevant to understand whether a phenomenon like OCT is objectively or subjectively viewed and understood by the research participants.

Objectivism, associated with quantitative research, perceives social entities in a reality that is external to the social actors concerned with their existence. Subjectivism holds that social phenomena are created from the perception and the consequent actions of the social actors concerned with their existence (Saunders et al., 2009).

3.4 Research approach

According to Creswell (2003), the selection of the research approach is important in allowing the researcher to meet the stated objectives. Saunders *et al* (2007) and Yin (2003) state that the two main methodological approaches are deductive (testing theory) and inductive (building theory).Saunders *et al*. (2009)present (see Table 3.1) the major differences between the deductive and inductive approaches to research.

Table 3-1: The major differences between the deductive and inductive approaches to research, according to Saunders et al. (2009)

Deduction emphasises	Induction emphasises
• Scientific principles • Moving from theory to data • The need to explain causal relationships between variables	• Gaining an understanding of the meanings humans attach to events • A close understanding of the research context

• The collection of quantitative data • The application of controls to ensure the validity of the data • The operationalisation of concepts to ensure clarity of definition • A highly structured approach • Researcher is independent of what is being researched • The necessity to select samples of sufficient size in order to generalise a conclusion	• The collection of qualitative data • A more flexible structure to permit changes in research emphasis as the research progresses • A realisation that the researcher is part of the research process • Less concern with the need to generalise

3.4.1 The deductive approach

The deductive approach traditionally implies an inquiry into an identified problem based on the testing of a theory. It goes from theory to its empirical investigation. That is to say, it is a theory testing process which commences with an established theory or generalisation, seeking to establish whether it applies to specific instances. Deductive reasoning works from the more general to the more specific, sometimes called a "top-down" approach. We may start by thinking up a theory about our topic of interest. We then narrow that down into a more specific hypothesis which we can test. We narrow it down even further when we collect data to address the hypothesis. This in the end leads us to be able to test the hypothesis with specific data, confirming (or rejecting) our original theories (Robson, 2002).Saunders *et al*. (2009), as quoted by Robson (2002),list five sequential stages through which deductive research will progress:

- Deducing a hypothesis (a testable proposition about the relationship between two or more concepts or variables) from the theory.

- Expressing the hypothesis in operational terms (that is, indicating exactly how the concepts or variables are to be measured), which propose a relationship between two (or more) specific concepts or variables.
- Testing this operational hypothesis.
- Examining the specific outcome of the inquiry (it will either tend to confirm the theory or indicate the need for its modification).
- If necessary, modifying the theory in the light of the findings.

3.4.2 The inductive approach

The inductive approach, by contrast, understands a social or human problem from multiple perspectives (Yin, 2003), starting with an empirical investigation of an area to develop corresponding theory. Inductive reasoning moves from specific observations to broader generalisations and theories. Sometimes this is called a "bottom up" approach; we might start with specific observations and measures, begin to detect patterns and regularities, formulate some tentative hypothesis that we can explore, and finally end up developing some general conclusions or theories (Robson, 2002).

3.4.3 The adopted approach

In the process of conducting real research, it is hard to separate completely the inductive and deductive approaches, however, as both are always involved, often simultaneously, and it is impossible to go theory-free into any study (Richards, 1993). Saunders *et al.* (2007) agree that a combination of research methods may be effective in achieving specific research objectives, arguing that, depending on the nature of the research topic, it is perfectly possible to combine deduction and induction within the same piece of research; indeed, it is often advantageous to do so.

Deductive research is associated with the positivist paradigm; Inductive research is associated with the interpretive paradigm. To aid the understanding of complex abstract ideas, academic discussion often presents these ways of thinking as binary choices, suggesting that they are completely separate. Although we represent their traits in opposition to each other, in practice, we combine them in the research. In this research, the two research approaches (inductive and deductive) are combined in a mixed methods research study.

Deductive reasoning applies general principles to reach specific conclusions, whereas inductive reasoning examines specific information, to derive a general principle. It takes a top-down approach. We begin with an area of interest, OCT, and establish a theory about it. We then develop specific hypotheses by summarising the OCT research, which are statistically test. We narrow down even further when we collect observations to address the hypotheses.

Inductive reasoning takes a bottom up approach, and the research seed is a specific observation from which patterns are detected. From this point, the emphasis changes; whereas Deduction is confirmatory and fact-centred, Induction, particularly at the beginning, is open-ended and exploratory of both facts and feelings. Induction is a more flexible way of thinking because it is not bound by a pre-determined set of hypotheses, and it encourages interaction between the researcher and interviewees. Both modes of thinking produce general conclusions or theories, and most social research involves both inductive and deductive reasoning processes at some point in the project.

3.5. Methodological choices

The most important criterion when choosing a research strategy is its ability to help the researcher to answer the research questions and meet the stated objectives (Saunders et al., 2007).Yin (2003) argues that the research strategy should be chosen as a function of the research situation. Malhotra and Birks (2007) define primary data as "data originated by the researcher specifically to address the research problem". Primary data are data collected by the researcher to meet specific aims and objectives.

3.5.1 Quantitative Research

Quantitative research is a numerically measured inquiry into an identified problem, which tests a theory and analyses it using statistical techniques. The goal of quantitative methods is to determine whether or not the predictive generalisations of a theory hold true (Creswell, 1994). According to Fellow and Liu (2008), the quantitative approach is based on positivist principles and seeks to gather factual data and study relationships. Scientific techniques are used to obtain measurements, i.e. quantitative data. Analyses of these data yield quantified results, and conclusions are derived from an evaluation of the results in the light of both the theory and the literature.

Quantitative research methods are associated with positivist forms of enquiry, which are concerned with a search for facts. Questionnaires are viewed as objective research tools because they numerically interpret large sample sizes and can produce generalisable results, which means that conclusions can be drawn from specific data to a more general application. In contrast, the interpersonal nature of the interview provides a more subjective context whereby participants can seek clarification and use their own words to explain their attitudes. The subjectivity of the interview is amplified if the interviewer leads or manipulates the interviewee responses, or if the participants respond in ways that they deem to be socially desirable. The initial impetus of this research was data collection by means of a quantitative questionnaire. Because of the questionnaire's perceived statistical significance (147 responded to the questionnaire, only 6 were interviewed), a greater initial importance was placed on the quantitative methodology and the positivist values which inform it but, in the qualitative phase of the interviews, the researcher adopted a constructivist paradigm.

3.5.2 Qualitative Research

Denzin and Lincoln (2000) define qualitative research as "a situated activity that locates the observer in the world" and "consists of a set of interpretive, material practices that makes the world visible". These practices turn the world into a series of representations, (which, in the case of this research, is the use of interviews).They argue that the word 'qualitative' implies an emphasis on processes and meanings.

Using interviews informed by constructivist values, the researcher can respond to aspects of the research process which are subject to change in response to information or events. The qualitative methodology is concerned with describing experiences, emphasising meaning and exploring the nature of an issue (Coolican, 2004). Therefore a mixed methods approach provides a less structured template for recording people's attitudes and interpretations of a world with significant cultural variation. Flexibility is needed to quantify and describe the factors of context, experience, demand, culture and environment, which contribute to the operation of off-site construction.

Qualitative research involves the use of qualitative data gained by using methods such as interviews, conversations with participants, and participant observation, to understand and explain social phenomena (Myers, 2004). Qualitative approaches are commonly used to capture meaning (in the form of individuals' thoughts, feelings, behaviour, etc.) rather than numbers, and to describe processes rather than outcomes (Mayan, 2001). That is to say, qualitative methods allow the researcher to study issues in depth; data collection is not limited to predetermined categories. Qualitative research has the following characteristics, as reported by Creswell (2009):

- Data collections take place in the field at the site where the participants experience the issue or problem being investigated.
- Qualitative researchers collect data by examining documents, observing behaviour, or interviewing participants.
- Qualitative researchers use inductive data analysis by organising the data into an increasing number of abstract units of information to build their patterns, categories, and themes from the bottom up.
- The researcher maintains a focus on learning the meaning that the participants hold about the problem or issue throughout the research process.
- The initial plan for qualitative research cannot be tightly prescribed, and all phases of the process may change or shift after the researcher enters the field and begins to collect data.
- Qualitative researchers often use a theoretical lens to view studies which involve the concept of culture.

- Researchers in qualitative studies make an interpretation of what they see, hear and understand.
- The picture of the problem or issue under study in qualitative research is complex due to the fact that researchers report multiple perspectives or identify many factors involved in a situation.

3.5.3 Adopted methodological choices

This study employs used two methods for collecting the primary data: quantitative data collection methods to give it statistical significance, and qualitative data collection methods to give it contextual depth and establish reliability and validity by careful sampling and appropriate statistical treatments of the data to achieve the research aims and objectives. The aim is to obtain quantitative data through the use of questionnaires to determine the functional factors affecting off-site construction, and to obtain qualitative data through interviews, to achieve greater in-depth knowledge regarding the attitudinal factors affecting off-site construction in Saudi Arabia.

There are several advantages to adopting a multiple method approach. According to Tashakkori and Teddlie (2003), multiple methods answer the research questions more comprehensively and allow the researcher better to evaluate the extent to which the research findings can be trusted(Powell et al., 2008).Collecting quantitative data enhances interpretations by helping researchers better to contextualise qualitative findings. Quantitative research generates factual, reliable data that are usually generalisable to some larger population because of the large sample sizes, while qualitative research produces rich, detailed and valid process data based on the participants', rather than the investigator's, perspectives and interpretations. Tashakkori and Teddlie (2003) argue that multiple methods assist the collection of a broader range of data and therefore add to the researcher's ability to answer the research questions, trust the research findings and draw inferences from them.

The present study combines both qualitative and quantitative research to avoid the weaknesses in both (see table 3.2). Quantitative research methods are associated with positivist forms of enquiry concerned with a search for facts. Questionnaires are usually viewed as a more objective research tool because the large sample sizes produce generalisable results; that is, the findings can be reproduced and applied to a broader population. In the final validation phase, surveys were conducted using the ISM methodology (see Chapter 6). The data from the surveys generated the main findings and developed and tested an implementation strategy for OCT.

Table 3-2: Strengths and Weaknesses of Quantitative and Qualitative Research (Easterby-Smithet al., 2002)

	Quantitative Paradigm	Qualitative Paradigm
Strengths	•Can provide wide coverage for a range of situations. •Can be fast and economical. • Can be of considerable relevance to policy decisions where statistics are aggregated from large samples.	•Data gathering methods are seen as natural rather than artificial. • Ability to look at the change process over time. • Ability to understand people's meaning. • Ability to adjust to new issues and ideas as they emerge. • Contributes to theory generation.

Weaknesses	•The methods used tend to be rather inflexible and artificial. • They are not very effective in understanding processes or the significance that people attach to actions. • They are not very helpful in generating theories.	•Data collection can be tedious and require more resources. • Analysis and interpretation of the data may be more difficult. • Harder to control the pace, progress and end-points of the research process. • Policy-makers may give low credibility to results obtained by using the qualitative approach.

3.6 Research strategy

The most important criterion when choosing a research strategy is its ability to help the researcher to answer the research questions and meet the research objectives (Saunders *et al*., 2007). Yin (2003) argues that the research strategy should be chosen as a function of the research situation. As noted in the literature, a number of major strategies are available for primary data research, including experiment, survey, case study, grounded theory, ethnography and action research (Easterby-Smith *et al*., 2002; Yin, 2003; Saunders *et al*., 2007). Some of these belong to the quantitative research paradigm, while others belong to the qualitative research paradigm.

3.6.1 Quantitative Research

Quantitative research is an inquiry into an identified problem, based on testing a theory, measured with numbers, and analysed using statistical techniques. The goal of quantitative methods is to determine whether the predictive generalisations of a theory hold true (Creswell, 1994). According to Fellow and Liu (2008), quantitative approaches are generally informed by positivist values and seek to gather factual data and study relationships in accordance with theories and the findings of any previously executed research. Scientific techniques are used to obtain measurements, i.e. quantitative data. Analyses of these data yield quantified results and the conclusions are derived from an evaluation of the results in light of the theory and the literature.

The following sections describe the two most commonly used quantitative research approaches; namely, experimental research and survey research.

3.6.1.1 Experiments

Experiments are undertaken on a sample of the population within a controlled environment to test whether there is a causal relationship between the variables under investigation (Baker, 2001).

Bryman (2008) reported that there are two types of data collection techniques for experimental research; namely, laboratory experiments and field experiments. Laboratory experiments take place in a laboratory or in a contrived setting while field experiments occur in a real-life setting such as a class room or within an organisation. Neuman (2005) stated that experimental data collection methods are less expensive, less time consuming and easier to replicate than other techniques. The limitation of the experimental research is that they cannot address certain questions because control and experimental manipulation are impossible. In addition, experiments usually test more than one hypothesis at a time (Neuman, 2005).

3.6.1.2 Surveys

Surveys are a tool for gathering invaluable data about attitudes, values, personal experiences and behaviour. Unlike experiments, surveys are conducted on a wider population using economic data collection methods, such as questionnaires (Saunders *et al*., 2007). Surveys take the form of face-to-face interaction, telephone interviews, postal questionnaires and, most recently, online surveys (Gilbert, 2008). Surveys can take the form of highly structured questionnaires or unstructured interviews; the subject matter of the study must be introduced to the respondents, irrespective of the form adopted (Fellows and Liu, 2003).

3.6.1.3 Non-experimental Research

Kerlinger (1986) defines non-experimental research as a "systematic empirical inquiry in which the scientist does not have direct control of independent variables because their manifestations have already occurred or because they are inherently not manipulable" (p.348). Johnson (2001) shows that there are two methods of non-experimental research: causal-comparative research and correlational research. Neuman (2005) uses the term "survey research" to refer to non-experimental research, including the causal comparative and correlational. Belli (2008) offers two reasons for using non-experimental research:

- Many variables of interest in social science cannot be manipulated because they are attribute variables.
- It would be unethical randomly to assign individuals to different treatment conditions.

3.6.2 Qualitative Research

The following sections will describe the most commonly used qualitative research approaches:

3.6.2.1 Case study

The case study method is an intensive analysis of a single case. It can take the form of interview notes, observations and video material, documents and records to provide an in-depth investigation of particular instances with the research subject.

Naoum (1998) and Yin (2003) report three case study designs: descriptive, analytical and explanatory. An explanatory case study deals with a theoretical approach to the problem, trying to explain causality and showing links among the objects of the study. Explanatory case studies are used to provide clearer, more precise statements of the recognised problems where researchers have a limited amount of knowledge about the cases. A descriptive case study is applied to a detailed case and aims to count the number of respondents with certain opinions/attitudes towards a specific objective. An analytical case study also aims to establish relationships and associations between the attributes/objectives of a study (Naoum, 1998).

According to Gummesson (2000), qualitative methods such as case studies provide powerful tools for research on management and business subjects, including general management, leadership, organisation, corporate strategy, marketing and more.

3.6.2.2 Grounded theory

Grounded theory is a strategy whereby data are collected without an initial theoretical framework. Theory is developed from the collected data itself and these theories are further tested to derive conclusions (Partington, 2000). In contrast, ethnography and action research are deeply rooted in social science and characterised by the intervention of the researcher and their involvement with the subject of research (Berg, 2004).

Bryman (2008) defines grounded theory as “theory that was derived from data” is systematically gathered and analysed through the research process, in which “data collection, analysis and eventual theory stand in close relationship to one another”. For grounded theory, the main data collection methods are: interviews, observations, documents, historical records, videotape, and anything else of potential relevance to the research question.

Smith *et al* (2008) reported that the methods of grounded theory have been developed mainly within an educational and health setting where access to data is relatively easy and flexible. They also pointed out that access is more difficult within a commercial organisation, and researchers are rarely given the freedom to select their samples on theoretical grounds. As a result, certain assumptions of grounded theory need to be amended further in order to deal with this kind of situation.

3.6.2.3 Action Research

Action research is carried out to identify areas of concern, develop and test alternatives and experiment with new approaches. In this approach, a researcher reviews the current situation, identifies the problem, and gets involved in introducing changes to improve the situation. This type of research is most commonly used by practitioners, industrialists and students from professional backgrounds who have identified a problem during the course of their work and wish to investigate and propose a change to improve the situation (Kumar, 2005; Naoum, 1998).

Four main characteristics of action research reported by Blumberg at al. (2005) are listed below. According to them, action research is

- bounded by the context and addresses real-life problems;
- requires collaborative ventures by researchers, participants and practitioners;
- made up of a reflective process of research and action;
- Judged for credibility and validity in terms of whether the action solves the problems and realises the desired change.

3.6.2.4 Ethnographic Research

Ethnographic research is a study whereby a "researcher immerses him or herself in a group for an extended period of time, observing behaviour, listening to what is said in conversations both between others and with the field worker, and asking questions" (Bryman, 2008). The data collection in ethnographic research entails a wide range of methods such as interviews and the collection of documents. Ethnographic research usually entails long periods of time being spent in the field in an organisation or in the company of a group, and has a specific focus on the culture of that group (Gilbert, 2008).

3.6.3 Mixed Research

Mixed methods research integrates the collection and analysis of quantitative and qualitative research data into a single study to provide a better understanding of a research problem. This approach mixes competing paradigms of Positivism and Constructivism. The purist stance argues that paradigms "have rigid boundaries and cannot be mixed" because they rely on contradictory understandings of how meaning is constructed. However, the separate paradigms informed different phases of the research design and execution, so that they were included in the discussion but remained linked to the research designs (Creswell 2007, 2011).

The constructivist or interpretive philosophical stance associated with qualitative research argues that the scientific method is reductionist in nature. An interpretive perspective informs qualitative research's efforts to reveal multiple realities as opposed to searching for one objective reality. To investigate the diverse perceptions of and attitudes towards OCT and how it is shaped by cultural contexts, the researcher used a mixed methods approach, because the questions asked within an intepretivist paradigm differ from those asked within a positivist paradigm and, therefore, require different data.

Creswell et al. (2003) define the mixed method as one that "involves the collection or analysis of both quantitative and qualitative data in a single study in which the data are collected concurrently or sequentially, are given a priority, and involve the integration of the data at one or more stages in the process of research" (p.212).

It is a new research method that has been developed in recent decades. Gelo et al. (2008) define the mixed method as "a research approach that combines and integrates quantitative and qualitative research approaches" (p.278). Mixed method approaches seek to maximise the advantages and minimise the disadvantages of the particular application of one of the two approaches (Gelo et al., 2008). Yin (2003) introduces two disadvantages associated with mixed method research:

- Collecting data from multiple sources can be more expensive
- Implementing converging lines of investigation could be lost if any research method is used inappropriately

3.6.4 The adopted research strategy

This study relies primarily on a survey research strategy of 136 questionnaire respondents and, secondarily, on 6 interviews with experienced Saudi construction professionals, to draw upon the strengths of both qualitative and quantitative research (see Table 3.3).For the first phase, the researcher used a questionnaire to identify the drivers and barriers related to OCT in Saudi Arabia, in order to test certain behaviours and seek a numeric understanding to confirm or to refute the hypotheses incorporated into the questionnaire. Subsequently, the researcher adopted an objective stance (objectivism) in the form of interviews to seek an understanding of OCT practice in Saudi Arabia. Following this, in the last validation phase, surveys were conducted using the ISM methodology. The data from the surveys generated the main findings and also developed and tested an implementation strategy for OCT.

3.7 Research Design

A research design is basically a plan for conducting research. Yin (2003) states that it provides a blueprint for research, dealing with which questions to study, what data are relevant, what data to collect, and how to analyse the results. A study that has a solid research design means that it has a good conceptual structure within which research is conducted. Parahoo (1997) defines the research design as “a plan that describes how, when and where data are to be collected and analysed” (p.142).

In fact, any research methodology is influenced by two aspects: (i) the aim of the research; (ii) the kind of data that are needed to answer the research questions. This study used a mix of quantitative and qualitative methodologies. The quantitative methodology is related to the mathematical form used to examine a research hypothesis. The qualitative methodology focuses on the significance of the interpretive approach to provide a rich picture that is used to solve the research questions. Figure 3.3 shows the research design of this study as the basic plan for an empirical research project.

3.7.1 Developing an implementation strategy

To develop a strategy for investigating OCT, the researcher set out to obtain reliable and robust data for every type of OCT in use in Saudi Arabia. This data were broken down into three major categories, the first consisting of the reasons for employing such techniques, the second consisting of the challenges related to employing such techniques and the third consisting of the impact factors affecting OCT use. These sets of results were quantitatively recorded through means of a survey, detailing the characteristics above with their satisfaction and overall popularity. Subsequently, an analysis was carried out initially by means of filtering through all of the recorded statistical data gathered from the survey, using Spearman ranking correlation rules to systematise satisfaction feedback, and a Mann Whitney U Test to arrange the ranking of its use. Further analysis was carried out to investigate the findings by undertaking a cross-examination of all of the techniques, in the form of a discussion of what the results yielded.

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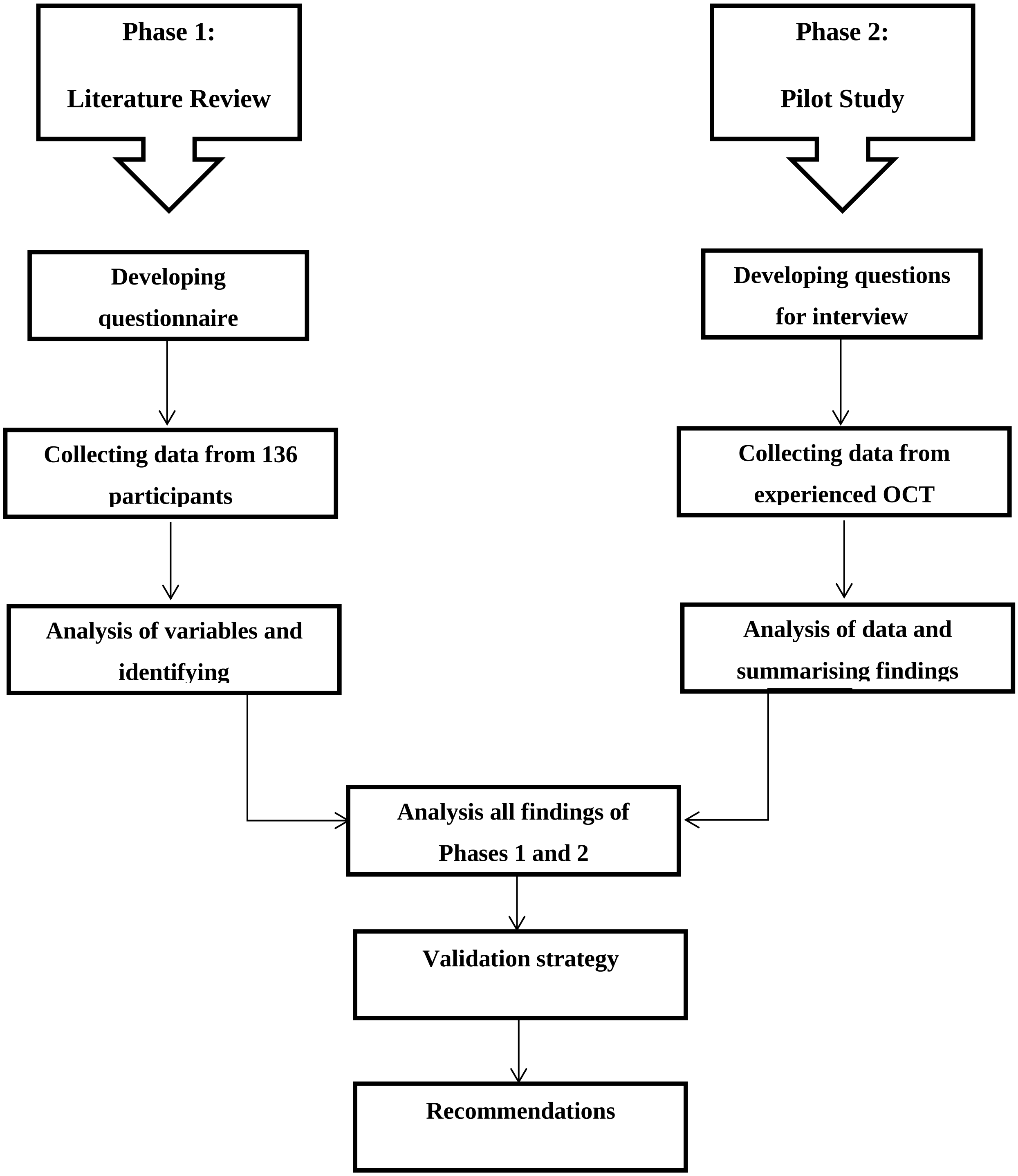

Figure 3-3: Research Design

3.8 Data Types

3.8.1 Secondary Data

According to Malhotra and Birks (2007), secondary data are "data already collected for purposes other than the problem at hand". In other words, these are data that have already gathered by others which can be used in the research undertaken in several ways. Data can be obtained from different sources, such as books, journals and company websites.

Secondary data can help the researcher in terms of providing the best understanding of the research undertaken by clarifying the problems from different points of view and opinions, and involve the background and financial statements of companies, which might be difficult to gain through using primary data. According to HoHensen and Schmidt (2006), secondary data are "relatively inexpensive, easily accessible, and quickly obtained". In addition, they can help researchers to expand their knowledge and develop their assumptions, as well as provide real solutions to any problems which might arise during studies by answering the major questions and testing specific hypotheses.

This data can be accessed easily, as mentioned previously, by searching online databases, government statistics and books. The literature review involved two steps of research in terms of the data collection. The literature review helped the researcher to develop, evaluate and refine an OCT strategy by exploring the related frameworks/studies for this research to achieve the research objectives and answer the research questions. From the literature review, 19 impacts of successful OCT and the specific techniques used for it were identified.

3.8.2 Primary Data

Malhotra and Birks (2007) define primary data as "data originated by the researcher specifically to address the research problem". Primary data are data collected by the researcher to fulfil the specific aims and objectives related to the research. However, after obtaining the required information by researching secondary data, the need arises for primary data in any research, due to its role in providing more accurate and specific information for the specific research project.

3.9. Data Collection Methods

This research involved two types of data: primary and secondary. These data helped the researcher to obtain the information required during the data gathering process. Secondary data from the literature review helped the researcher to identify the factors related to OCT by examining the related drivers, barriers and challenges. In terms of primary data, this research adopted both quantitative and qualitative data collection methods to answer the research questions. The nature of this research required the use of both methods. Quantitative data helped to determine the factors affecting OCT through the use of the questionnaires. Qualitative data helped to compile more in-depth knowledge regarding the factors related to OCT in Saudi Arabia.

Many authors have combined qualitative and quantitative techniques and procedures. Tachakkori and Teddlie (2003) use the more generic term “research design” when referring to multiple methods. According to Saunders *et al*. (2009), there are two combination designs that the researcher can choose from: a single data collection technique and corresponding analysis procedure (Mono Method), or the use of more than one data collection technique and analysis procedure to answer the research question (Multiple Methods). Under the mono method, the researcher will combine either a single quantitative data collection technique, for example questionnaires, with quantitative data analysis procedures, or a qualitative data collection technique, such as in-depth interviews, with qualitative data analysis procedures. On the other hand, under the multiple methods, the researcher can choose to combine data collection techniques and procedures using some form of multiple methods design. There are four different possibilities, as shown in figure3.4.

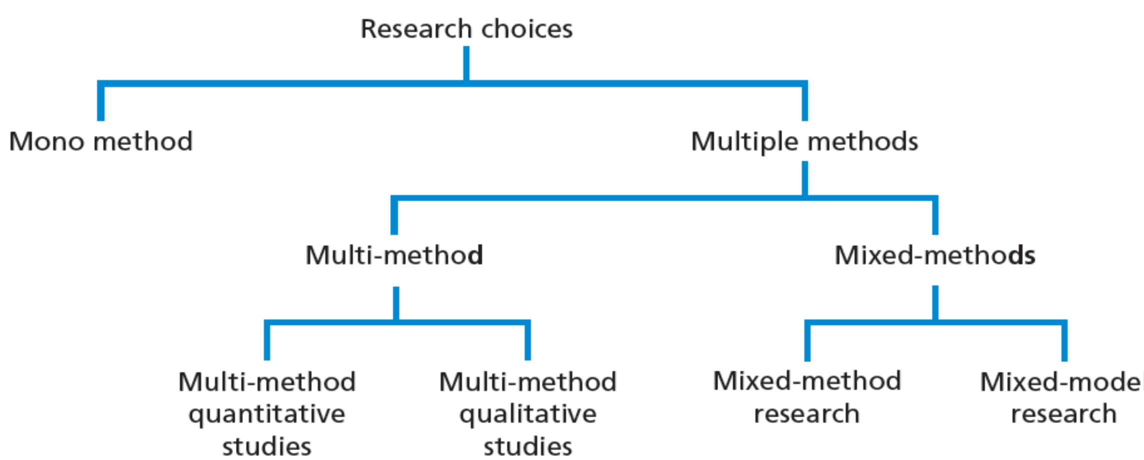

Figure 3-4: Combination Design. Saunders et al. (2009)

Under the mixed method approach, both quantitative and qualitative data collection techniques and analysis procedures are used in the research design. There are two types of mixed method research. The first type is when the research uses quantitative and qualitative data collection techniques and analysis procedures either at the same time (parallel) or sequentially, but does not combine them. In other words, quantitative data are analysed quantitatively and qualitative data analysed qualitatively. The second type is mixed-model research, which combines quantitative and qualitative data collection techniques and analysis procedures as well as quantitative and qualitative data approaches from other phases of the research, such as research question generation.

The other two choices of multiple methods refers to those combinations where more than one data collection technique is used with associated analysis techniques, but this is restricted within either a quantitative or qualitative world view (Collis and Hussey, 2009).

If the researcher chooses to collect quantitative data using, for example, both questionnaires and semi-structured interviews and analyses these data using a statistical (quantitative) procedure, this is a multi-method quantitative study. On the other hand, if the researcher chooses to collect qualitative data using, for instance, in-depth interviews and diary accounts, and analyses these data using a non-numerical (qualitative) procedure, this is called a multi-method qualitative study.

There are several advantages associated with the adoption of multiple methods. According to Tashakkorl and Teddlie (2003), multiple methods are useful in assisting researchers to answer the research questions and evaluating more effectively the extent to which the research findings can be trusted for drawing inferences. In addition, different methods can be used for different purposes in the study, giving the researcher confidence to address the most important issues (Powell *et al*., 2008).This research has adopted 'both qualitative and quantitative' methods for the data collection.

The development of an OCT strategy was the purpose of this research. The use of a mixed method approach which involved both qualitative and quantitative methods was found to be the most appropriate approach to adopt in this case. According to Fellows and Liu (2007), by adopting both methods, the researcher can reduce or eliminate the disadvantages of each individual approach, whilst gaining advantages from both as well as from the combined multi-dimensional view.

Tashakkori and Teddlie (2003) argue that multiple methods are useful if they provide better opportunities for the researcher to answer the research questions and where they allow the researcher better to evaluate the extent to which the research findings and inferences made from them can be trusted. In addition, another reason for choosing both approaches for this research was to support the research strategy.

Since this research has adopted a mixed methods approach, the following sections will explain each of these stages and the methods used to collect the data. This research uses primary and secondary data to investigate the Saudi Arabian construction sector. The secondary data identified the factors related to OCT by examining the drivers, barriers and challenges related to this phenomenon. Primary data were drawn from interviews with six professionals with knowledge of the Saudi construction industry and from questionnaires distributed among workers in construction companies that use OCT.

3.9.1. Secondary Data (Literature Review)

Secondary data are "data already collected for purposes other than the problem at hand". In other words, they are data gathered by others which can be used in a research project in several ways. Data were obtained from various sources, such as books, journals and company websites (Malhotra and Birks 2007).Secondary data can enhance our understanding of the research by clarifying the problem from different points of view. Secondary data are "easily accessible” and can help researchers both to expand their knowledge and develop their assumptions. Moreover, they provide real solutions to any problems which might arise during the studies, by answering the major questions and testing specific hypotheses.

3.9.2. Questionnaire Method

This research used questionnaires as the quantitative data collection method because it accommodated data collection from employees with a range of positions, locations and levels of experience. Moreover, this method helped to group the variables and rate their impact on the construction sector. The researcher used a self-administered questionnaire; some were completed electronically online, while approximately half were delivered by hand to appointed supervisors who distributed and collected them later.

The researcher relied upon a combination of social media and face to face connections to build a network of friends and acquaintances within Saudi construction and commercial businesses to access potential respondents (the snowball technique). Questionnaires were sent out online or distributed by hand and collected following their completion. The researcher chose this method to increase the reliability of the research data. According to Oppenheim (2000), this method (the self-administered questionnaire)is the most commonly used for collecting quantitative data in social science surveys, because it ensures a high response rate and also minimal interviewer bias by distancing the interviewer. However, the main disadvantage of this method is that the respondents control the timescale within which they complete the questionnaire, and the questions must be easily understood before distribution to ensure that high quality feedback is obtained.

The questionnaire was divided into 5 sections: namely, Respondent Background, OCT, the factors related to OCT, the reasons for using OCT, and the challenges related to OCT.

3.9.2.1 Measurement and Scaling

The questionnaire was designed to identify the factors associated with OCT in Saudi Arabia. The survey was self-administrated using a five-point Likert scale, which measures attitudes and opinions. Summated scales often use a five- or seven-point scale to assess the strength of agreement about a group of statements (Hair *et al*., 2007). The response options ranged from "strongly disagree" to "strongly agree" and from “not satisfied at all" to "extremely satisfied". Hair *et al*. (2007) define rating scales as the use of statements on a questionnaire accompanied by pre-coded categories, one of which is selected by the respondents to indicate the extent of their agreement or disagreement with a given statement. Possible responses to rating questions should be presented in a straight line rather than in multiple lines or columns, as this is how respondents are most likely to process the data (Dillman, 2007).The five agreement points on the rating scale, including one which allows the respondents to select the middle, ‘neutral’ option, is less threatening to the respondents than admitting that they do not know something. Using this type of scale allowed the researcher to determine and assess the impact of the drivers identified from the literature on OCT.

3.9.2.2 Questionnaire Layout and Wording

The researcher prepared straightforward and easy to understand questions. The questionnaire was divided into five parts. The first part included general questions about the respondent's background, experience and educational level to help the researcher to understand the sample and link it to the research findings. The second part presented a list of the various types of OCT, such as hybrid systems and modular building, the third a list of the factors related to OCT, the fourth section the reasons for using OCT and the final section related to the challenges associated with using OCT.

3.9.2.3 Administering the questionnaire

After the questionnaire had been designed and pilot tested, the sample was selected; the questionnaire was then used to collect the primary data (this is sometimes referred to as 'administering' the questionnaire). Saunders *et al*. (2009) suggested several stages in the delivery and collection of the questionnaires as follow:

- Ensure that all snowball questionnaires and covering letters have been printed and that a collection box is ready.
- Contact the respondents by email, post or telephone, advising them to attend a meeting in the organisation's time.
- At this meeting, hand out the questionnaire with a covering letter to each respondent.
- Introduce the questionnaire and stress its anonymous or confidential nature.
- Ensure that the respondents place their completed questionnaires in a collection box before they leave the meeting.

3.9.2.4 Self-administered Questionnaire Sample

The questionnaire was distributed to 174 participants (by hand to selected individuals and online to third parties). The researcher was able to collect 136 completed questionnaires from the total of 174 copies distributed.

3.9.3. Interview Method

An interview is a method for collecting data in which selected participants are asked questions to find out what they do, think or feel (Hussey and Hussey, 1997). They can be conducted at a mutually-agreed location. An interview implies some form of verbal discourse in which the participant provides the researcher with information. Non-verbal behaviour in the interview context is noted by the researcher and becomes part of the data. In addition, interviews are useful when a particular issue needs to be explored in depth.

There are three basic types of interviews: unstructured, semi-structured and structured (Fellow and Liu, 2008). Structured interviews are based on questions planned in advance and asked of all interviewees; this provides a high degree of reliability and validity. The primary disadvantage is the inflexibility in exploring areas of interest that may arise during the interviews. Unstructured interviews are based on questions that are unplanned. Basically, the interviewer must rely on his or her interviewing experience to extemporise. The advantage of this approach is that it requires little preparation time, while the disadvantages are that important issues may remain unexplored, and that inappropriate questions may be asked on the spur of the moment.

The six interviews were carried out within a large company and university over a period of 30 days. The interviewees did not feel comfortable about recording the interviews so the researcher took notes during the interviews and wrote them up immediately afterwards. The interviews lasted initially around 50 minutes, and then decreased to an average of 55 minutes. The interviews produced around 1,000 words. The notes were edited for grammatical errors, although every effort was made to recall the conversation verbatim. The notes were also edited for coherence and clarification. All transcripts and notes were sent back to the interviewees, each of whom confirmed the accuracy of the notes without requesting any changes. The transcripts and notes were not included in the appendix due to the mutual agreement regarding non-disclosure. However, all of the interviewees agreed to be quoted anonymously in the document.

A semi-structured interview is useful where the researcher has a list of questions. It can differ from interview to interview, which means that the researcher may omit certain questions during particular interviews, depending on the specific organisational contexts encountered in relation to the research topic. However, further questions may be required in order to explore the research question and objectives. Easterby-Smith *et al*. (2002) suggest that unstructured or semi structured interviews are appropriate when:

- It is necessary to understand the interviewees' opinions and beliefs about a particular matter or situation.
- One aim of the interview is to develop an understanding of the respondents' world so that the researcher might influence it, either independently or collaboratively.
- The step-by-step logic of a situation is unclear.

- The subject matter is highly confidential or commercially sensitive.
- The interviewee may be reluctant to be truthful about an issue other than confidentially in a one-to-one situation.

Semi-structured interviews were selected to provide the researcher with the opportunity to probe for answers when it is appropriate for the interviewees to explain or build on their responses. Furthermore, semi-structured interviews can lead the discussion into areas not previously considered but which could help to address the research questions and objectives. In this research, semi-structured interviews provided the researcher with information on which to design the questionnaire.

3.9.3.1 Interview sample

The research population is the entire group of people, events, or phenomena of interest that the researcher wishes to investigate (Sekaran, 2003). Awell-defined sampling strategy can provide unbiased and robust results. Qualitative research aims to provide an in-depth understanding of the world as seen through the eyes of those being studied. The research sample was selected from a population of interest to the research in order to obtain proper data and so obtain maximum value from the selected projects for the interviews. The contractor companies from which the interviewees were selected for this research were large and complex, and classified into the top first or second category by the Saudi Agency of Contractor's Classification in the Ministry of Municipal and Rural Affairs (MACC, 2013).

The semi-structured interviews used a sample of six interviewees with experience as project managers in the construction sector in Saudi Arabia. They were nominated by a manager who was working in one of the leading contractor companies in Saudi Arabia. He chose them based on their experience of working on projects that employed OCT; the researcher met with the respondents and asked questions face to face. The interview was divided into the following sections:

- The use of OCT
- The benefits of using OCT
- The barriers to using OCT
- The opportunities that OCT provides stakeholders

3.9.4 Interpretive Structural Modelling (ISM):

Interpretive Structural Modelling (ISM) can be used for identifying and summarising the relationships among specific variables, which define a problem or issue (Warfield 1974, Sage 1977). The main objectives of the ISM are: to identify and rank the barriers related to the subject; to explore the interaction among the identified barriers related to the use of ISM; and to discuss the managerial implications of this research. For ISM to be successful, it is necessary to identify the variables in the focus group and develop a Structural Self-Interaction Matrix (SSIM) to identify the relationship between each variable horizontally.

The various steps involved in the ISM methodology are as follows:

1. Variables affecting the system under consideration are listed, which can be Objectives, Actions, Individuals, etc.

2. From the variables identified in Step 1, a contextual relationship is established among the variables with respect to which pairs will be examined.

3. A Structural Self-Interaction Matrix (SSIM) is developed for variables, which indicates pair-wise relationships among the variables within the system under consideration.

4. A reach ability matrix is developed from the SSIM and this matrix is checked for transitivity. The transitivity of the contextual relation is a basic assumption made in ISM. It states that, if variable A is related to variable B and variable B is related to variable C, then variable A is necessarily related to variable C.

5. The reachability matrix obtained in Step 4 is partitioned into different levels.

6. Based on the relationships given above in the reachability matrix, a directed graph is drawn and the transitive links are removed.

7. The resultant digraph is converted into an ISM, by replacing variable nodes with statements.

3.10 Data Analysis

The analysis of the data is a critical stage in any research project, once the primary and secondary data have been collected. This stage aims to transfer data from the questionnaires and interviews into useful and reliable information in order to achieve the research objectives and answer the research questions (hypothesis). Since this research adopted a mixed method approach for the data collection, there are various techniques available for the data analysis. Table 3.3 shows the distinctions between quantitative and qualitative data.

Table 3-3: The Distinctions between Quantitative and Qualitative Data. Source: Hair et al. (2007).

Quantitative data	Qualitative data
Based on meaning derived from members	Based on meanings expressed through words
Collection results in numerical and standardised data	Collection results in non-standardised data requiring classification into categories
Analysis conducted through the use of diagrams and statistics	Analysis conducted through the use of conceptualisation

In social research, the data analysis usually involves three main steps, which are performed in roughly the following order: data preparation, descriptive statistics and finally inferential statistics. Preparing the data involves checking them, entering them into the computer, and then transforming them. Quantitative data were prepared in this research by entering the data collected from the questionnaire using computer software (SPSS). Different types of data can be obtained from questionnaires. For this research, the questionnaire ranked the data using Likert scale questions to rate the culturally determined factors; categorical data that refer to values cannot be measured numerically, but can be quantified based on percentages (frequency of the answers). The data were coded in SPSS using the multiple-response method, which employs the same number of variables as the maximum number of different responses from any one case.

Descriptive statistics involve describing the basic features of the data in a study, which provides simple summaries about the sample. In terms of quantitative data, the researcher presented the data using advanced statistical and factor analysis software (SPSS). Factor analysis is an important test for grouping the variables and discovering any hidden or latent variables; however, it usually requires a high number of participants. In this study, factor analysis was conducted, but the 19 variables were not grouped into logically comprehendible categories; hence, the researcher chose not to include this analysis. More information about the analysis will be provided in the Results chapter (Chapter 4).

3.11 Ethical Issues

Ethical issues arise in connection with the collection of data and in relation to the rights of the participants involved in this research. Ethical issues are usually concerned with the participants' voluntary, informed consent, confidentially and anonymity. In terms of voluntary disclosure, the researcher gave the participants the freedom to choose to participate in the research questionnaire and interviews; they were not coerced into participating in the research. Even during the interviews, if the participants did not wish to continue at any time, they had the option of withdrawing from the interview.

The participants were informed about the procedures and risks associated with the research before they agreed to participate. The researcher gave an introduction to the participants about the research topic, procedures, and the purpose of the questionnaire and interviews, only after which was their participation in this research solicited. In addition, the researcher took the participants' privacy seriously to avoid any harm or risk to them arising (as individuals and organisations). Therefore, the researcher kept their information confidential, as it is only available to those directly involved in this research. Furthermore, the research findings were shown to the respondents for approval at each stage due to any perceived risk they might discover. Moreover, the participants retained their anonymity throughout the research; in the case of the questionnaire respondents, their identity was not known even to the researcher. The cover letter explained that participant anonymity would be respected and that names would not be included in the questionnaire or interviews. Additionally, the questions on the questionnaires and during the interviews were confined to the research subject. There were no personal questions, which could place the participants at risk or had the potential to make them feel uncomfortable. It is important to note that the researcher completed the ethical approval forms for this research before collecting the data. These forms dealt with the ethical issues discussed above and the data collection procedures. This form was confirmed by the research governance and ethics committee at Salford.

3.12 Types of Variables

Dillman (2007) distinguishes between three types of data variables that can be gained through questionnaires: opinions, behaviour, and attributes. Opinion variables record how respondents feel about something or what they think or believe is true or false (Saunders *et al*., 2009). For example, in this research, the researcher included on the questionnaire questions or lists of variables and asked the respondents about the degree to which each one affects OCT. On the other hand, behaviour variables contain data on what people or organisations did in the past, do now or will do in the future. An example is the question, “Do you expect that using off-site construction techniques will increase in the upcoming years?” The last type, ‘attribute variables’, contains data about the respondent's characteristics. Dillman (2007) states that attributes are best thought of as things that a respondent possesses rather than things that a respondent does, and that they are used to explore how opinions and behaviour differ between respondents as well as to check that the data collected are representative of the total population. Questions about field of study, experience and educational level that are used for this research questionnaire fall into this category.

In this research, the variables were divided into two categories: Independent Variables and Dependent Variables. The Independent Variables in this research were the variables that the researcher manipulated or used. These were drawn from the interviews (and related to OCT):

1- Offsite Pre-assembly
2- Hybrid System
3- Panelised system
4- Modular Building

The Dependent variables are those which are measured on the 5-point Likert scale (strongly disagree→strongly agree). In this research, these factors were: Overall Project Schedule; The Need for Skilled Craft Workers On-Site; Product Quality; Overall Labour Productivity; Design Options; Safety; On-Site Disruption of Other Operations; Environmental Impact of Construction Operations; Project Design Efficiency; Design Cost; Overall Project Cost; Transportation; The Owner's Negative Perception; The Ability to Make Changes to On-site Work; IT in a construction industry; Lack of available codes and standards, initial cost property, marketing value, complexity for maintenance, the construction waste.

3.13 Pilot Study

Once the questionnaire was designed and the semi-structured interview questions selected, they were pilot tested prior to their use for collecting data. The motive for piloting and pre-testing the questions was to refine the questionnaire, and to eliminate potential problems that the respondents might encounter related to answering the questions and recording the data. Simmons (2006) defined pilot testing the data collection techniques on typical respondents before the main study is conducted. Similarly, Saunders *et al* (2009) defined a pilot test as a small-scale study to test a questionnaire or interview to minimise the likelihood of respondents encountering problems answering the questions and also as a means of anticipating data recording problems.

Since the researcher adopted self-completion questionnaires, a pilot study was important for the research because no interviewer was present to clear up any confusion. Bryman and Bill (2007) suggest seven issues that should be checked if self-administered questionnaires are used. These are:

- How long the questionnaire takes to complete;
- The clarity of the instructions;
- Which questions, if any, were unclear or ambiguous;
- Which questions, if any, the respondent felt uneasy about answering;
- Whether there were any major topic omissions;
- Whether the layout was clear and attractive;

- Any other comments.

It is useful to test the questionnaire and interview questions on colleagues with previous experience of interviews, data collection and analysis, while selecting participants familiar with the research topic. Therefore, the researcher tested the questionnaire and interviews on a small size sample, targeting a number of current PhD students and academic staff at the University of Salford and other universities. Firstly, the questionnaire was distributed to three PhD students with previous experience in questionnaire design, and the researcher explained the purpose of the questionnaire and the research topic to obtain useful feedback. The participants were asked a number of questions about the questionnaire in terms of its layout, clarity of content, number of questions and duration. Based on this feedback, the researcher added some general questions about the participants' background to understand their experience and educational level. Secondly, the researcher requested two members of the academic staff at the University of Salford with previous experience in designing questionnaires and data collection and analysis, who were also familiar with the research problem, to make comments about its layout and content. Their feedback gave the researcher further ideas about writing the cover letter for the questionnaire and thus making it easier for participants to understand the research problem and the purpose behind the questionnaire. They also suggested that the questions should be reordered, and the scale relabelled. For example, the satisfaction questions were measured based on a 5-point agreement scale(strongly agree→strongly disagree) but, based on the pilot study, the researcher changed it to a 5-point satisfaction scale (not satisfied at all→ extremely satisfied).

3.14 Validity and Reliability

Validity and reliability are critical components of research development, to give it quality assurance. The concepts of validity and reliability are important to researchers in terms of the data collection and analysis. Saunders and Lewis (2012, pp.127-128) define validity as the extent to which:

- the data collection method/methods accurately measure what they were intended to measure (as shown in this chapter– Chapter 4– for quantitative and qualitative methods)
- the research findings are really about what they profess to be about (as shown in the Discussion chapter – Chapter 5)

According to the above authors, reliability means the extent to which the data collection methods and analysis procedures produce consistent findings.

Because this research used questionnaires and semi-structured interviews as the data collection methods, this raises data quality issues in terms of the validity and reliability that need to be covered.

3.14.1 The Validity of the Data Collection Methods

Validity concerns the integrity of the conclusions arrived at in a piece of research (Bryman and Bill, 2007), as well as the observation of protocols for measurements and procedures relating to data quality that are undertaken by the researcher in the course of the data collection. The mere use of a questionnaire does not guarantee the collection of relevant or useful data; it depends on how the questionnaire is undertaken in terms of the suitability for the research, measurements, procedures, and the design of the questionnaire. Leedy and Ormrod (2001) stated that a questionnaire may not accurately measure what it is intended to measure, which in turn can affect the probability of a researcher obtaining statistical significance in the data analysis and drawing meaningful conclusions from the data. Thus, the following procedures were undertaken to meet the requirements of validity for this research.

3.14.1.1Validity in Quantitative Research Method

There are three key types of validity: content validity, construct validity, and criterion-related validity (Churchill, 1991; Sekaran, 2003; Hair et al, 2009).

Straub (1989) suggests that a literature review and a panel of experts can build content validity. According to Churchill (1991), content validity measures the degree to which "the domain of the characteristic is captured by the measure" (p.490). In fact, conducting a literature review for this research project helped to achieve survey content validity.

Construct validity is "directly concerned with the question of what the instrument is, in fact, measuring" (Churchill, 1991, p. 491). According to Nunnally and Bernstein (1994), convergent validity and discriminant validity can achieve construct validity. McDaniel and Gates (1998) define convergent validity as "degree of correlation among different measures that purport to measure the same construct", while they define discriminant validity as "the lack of or low correlation among constructs that are supposed to be different" (pp.236-237). Thus, conducting a pilot study helped to enhance the construct validity by making it easier to understand the survey questions.

According to McDaniel and Gates (1998), criterion-related validity checks "the ability of a measuring instrument to predict a variable that is designated as criterion" (p.235). Criterion-related validity can be divided into two subcategories: predictive validity and concurrent validity. Predictive validity is "the extent to which a future level of a criterion variable can be predicted by a current measurement on a scale", while concurrent validity is concerned with "the relationship between the predictor variable and the criterion variable" (McDaniel and Gates, 1998, p.236). Indeed, the data collection was successful in presenting outcomes and findings that assisted the main aim of this research project.

3.14.2. The Reliability of the Data Collection Method

Somekh and Lewin (2007) define reliability from a quantitative and qualitative point of view. In terms of the quantitative point of view, reliability refers to measurements which repeatedly produce the same result. In qualitative research, it refers to the truth of the findings by ensuring that they are supported by sufficient and compelling evidence. From this definition, three main aspects are needed to achieve the research reliability: sufficiency, supporting evidence, and rigorous data collection and analysis.

3.14.2.1. Reliability of the Quantitative Research Method

Before performing any statistical analysis, it is important to gauge the reliability of the data. Reliability is generally defined as the level of stability of a measure. Also, it is the agreement between two efforts to gauge the same feature through employing analogous methods (Churchill and Iacobucci, 2002). According to Nachmias and Nachmias (1992), there are three general techniques for assessing reliability: test-retest, parallel-forms, and the split-half.

The test-retest technique is used by researchers to deliver the survey to the same group of respondents at two different times, and to compute the relationships between the two sets of scores. In fact, under this technique, an error is defined as anything that leads one to find different scores from the two different measurements (Oppenheim, 1992).

The researcher, under the parallel-forms technique, builds up two parallel versions of a measuring instrument. These two forms are administered to the same group of respondents, and then the two sets of outcomes must be correlated in order to obtain a proper assessment of reliability.

The split-half technique assesses consistency by treating each of two or more components of a measuring survey as a split scale, and scoring them accordingly. Then, these two components are correlated and compared (Nachmias and Nachmias, 1992).

From another point of view, there are two factors which lead to the reliability of an instrument: repeatability and internal consistency (Zikmund, 2003). Repeatability can be measured using the test-retest technique as explained above; this technique was not used in this research as most of the items on the questionnaire had been used successfully in previous studies (Dai, 2001). Internal consistency can be measured by using either the split-half or the parallel-forms technique; the Cronbach's alpha technique can also be used to measure internal consistency, as in the case of this research.

The Cronbach's alpha is a popular technique for measuring internal consistency reliability (Sekaran, 2003). The value of the alpha varies from 0 to 1, with a value of 0.6 or less indicating an insufficient level of internal consistency reliability (Malhotra, 2004). Nunnally and Bernstein (1994) show that 0.7 is the lowest alpha value that is satisfactory for ensuring reliability. However, adequate reliability is seen as being achieved in the social sciences if the value is between 0.7 and 0.8 (Nunnally and Bernstein, 1994). Evidence of the reliability of the questionnaire will be explored in the results chapter (Chapter 4).

3.14.2.2 Validity and Reliability of the Qualitative Research Method

The methods of qualitative research should be verified to demonstrate that findings are 'true' (Denscombe, 1998). In this study, the researcher employed four strategies to enhance the validity and reliability of the semi-structured interviews: (a) credibility (b) transferability (c) dependability and (d) confirmability (Lincoln and Guba, 1985).

Credibility

Credibility shows the accuracy of qualitative data, and in this research it improves the truth of the findings. It depends more on the richness of data gathered and on the analytical skills of the researcher than on the size of the sample (Patton, 2002). The researcher used ISM to ensure that the data were accurate and reliable, as detailed in Chapter 6.

Transferability

Transferability is the extent to which the findings can be transferred to other instances (Denscombe, 1998). It is the generalisability of the data, in other words, so the researcher used several methodsways to ensure the transferability of findings in this study (Lincoln and Guba, 1985):

- Interviews were conducted with Engineer managers from different membership organisations and with different levels of experience in the construction industry
- Qualitative data answers were compared with the literature review

- Qualitative data responses by different Engineer managers were compared

Dependability

According to Patton (2002), dependability focuses on whether the findings are consistent with the data gathered. Hence, the findings reflect the procedures of research that "other researchers can 'see' and evaluate in terms of how far they constitute reputable procedures and reasonable decisions" (Denscombe, 1998). Therefore, all phases of this research were described in detail (see Figure 3.3).

Confirmability

According to Denscombe (1998), confirmability refers to the extent to which qualitative research can generate results that are free from the bias of the subjective views of the researcher who conducted the analysis. In this study, the researcher used several methods to ensure the confirmability of the findings (Lincoln and Guba, 1985):

- Interviews were conducted on a one to one basis in a meeting room rather than in the participant's office, to avoid interruption.
- Comparisons were made with the literature review and data gathered from the participants.

3.15 Research Limitations

Subject to the qualifications below, the research processes were successful in achieving the research objectives and answering the research questions. However, several difficulties were encountered in the course of the research process. The first obstacle faced was the reluctance of some people to participate in the study. The second was the lack of any significant Saudi-specific literature on the topic.

In terms of data collection, too, several difficulties were encountered. The collection procedure involved handing out the questionnaire to the participants and then collecting them in the same way after completion to obtain a high response rate. However, not all of the questionnaires were completed.

3.16 Chapter Summary

This chapter explains and justifies the research philosophy, and the procedures and strategies used to answer the research questions, meet the objectives and test the hypotheses. The researcher relied on secondary data generated from the literature review and on primary data generated from the mixed methods of semi-structured interviews and questionnaires. The interviews provided the researcher with a deeper understanding of OCT practices in Saudi Arabia. Using this evidence, the researcher aims to recommend a strategy for applying OCT in Saudi Arabia

The next chapter analyses the data generated through interviews and self-administered questionnaires. This analysis chapter (Chapter 4) will be followed by a discussion chapter which will link the evidence from the questionnaires and interviews with the literature review, after which comes the conclusion chapter, based on the main findings. The outcome will be the recommendation of a strategy for applying OCT in Saudi Arabia. This will be tested in the following chapters.

Chapter 4: Analysis of Results

4.0 Introduction

This chapter presents the results of the statistical tests undertaken on the data that were collected. Ross (2004) reported that statistics are the art of learning from data which often leads to the drawing of conclusions. The responses to the survey questions will be presented and discussed in this chapter. The chapter will focus on descriptive statistics, the Reliability of the Questionnaire, the Techniques of Offsite Construction & Satisfaction, the Factors affecting Offsite Construction Techniques, the Reasons for using Offsite Construction Techniques, the Challenges related to using Offsite Construction Techniques, and Inferential statistics, as well as present the results of the qualitative data, which include: the Current Application of Offsite Construction Techniques (OCT), the Profile of the Interviewees, the Benefits of Utilising OCT, the Barriers to Utilising OCT, the Opportunities Provided by OCT, the Main Factors related to the Use of OCT, and recommendations.

4 .1 Questionnaire Analyses

4.1.1 Introduction

The aim of this research is to establish a means of ensuring that offsite construction in Saudi Arabia is both valid and achievable. This chapter will: (1) analyse data generated from questionnaires and interviews to investigate the feasibility of implementing offsite construction techniques in Saudi Arabia; (2) explore the possible advantages of their application and the ways in which they might be used; (3) discuss potential reasons for their use and the challenges they present in a Saudi Arabian context.

A number of themes have emerged from the literature review: (1) inconsistent claims are made concerning the time and cost advantages of using offsite fabrication; (2) access to (and familiarity with) technology is frequently presented as sufficient grounds for its use, without consideration of the important contribution made by architects, developers, contractors and sub-contractors to the success of innovative modern manufacturing technologies (3) not enough consideration is given to the capacity of construction personnel to absorb and share technical knowledge and participate in a collaborative process .

This chapter will analyse the reliability of the questionnaire. It will also provide a descriptive analysis of the background information, followed by a description of the main characteristics of all variables (using descriptive statistics) from which inferences will be made, based on statistical data, to answer the main research objectives.

4.1.2 The Reliability of the Questionnaire

Reliability refers to the consistency between answers on a given scale, i.e. to what extent the answers within a scale are consistent with each other (Field, 2011). In this current study, reliability (i.e. consistency) is measured through Cronbach's alpha. In this test, reliability is measured on a 0-100% scale (negative or positive), the higher the value, the greater the consistency between items.

The Cronbach's alpha was measured in this current study by means of one scale, i.e.

‘Factors related to offsite construction’, containing 19 items. Using SPSS, the results reflected almost 72% (0.721) consistency between answers when all 19 items were employed simultaneously. Although this study aspired to a higher rating, it is sufficient to reflect that this is a reasonable consistency between answers, and hence the construct can be considered reliable.

Table 4-1: reliability using Cronbach’s alpha for the factors related to offsite construction

Reliability Statistics

Cronbach's Alpha	N of Items
.721	19

4.2 Descriptive Analysis of the Questionnaire

Descriptive statistics refers to the description of the main features of the data in a quantitative (numeric) manner. It is distinguishable by its use of data to describe the sample unfit for consideration without referring to the population. In this study, the researcher will use frequency (i.e. the number of participants per answer) along with the percentage (%) of participants per answer. Based on the frequency and percentage, the items within the questionnaire will be ranked in terms of importance (or highest agreement. Such descriptive statistics (i.e. frequency; percentage; rank) are chosen due to the assumption that the scale followed in the questionnaire is ordinal (i.e. a 5-point Likert scale), and hence such statistical tests are most effective when describing the data.

The first part of the descriptive analysis will introduce personal and organisational background information, followed by: (1) a description of the techniques of offsite construction, and an examination of the extent to which they provide satisfaction; (2) a description of factors related to offsite construction techniques; (3) reasons for using offsite construction techniques; (4) the challenges of using offsite construction techniques.

4.2.1 Personal and Organisational Background

This section outlines the general personal and organisational characteristics shared by the respondents to the questionnaire. All respondents were asked to state the following: (1) their original field of study; (2) their education level; (3) any communication difficulties existing with colleagues; (4) their experience in offsite construction; (5) their organisational background.

4.2.2 Original Field of Study

The graph below demonstrates the professional background of respondents: the majority (72.5%) studied engineering; 17.6% studied management; 6.1% studied architecture; 3.8% highlighted other fields of study (or were contractors).

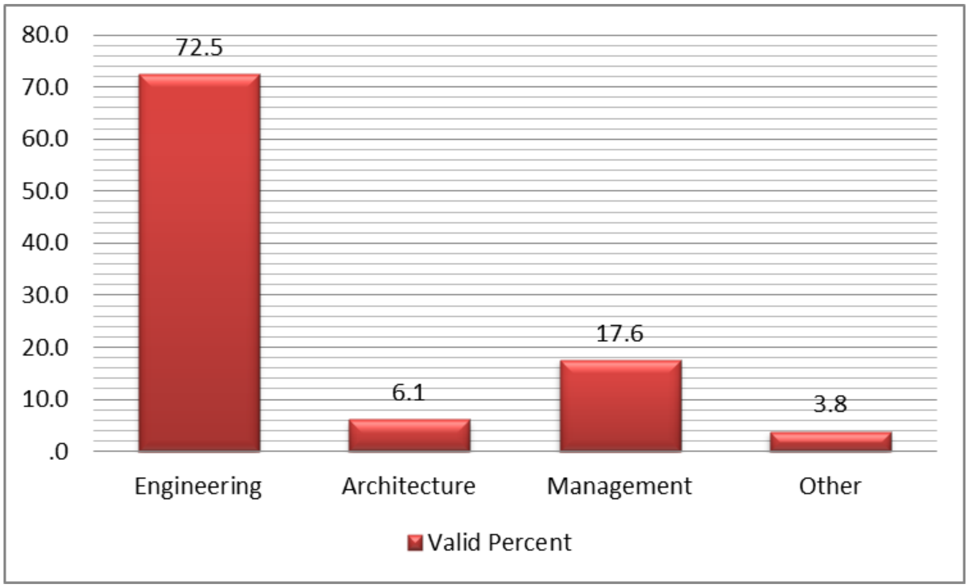

Figure 4-1: Demonstrates the frequency of answers in percentages in relation to the original field of study

4.2.3 Highest Educational Level

The most frequently observed educational qualification level among the questionnaire participants consisted of a bachelor’s degree (66.2%) followed by a higher diploma (18%), and a master’s (10.5%). 5.3% stated that they held a qualification below a bachelor’s degree.

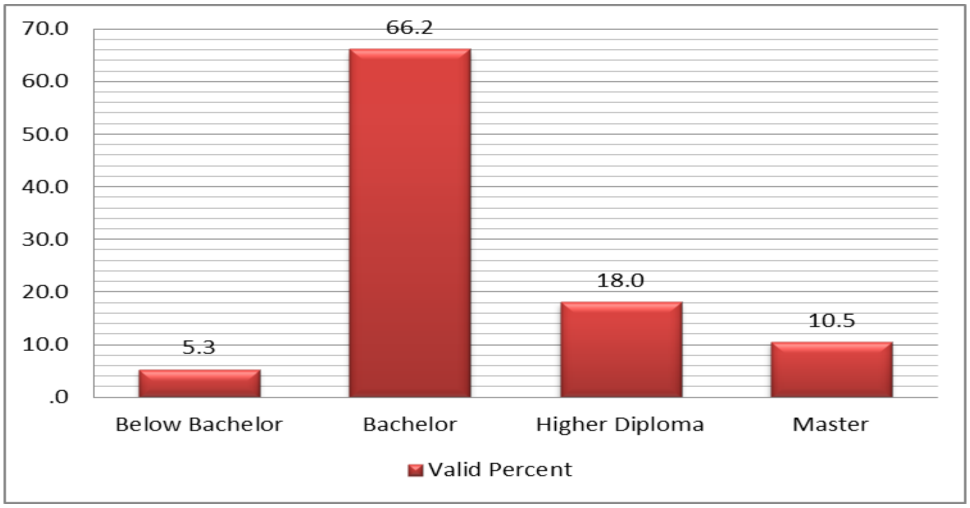

Figure 4-2: Shows the frequency of answers regarding education in percentages

4.2.4 Communication with other workers

Participants were invited to describe their level of communication with other colleagues (workers) during their construction and offsite construction work in Saudi Arabia. They were given a scale between 1 and 5 (i.e. from 'very poor' to 'very good'). All participants indicated positive levels of communication with their colleagues. The majority (60%) stated that their level of communication with other workers was very good; 20.7% stated that communication was good; 19.3% stated an extremely good level of communication.

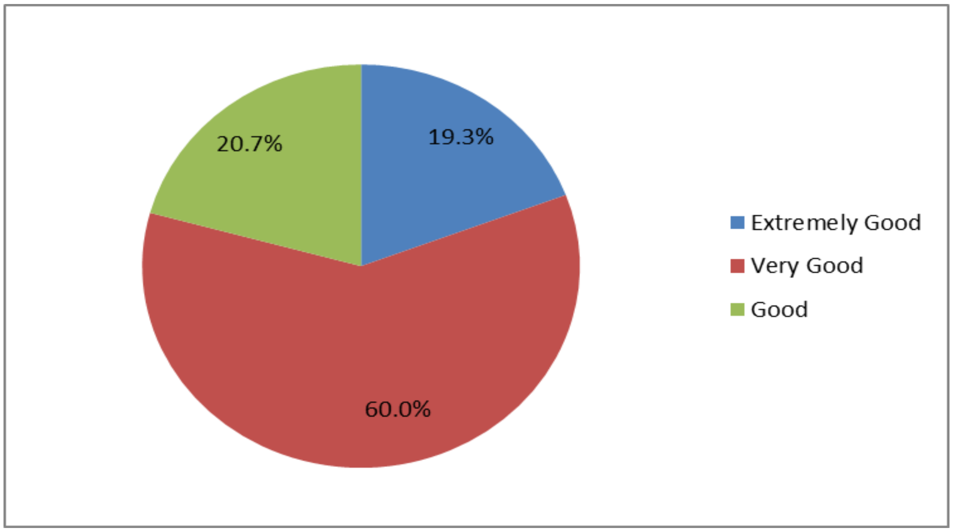

Figure 4-3: Demonstrates the rating of communication levels with fellow workers

4.2.5 Experience in offsite construction

The core focus of this study concerns offsite construction, and it was therefore vital to establish the participants' level of experience in this field. The level of the respondent's experience was varied, with almost half (47.1%) having less than 5 years' experience; 24.3% having 5-10 years' experience; 11.8% having between 11-15 years' experience; 7.4% having 16-20 years' experience; 9.6% having over 20 years' experience.

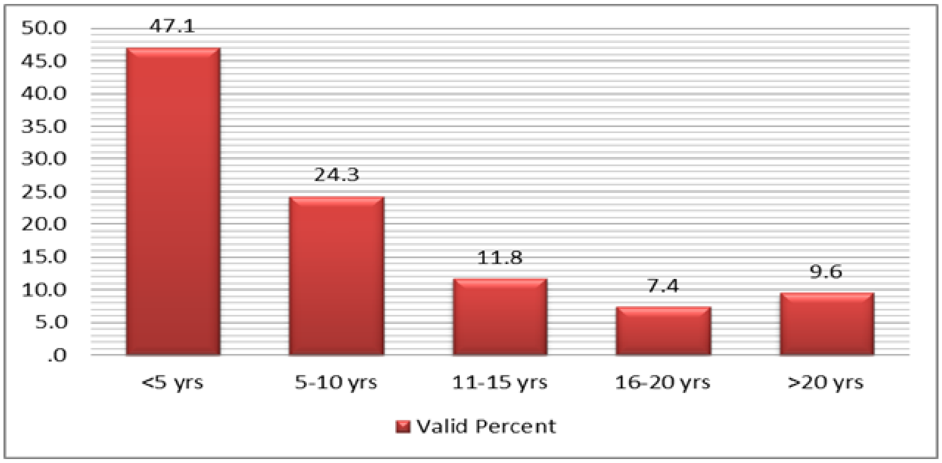

Figure 4-4: Demonstrates participants' experience of offsite construction in percentages

4.2.6 Organisational Background

Participants were asked to rank 3 of their design works in the workplace, by ticking the designs they had used or practiced. The most common design practice at work was 'residential', which was ticked by half of the participants (50%), followed by 'government design work' (49.3%) and 'private companies' (36.2%). The less practiced work designs consisted of 'industrial' (19.7%) and 'institutional' (12.3%).

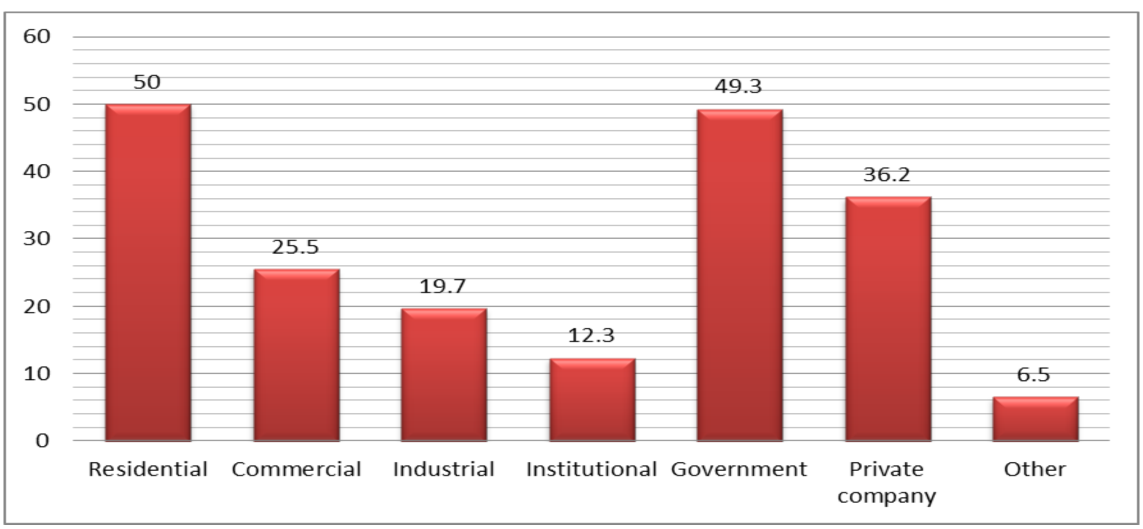

Figure 4-5: Demonstrates participants' design work

4.3 The Techniques of Offsite Construction & Satisfaction

This section describes the techniques of offsite construction and the satisfaction of participants regarding these techniques. The first section required participants to rate the frequency of the 4 offsite construction techniques (e.g. offsite preassembly; hybrid system; panelised system; modular building) from 1=most used, to 4=least used. An examination of the replies demonstrates that many of the participants ticked one of the 4 without providing the rank, and therefore all 4 techniques were ranked based on the number of ticks/agreements they received. An analysis of the responses revealed that 74.6% of participants used offsite preassembly; 63.8% used panelised systems; 37.7% used modular building; 55.1% used the hybrid system.

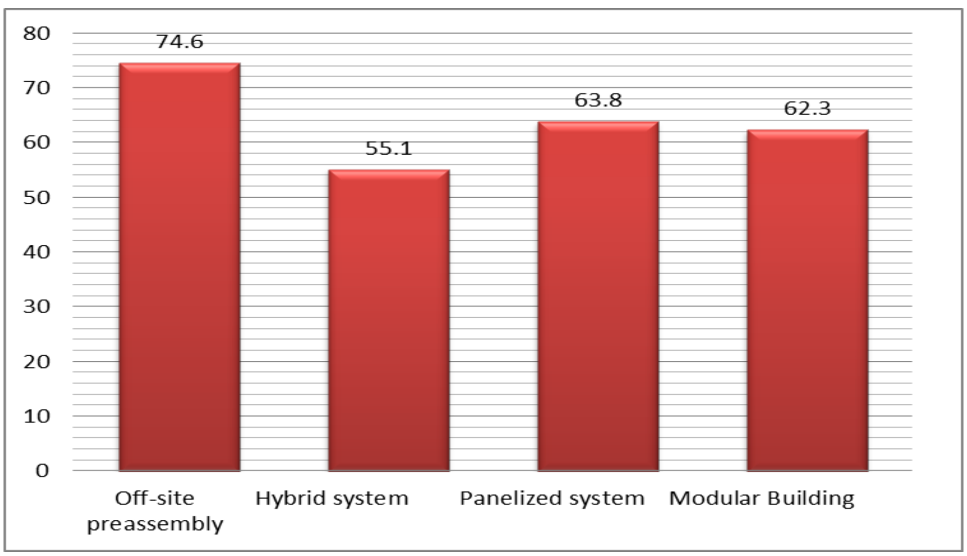

Figure 4-6: Demonstrates the offsite techniques used by participants

The ***satisfaction*** of participants concerning offsite construction techniques was rated on a 5-point Likert scale (i.e. 1=Very Dissatisfied; 2=Dissatisfied; 3=Neutral; 4=Satisfied; 5=Very satisfied).

Table 4-2: Demonstrates the participants' satisfaction with the use of each offsite construction technique

Techniques	Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very satisfied	Disagreement	Agreement
Offsite preassembly	1	0	23	56	41	.8%	80.20%
	.8%	0%	19.0%	46.3%	33.9%		
Hybrid system		2	67	50	2	1.7%	43%
		1.7%	55.4%	41.3%	1.7%		
Panelised system		17	22	44	38	14.0%	67.80%
		14.0%	18.2%	36.4%	31.4%		
Modular Building	1	1	44	64	11	1.6%	62%
	.8%	.8%	36.4%	52.9%	9.1%		

4.3.1 OCT Levels used and Satisfaction

The figure below demonstrates the use of each OCT, along with the participants' level of satisfaction with their use. It was established that offsite preassembly demonstrated the highest satisfaction (80.2%); followed by (1) the panelised system (67.8%); (2) the modular building (62%); (3) the hybrid system (43%).

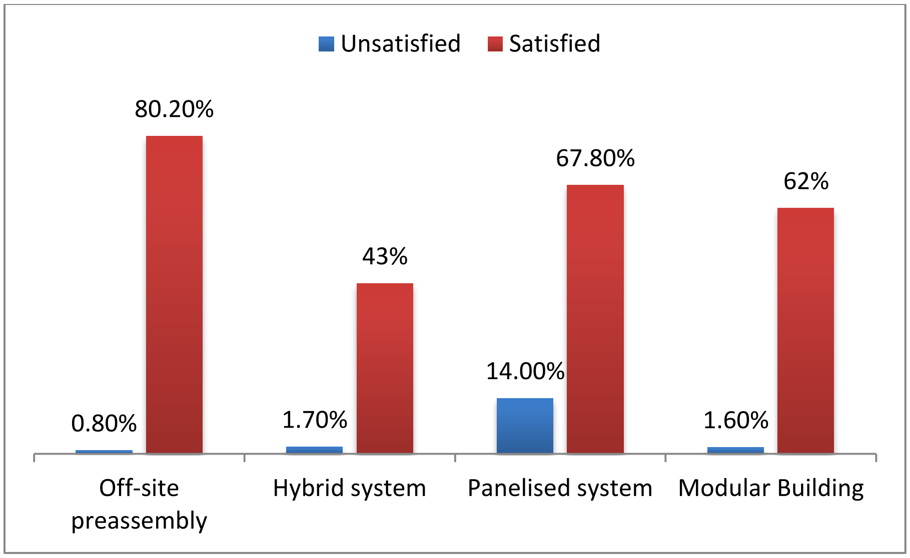

Figure 4-7: Demonstrates the participants' level of satisfaction with the use of each of the offsite construction techniques

4.3.2 Factors affecting Offsite Construction Techniques

This section of the analysis of the questionnaire concerns itself with an assessment of the effects of offsite construction techniques in general. Participants were presented with 19 possible effects of offsite construction techniques, and asked to rate their levels of agreement or disagreement according to a 5-point Likert scale (i.e. 1=Strongly Disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly Agree). Each of the 19 effects (or factors) affecting the offsite construction techniques is explained below, before being ranked on the 5-point scale. Thereafter all 19 items have been ranked based on agreement and disagreement percentages. Here 'Strongly Disagree' and 'Disagree' were combined, as were 'Agree' and 'Strongly Agree'.

4.3.2.1 Factors Prior to Ranking

The tables below demonstrate the frequency of the answers concerning each of the 19 factors affecting offsite construction:

1.) 77.6% agreed with the statement "offsite construction techniques reduce the overall project schedule"; 8% disagreed; 14.5% were undecided.

Factor 1:	**SD**	**D**	**N**	**A**	**SA**
Offsite construction techniques reduce the overall project schedule.	9	2	20	67	40
	6.5%	1.4%	14.5%	48.6%	29.0%

2.) 74% agreed with the statement "Offsite construction techniques reduce the need for more skilled craft workers onsite"; 18% disagreed.

Factor 2:	**SD**	**D**	**N**	**A**	**SA**
Offsite construction techniques reduce the need for more skilled craft workers onsite.	7	18	11	85	16
	5.1%	13.1%	8.0%	62.0%	11.7%

3.) 78% agreed with the statement "Offsite construction techniques increase product quality"; 5.0% disagreed; 17% were undecided.

Factor 3:	**SD**	**D**	**N**	**A**	**SA**
Offsite construction techniques increase product quality.	2	5	23	59	49
	1.4%	3.6%	16.7%	42.8%	35.5%

4.) 79% agreed with the statement "Offsite construction techniques increase overall labour productivity"; 4.0% disagreed; 17% were undecided.

Factor 4:	**SD**	**D**	**N**	**A**	**SA**
Offsite construction techniques increase overall labour productivity.	2	4	23	59	49
	1.5%	2.9%	16.8%	43.1%	35.8%

5.) 63.5% agreed with the statement “offsite construction techniques limit design options”; 18.0% disagreed; 18% were undecided.

Factor 5:	SD	D	N	A	SA
Offsite construction techniques limit design options	1	24	25	79	8
	0.7%	17.5%	18.2%	57.7%	5.8%

6.) 61% agreed with the statement “Offsite construction techniques increase safety performance”; 13.6 % disagreed.

Factor 6:	SD	D	N	A	SA
Offsite construction techniques increase safety performance.	1	9	44	61	22
	.7%	6.6%	32.1%	44.5%	16.1%

7.) 65% agreed with the statement “offsite construction techniques reduce onsite disruption of adjacent operations”; 9 % disagreed.

Factor 7:	SD	D	N	A	SA
Offsite construction techniques reduce onsite disruption of adjacent operations.		12	36	79	11
	0	8.7%	26.1%	57.2%	8.0%

8.) 66% agreed with the statement “Offsite construction techniques increase sustainability”; 7 % disagreed; 27% were undecided.

Factor 8:	SD	D	N	A	SA
Offsite construction techniques increase sustainability.		9	37	68	23
		6.6%	27.0%	49.6%	16.8%

9.) 58% agreed with the statement “Offsite construction techniques increase project design efficiency”; 5 % disagreed; 37% were undecided.

Factor 9:	SD	D	N	A	SA
Offsite construction techniques increase project design efficiency.		6	51	38	42
		4.4%	37.2%	27.7%	30.7%

10.) 50% agreed with the statement "Offsite construction techniques increase initial costs"; 25% disagreed; 25% were undecided.

Factor 10:	SD	D	N	A	SA
Offsite construction techniques increase initial costs.	4	30	38	26	39
	2.9%	21.9%	25%	21.0%	28.7%

11.) 51% agreed with the statement "Offsite construction techniques decrease overall project costs"; 29% disagreed; 21% were undecided.

Factor 11:	SD	D	N	A	SA
Offsite construction techniques decrease overall project costs.	15	24	29	36	34
	10.9%	17.4%	21.0%	26.1%	24.6%

12.) 64% agreed with the statement "transportation limitations (i.e. size constraints; transportation cost; impact on building structures) limit the use of offsite construction techniques"; 8% disagreed; 27% were undecided.

Factor 12:	SD	D	N	A	SA
Transportation limitations (i.e. size constraints; transportation cost; impact on building structures) limit the use of offsite construction techniques		11	38	78	11
		8.0%	27.5%	56.5%	8.0%

13.) 59% agreed with the statement that "the **investor's** negative perception of offsite construction techniques limits the use of such techniques"; 11 % disagreed; 30% were undecided.

Factor 13:	SD	D	N	A	SA
The investor's negative perception of offsite construction techniques limits the use of such techniques.	2	13	41	70	11
	1.5%	9.5%	29.9%	51.1%	8.0%

14.) 75% agreed with the statement "offsite construction techniques limit the ability to change onsite work"; 9% disagreed; 16% were undecided.

Factor 14:	SD	D	N	A	SA
Offsite construction techniques limit the ability to change onsite work.	2	10	22	63	40
	1.5%	7.3%	16.1%	46.0%	29.2%

15) 37% agreed with the statement that prefabrication "increases the complexity of maintenance"; 4.4% disagreed; 19% were undecided. (These figures indicate that, in the opinion of respondents, this factor has little impact on offsite construction.)

Factor 15:	SD	D	N	A	SA
Offsite construction techniques Increases the complexity of maintenance.	9	50	25	45	4
	6.8%	37.6%	18.8%	33.8%	3.0%

16.) 30.1% agreed with the statement that "Offsite construction reduces construction waste"; 44.4% disagreed; 26% were undecided. (These figures indicate that, in the opinion of respondents, this factor has little impact on offsite construction.)

Factor 16:	SD	D	N	A	SA
Offsite construction techniques Reduces construction waste.	2	57	34	40	
	1.5%	42.9%	25.6%	30.1%	

17.) 22% agreed with the statement that offsite construction "increases the market value of property"; 46% disagreed; 32% were undecided.

Factor 17:	SD	D	N	A	SA
Offsite construction techniques	5	56	43	28	1
Increases the market value of property.	3.8%	42.1%	32.3%	21.1%	.8%

18.) 44% agreed with the statement that "using offsite construction requires expertise in the use of IT"; 26% disagreed; 30% were undecided.

Factor 18:	SD	D	N	A	SA
Offsite construction techniques		35	40	52	5
Using offsite construction requires expertise in the use of IT.		26.5%	30.3%	39.4%	3.8%

19.) 15% agreed with the statement "a lack of available codes and standards impedes the use of offsite construction"; 55% disagreed; 30% were undecided.

Factor 19:	SD	D	N	A	SA
Lack of available codes and standards.	16	58	41	17	3
	11.9%	43.0%	30.4%	12.6%	2.2%

4.3.2.2 Factors after Rank

One of the main objectives of the current study is to identify the primary factors affecting offsite construction in Saudi Arabia, as outlined in the section above. The researcher will now focus on the most and least influential factors. The following table includes all factors ranked from 1 to 19, based on the agreement percentages generated by the total number of participants. The 3 highest ranked factors are discussed below.

The 4 highest ranked factors in terms of importance are: (1) "Offsite construction techniques increase overall labour productivity." This generated the highest level of agreement (79%); (2) "Offsite construction techniques increase product quality" (78%);

(3) “Offsite construction techniques reduce the overall project schedule” (77.6%); (4) “Offsite construction techniques limit the ability to change onsite work” (75%).

The 4 lowest ranked factors are: (1) “Offsite-construction techniques increase the complexity of maintenance” (37%); (2) “Offsite-construction techniques reduce construction waste” (30.1%); (3) Offsite-construction techniques increase the market value of property (22%); (4) “Offsite-construction techniques lack available codes and standards” (15%).The table below summarises the ranking of the factors affecting the application of Offsite construction techniques.

Table 4-3: The ranking of the factors affecting the application of Offsite construction techniques.

Rank	Factors affecting offsite construction techniques.	Disagreement	Agreement
1	Offsite construction techniques increase overall labour productivity.	4%	79 %
2	Offsite construction techniques increase product quality.	17%	78 %
3	Offsite construction techniques reduce the overall project schedule.	14.5%	77.6%
4	Offsite construction techniques limit the ability to make changes to onsite work.	9%	75%
5	Offsite construction techniques reduce the need for more skilled craft workers onsite.	18%	74 %
6	Offsite-construction techniques increase sustainability.	7%	66%

7	Offsite construction techniques reduce onsite disruption of adjacent operations.	9%	65%
8	Transportation limitations (i.e. size constraints; transportation costs; impact on building structures) limit the use of offsite construction techniques.	8%	64%
9	Offsite construction techniques limit design options.	18%	63.5%
10	Offsite construction techniques increase safety performance.	13.6%	61%
11	The investor's negative perception of offsite construction techniques limits the use of such techniques.	11%	59%
12	Offsite construction techniques increase project design efficiency.	5%	58%
13	Offsite construction techniques decrease the overall project cost.	29%	51%
14	Offsite-construction techniques increase initial cost.	25%	50%
15	Using offsite construction requires high use of IT in a construction industry.	26%	44%
16	Offsite-construction techniques increase the complexity of maintenance.	44%	37%
17	Offsite-construction techniques reduce construction waste.	44.4%	30.1%

18	Offsite-construction techniques increase the market value of property.	46%	22%
19	Offsite-construction techniques lack available codes and standards.	55%	15%

4.4 Reasons for using Offsite Construction Techniques

One of the main aims of this study has been to examine the primary reasons for using offsite construction in Saudi Arabia. Participants were therefore asked to choose the 3 most influential reasons for the use of offsite construction in Saudi Arabia from a choice of 15. The table below demonstrates the percentage and the frequency of the participants' answers.

(1) The majority of participants (63.8%) agreed that the principal reason for the use of offsite techniques is that it helps "to reduce construction duration". (2) 46.4% of participants agreed that offsite construction contains the capacity "to reduce overall project costs". (3) 37% of the participants believed that it helps "to reduce the project's overall schedule".

The 3 least ranked items are also recorded in the table below. The third least ranked reason for using offsite construction techniques (3.6%) is that it helps "to reduce environmental impact". 2 answers were jointly ranked as the second least mentioned items, i.e. that offsite construction techniques helps "to compensate for the local weather conditions" and "To improve project safety performance". Both received an equal percentage of 2.9%. Finally, "Other reasons" received 1.4% of the answers. A summary of the reasons and their rank is outlined in the table below

Table 4-4: Demonstrates the frequency of the most common reasons for the use of offsite techniques

Reasons	No	Yes	Rank
To compensate for restricted working space onsite.	110	28	5
	79.7%	20.3%	
To compensate for a shortage of skilled craft workers.	111	27	6
	80.4%	19.6%	
To compensate for local weather conditions.	134	4	11
	97.1%	2.9%	
To increase overall labour productivity.	110	28	5
	79.7%	20.3%	
To reduce the duration of construction.	50	88	1
	36.2%	63.8%	
To reduce the overall project schedule.	87	51	3
	63.0%	37.0%	
To reduce overall project cost.	74	64	2
	53.6%	46.4%	
To increase product quality.	97	41	4
	70.3%	29.7%	
To reduce design duration.	110	28	5
	79.7%	20.3%	
Project owners demanding the use of offsite construction techniques.	131	7	9
	94.9%	5.1%	
To reduce the environmental impact.	133	5	10
	96.4%	3.6%	
To improve project safety performance.	134	4	11
	97.1%	2.9%	
To increase a company's profit margin.	128	10	7
	92.8%	7.2%	
To enhance a company's reputation.	129	9	8
	93.5%	6.5%	
Any other reason:	136	2	12
	98.6%	1.4%	

4.5 Challenges to use Offsite Construction Techniques

The researcher also wished to establish the challenges facing offsite construction in Saudi Arabia. In order to achieve this, the questionnaire listed 12 challenges, with participants being required to indicate the challenges they believed to be relevant to Saudi Arabia. All participants were asked to tick only 3 of the challenges, although some did tick more. The table below reveals the frequency and the percentage of participants agreeing with each of the 12 proposed challenges.

Based on the percentages, 2 statements received the same level of agreement (i.e. the number of ticks). (1) 37% of the participants agreed equally with the statements "Limited design options of using offsite construction techniques." and "there is an inability to make changes in the field when using offsite construction techniques". (2) 35% of the participants agreed that the designing Offsite construction firms "requires specialised computer software". (3) 30% of participants agreed that, "using offsite construction techniques will increase construction costs".

The least notable challenges according to participants' answers are: (1) "transportation restraints" (selected by 14.5% of participants); (2) "financial institutions restrict the use of offsite construction techniques" (13.8%); (3) "local zoning ordinance restricts the use of offsite construction techniques (5.8%). Participants did not provide any further challenges in addition to the 14 listed in the questionnaire. The table below includes the ranking for all challenges.

Table 4-5: The level of agreement with challenges to the use of offsite construction techniques

Challenges	No	Yes	Rank
Designing offsite construction components requires specialised computer software.	90	48	2
	65.2%	34.8%	
Limited design options of using offsite construction techniques.	87	51	1
	63.0%	37.0%	
Local zoning ordinance restricts the use of offsite construction techniques.	130	8	11
	94.2%	5.8%	
Local building regulations restrict the use of offsite construction techniques.	115	23	7
	83.3%	16.7%	
Financial institutions restrict the use of offsite construction techniques.	119	19	10
	86.2%	13.8%	
Project owners do not allow the use of offsite construction techniques.	117	21	8
	84.8%	15.2%	
Lack of local skilled assembly craft works.	103	35	5
	74.6%	25.4%	

Use of offsite construction techniques will increase design costs.	101	37	4
	73.2%	26.8%	
Using offsite construction techniques will increase construction costs.	96	42	3
	69.6%	30.4%	
Transportation restraints.	118	20	9
	85.5%	14.5%	
General contractors do not have expertise in assembling prefabricated building components onsite.	106	32	6
	76.8%	23.2%	
Inability to make changes in the field using offsite construction techniques.	87	51	1
	63.0%	37.0%	

Table 4-6: The level of agreement with reasons and challenges to the use of offsite construction techniques

Offsite Construction (OCT)	
Reason to use OCT	**Challenge of using OCT**
1. To reduce the duration of construction. 2. To reduce overall project cost. 3. To reduce the overall project schedule. 4. To increase product quality. 5. To reduce design duration. 6. To increase overall labour productivity. 7. To compensate for restricted working space onsite. 8. To compensate for a shortage of skilled craft workers. 9. To increase a company's profit margin. 10. To enhance a company's reputation. 11. Project owners demanding the use of offsite construction techniques. 12. To reduce the environmental impact. 13. To compensate for local weather conditions. 14. To improve project safety performance.	1. Inability to make changes in the field using offsite construction techniques. 2. Limited design options of using offsite construction techniques. 3. Designing offsite construction components requires specialised computer software. 4. Using offsite construction techniques will increase construction costs. 5. Use of offsite construction techniques will increase design costs. 6. Lack of local skilled assembly craft works. 7. General contractors do not have expertise in assembling prefabricated building components onsite. 8. Local building regulations restrict the use of offsite construction techniques. 9. Project owners do not allow the use of offsite construction techniques. 10. Transportation restraints. 11. Financial institutions restrict the use of offsite construction techniques. 12. Local zoning ordinance restricts the use of offsite construction techniques.

4.6 Inferential statistics

This section of the findings is concerned with exploring the data using inferential statistics. Here the researcher will test if: (1) there is a significant effect of using offsite techniques (e.g. offsite preassembly; hybrid system; panelised system; modular building) on factors affecting offsite construction in Saudi Arabia. (2) there is a significant relationship between satisfaction with the offsite techniques (e.g. offsite preassembly; hybrid system; panellised system; modular building) and factors affecting offsite construction in Saudi Arabia (i.e. 19 questions). Prior to testing these points, it is essential to examine the type of data employed in this study and the types of statistical tests to which they are suited.

4.6.1 Type of Data and Tests

Before proceeding with the testing of the hypothesis, it is essential to determine whether the data justifies the assumptions of parametric or non-parametric data. For the data to be parametric: (1) it needs to be measured through an interval scale; (2) it needs to justify normal distribution (i.e. the data follows a bell shape on a histogram); (3) It needs to fulfil the requirement for independence of observation (i.e. the questionnaires have been completed by the participants without assistance). Failure to meet any of these points leads to the acceptance that the data is non-parametric. In this current study, the data is assumed to be non-parametric because the questionnaire items have been measured through an ordinal scale (i.e. 5-points Likert scale). Hence, it will be assumed here that the data is non-parametric and that therefore appropriate tests need to be employed to suit this data.

In following section the study aims to measure the effects and relationships between independent variables (use of OCT and satisfaction using OCT) and other dependent variables (impact factors). In order to do so, two types of tests will be used (non-parametric). Firstly the data will be examined through the use of ***Mann-Whitney U test.*** This test measures the effect of an independent variable of 2 levels on the remainder of the dependent variables (i.e. measured through an ordinal scale). An alpha level below 5% reflects a significant effect on (or a significant difference between) the independent variable on the selected dependent variable. The alpha level measures the chance of the results being random and not due to the effect of the independent variable, with a value of 5% being the maximum limit. The second test is ***Spearman's rho correlation coefficient.*** This test determines the relationship between any 2 given variables. The coefficient value ranges between -1 and +1, with a negative value reflecting negative relationships and positive values reflecting positive relationships. An alpha level below 5% reflects a significant relationship ($p<0.05$), with a value above reflecting a lack of any relationship (Field, 2010).

4.6.2 The Use of Offsite Construction Techniques

This section is focuses on tests to determine whether the use of offsite construction techniques (e.g. offsite preassembly; hybrid system; panelised system; modular building) have any effect on the dependent variables, i.e. factors affecting offsite construction techniques (consisting of 19 items). All interdependent variables are scored as 0=no use, 1=use, and all dependent variables are scored on a 5-point Likert scale (from 1=strongly disagree to 5=strongly agree). Based on the data, it is suitable to use the Mann-Whitney U test, which measures the effect of an independent variable (2 levels) on ordinal/ranking dependent variables. The table below demonstrates the results generated from the Mann-

Whitney U test and descriptive outcomes.

4.6.2.1 Effect of Offsite preassembly

The effect of offsite preassembly techniques on 19 items was examined, leading to the conclusion that a significant effect was generated on only 6 items, as can be seen in Table 7. The techniques reveal a significant effect concerning: “reduce the need for more skilled craft workers onsite; increase overall labour productivity; increase initial cost; limits the ability to make change onsite work; increases the market value of property; requires high use of IT in a construction industry”. This demonstrates that those who use offsite preassembly had a higher agreement with the factors affecting offsite construction compared to those who do not ($p<0.05$). However, when it came to increasing the market value of property and the required high level of use of IT within the construction industry, participants who indicated use of offsite preassembly reflected a lower level of agreement with both questions compared to those who did not ($p<0.05$). There was no significant effect observed on any of the other factors by the use offsite preassembly ($p>0.05$).

Table 4-7: Descriptive statistics and Mann-Witney U results for the effect of offsite Preassembly

	No/ Yes	N	Mean	Mean Rank	U	Sig.
Offsite construction techniques	0	35	4.00	72.81	1686.5	0.54

reduce the overall project schedule.	1	103	3.89	68.37		
Offsite construction techniques reduce the need for more skilled craft workers onsite.	0	35	3.17	55.17	1301	0.006
	1	102	3.77	73.75		
Offsite construction techniques increase product quality.	0	35	4.00	67.03	1716	0.65
	1	103	4.10	70.34		
Offsite construction techniques increase overall labour productivity.	0	34	3.44	43.90	897.5	0
	1	103	4.30	77.29		
Offsite construction techniques limit design options.	0	35	3.34	64.83	1639	0.419
	1	102	3.56	70.43		
Offsite construction techniques increase safety performance.	0	34	3.71	71.12	1679	0.701
	1	103	3.68	68.30		
Offsite construction techniques increase sustainability.	0	35	3.43	61.49	1522	0.123
	1	103	3.72	72.22		
Offsite construction techniques reduce the environmental impact of construction operations.	0	35	3.91	78.01	1469.5	0.092
	1	102	3.72	65.91		

Offsite construction techniques increase the efficiency of project design.	0	34	3.71	64.84	1609.5	0.457
	1	103	3.89	70.37		
Offsite construction techniques Increase initial costs.	0	34	3.06	56.22	1316.5	0.025
	1	103	3.62	73.22		
Offsite construction techniques decrease the overall project cost.	0	35	3.14	63.30	1585.5	0.276
	1	103	3.44	71.61		
Transportation limitations.	0	35	3.66	73.39	1666.5	0.456
	1	103	3.64	68.18		
The owner's negative perception of offsite construction techniques limits the use of such techniques.	0	35	3.66	73.80	1617	0.365
	1	102	3.51	67.35		
Offsite construction techniques limit the ability to make changes to onsite work.	0	35	3.57	54.16	1265.5	0.006
	1	102	4.07	74.09		
Increases the complexity of maintenance.	0	35	3.00	71.00	1575	0.451
	1	98	2.85	65.57		
Offsite construction requires reduction of construction waste.	0	35	2.91	70.41	1595.5	0.514
	1	98	2.82	65.78		
Offsite construction increases the market value of property.	0	35	3.00	78.60	1309	0.027
	1	98	2.63	62.86		
Offsite construction lacks	0	34	3.29	69.74	1556	0.545

available codes and standards.	1	98	3.17	65.38		
Using offsite construction requires a high level of IT in a construction industry.	0	35	2.94	85.81	1126.5	0.001
	1	100	2.35	61.77		

4.6.2.2 The Effects of the Hybrid System

It was evident when the using independent sample t-test that a positive correlation exists between the use of hybrid systems and the advantages of offsite construction (Table 8). Those using the hybrid system demonstrated greater agreement on the following statements: “reduces the need for more skilled craft workers onsite; increases overall labour productivity; increase initial costs; limits the ability to make changes to onsite work” ($p<0.05$). Those not employing the hybrid system revealed significantly greater agreement with the statements: “reduces the overall project schedule; reduces environmental impact of construction operations; increases the complexity of maintenance; increases property marketing value; requires high level of use of IT in a construction industry” ($p<0.05$). No significant effect of the hybrid system’s use was established in relation to the other questions ($p>0.05$).

Table 4-8: Descriptive statistics and Mann-Witney U results for the effect of Hybrid system

	Q6H	N	Mean	Mean Rank	U	Sig.
Offsite construction techniques reduce the overall project schedule.	0	62	4.16	78.73	1784	0.008
	1	76	3.72	61.97		

Offsite construction techniques reduce the need for more skilled craft workers onsite.	0	61	3.28	59.89	1762	0.006
	1	76	3.89	76.32		
Offsite construction techniques increase product quality.	0	62	3.90	64.06	2019	0.123
	1	76	4.21	73.93		
Offsite construction techniques increase overall labour productivity.	0	61	3.69	52.31	1300	0.000
	1	76	4.41	82.39		
Offsite construction techniques limit design options.	0	62	3.32	63.32	1973	0.088
	1	75	3.65	73.69		
Offsite construction techniques increase safety performance.	0	61	3.80	75.91	1896.5	0.051
	1	76	3.59	63.45		
Offsite construction techniques increase sustainability.	0	62	3.63	69.98	2326	0.885
	1	76	3.66	69.11		
Offsite construction techniques reduce the environmental impact of construction operations.	0	61	3.92	78.00	1769	0.010
	1	76	3.64	61.78		
Offsite construction	0	61	3.77	66.71	2178.5	0.524

techniques increase the efficiency of project design.	1	76	3.91	70.84		
Offsite construction techniques increase initial costs.	0	61	3.07	55.70	1507	0.000
	1	76	3.82	79.67		
Offsite construction techniques decrease the overall project cost.	0	62	3.37	69.73	2341.5	0.949
	1	76	3.36	69.31		
Transportation limitations.	0	62	3.71	75.32	1995	0.084
	1	76	3.59	64.75		
The owner's negative perception of offsite construction techniques limits their use.	0	62	3.56	71.10	2194.5	0.538
	1	75	3.53	67.26		
Offsite construction techniques limit the ability to make changes to onsite work.	0	62	3.65	57.97	1641	0.002
	1	75	4.19	78.12		
Increases the complexity of maintenance.	0	59	3.10	74.14	1762	0.045
	1	74	2.72	61.31		
Offsite construction requires a reduction of construction waste.	0	59	2.76	64.10	2012	0.408
	1	74	2.91	69.31		
Offsite construction	0	59	2.98	77.06	1589.5	0.004

increases the market value of property.	1	74	2.53	58.98		
Offsite construction lacks available codes and standards.	0	58	3.26	68.53	2028	0.567
	1	74	3.16	64.91		
Using offsite construction requires a high level of use of IT in a construction industry.	0	60	2.92	83.72	1307	0.000
	1	75	2.17	55.43		

4.6.2.3 The effect of a panelised system

It was noted while using the independent sample t-test that there is a significant effect for the use of the panelised system on factors affecting offsite construction techniques in Saudi Arabia (Table 9). Those employing the hybrid system demonstrated a significantly improved agreement with the following statements: "reduces the need for more skilled craft workers onsite; increases product quality; increases overall labour productivity; increases initial cost; limits the ability to make changes to onsite work" ($p<0.05$). Those not employing the panelised system demonstrated significantly improved agreement with the following statements: "increases safety performance; reduces the environmental impact of construction operations; increases property marketing values; requires a high level of use of IT in a construction industry" ($p<0.05$). No significant effect of the hybrid system's use was identified on the remainder of the questions ($p>0.05$).

Table 4-9: Descriptive statistics and Mann-Witney U results for the effect of the Panelised system

	Q6P	N	Mean	Mean Rank	U	Sig.
Offsite construction techniques reduce the overall project schedule.	0	50	4.08	74.75	1937.5	0.209
	1	88	3.83	66.52		
Offsite construction techniques reduce the need for more skilled craft workers onsite.	0	50	3.34	60.65	1757.5	0.032
	1	87	3.78	73.80		
Offsite construction techniques increase product quality.	0	50	3.82	61.02	1776	0.044
	1	88	4.22	74.32		
Offsite construction techniques increase overall labour productivity.	0	49	3.65	50.99	1273.5	0.000
	1	88	4.33	79.03		
Offsite construction techniques limit design options.	0	50	3.40	66.99	2074.5	0.615
	1	87	3.56	70.16		
Offsite construction techniques increase safety performance.	0	49	3.84	77.36	1746.5	0.049
	1	88	3.60	64.35		
Offsite construction techniques increase sustainability.	0	50	3.70	72.43	2053.5	0.466
	1	88	3.61	67.84		
Offsite construction techniques reduce	0	49	3.98	80.44	1595.5	0.006

the environmental impact of construction operations.	1	88	3.65	62.63		
Offsite construction techniques increase the efficiency of project designs.	0	49	3.65	62.29	1827	0.119
	1	88	3.95	72.74		
Offsite construction techniques increase initial costs.	0	49	2.86	49.06	1179	0.000
	1	88	3.83	80.10		
Offsite construction techniques decrease the overall project cost.	0	50	3.36	69.14	2182	0.935
	1	88	3.36	69.70		
Transportation limitations.	0	50	3.68	73.68	1991	0.300
	1	88	3.63	67.13		
The owner's negative perception of offsite construction techniques places limitations on their use.	0	50	3.64	74.76	1887	0.160
	1	87	3.49	65.69		
Offsite construction techniques limit the ability to make changes to onsite work.	0	50	3.70	59.49	1699.5	0.023
	1	87	4.08	74.47		
Increases the complexity of maintenance.	0	48	3.00	70.79	1858	0.369
	1	85	2.82	64.86		
Offsite construction requires reduction of	0	48	2.83	66.97	2038.5	0.994

construction waste.	1	85	2.85	67.02		
Offsite construction increases the market value of the property.	0	48	2.96	76.13	1602	0.029
	1	85	2.60	61.85		
Offsite construction lacks available codes and standards.	0	48	3.25	68.21	1934	0.681
	1	84	3.18	65.52		
Offsite construction requires a high level of use of IT in a construction industry.	0	49	2.94	84.76	1286	0.000
	1	86	2.26	58.45		

4.6.2.4 The Effect of Modular Building

The use of the modular building was tested through the independent sample t-test (see Table 10). A significant effect of its use was established on the factors affecting offsite construction techniques in Saudi Arabia, and specifically on the following statements: "increases overall labour productivity; increases the initial cost; limits the ability to make changes to onsite work". Participants who used the technique demonstrated significantly improved agreement ($p<0.05$), while those who did not, demonstrated a significantly improved agreement with the following statements: "reduces the overall project schedule; increases safety performance; reduces the environmental impact of construction operations; requires a high level of use of IT in a construction industry" ($p<0.05$). No significant effect of the use of modular building was identified in relation to the remainder of the questions ($p>0.05$).

Table 4-10: Descriptive statistics and Mann-Witney U results for the effect of modular building

	Q6M	N	Mean	Mean Rank	U	Sig.
Offsite construction techniques reduce the overall project schedule.	0	52	4.13	77.46	1822	0.050
	1	86	3.79	64.69		
Offsite construction techniques reduce the need for more skilled craft workers onsite.	0	51	3.37	62.67	1870	0.098
	1	86	3.77	72.76		
Offsite construction techniques increase product quality.	0	52	3.88	64.60	1981	0.230
	1	86	4.19	72.47		
Offsite construction techniques increases overall labour productivity.	0	51	3.71	53.42	1398.5	0.000
	1	86	4.31	78.24		
Offsite construction techniques limit design options.	0	52	3.31	62.77	1886	0.107
	1	85	3.62	72.81		
Offsite construction	0	51	3.88	78.99	1683.5	0.015

techniques increase safety performance.	1	86	3.57	63.08		
Offsite construction techniques increase sustainability	0	52	3.69	72.97	2055.5	0.373
	1	86	3.62	67.40		
Offsite construction techniques reduce the environmental impact of construction operations.	0	51	4.00	80.75	1593.5	0.004
	1	86	3.63	62.03		
Offsite construction techniques increase project design efficiency.	0	52	3.75	65.74	2040.5	0.428
	1	85	3.91	70.99		
Offsite construction techniques increase initial costs.	0	52	2.92	51.17	1283	0.000
	1	85	3.82	79.91		
Offsite construction techniques decrease the overall project cost.	0	52	3.46	72.08	2102	0.546
	1	86	3.30	67.94		
Transportation limitations.	0	52	3.58	69.37	2229	0.973
	1	86	3.69	69.58		
The owner’s negative perception of offsite construction techniques places limitations on their use.	0	52	3.60	71.86	2061.5	0.472
	1	85	3.52	67.25		
Offsite construction	0	52	3.58	55.20	1492.5	0.001

techniques limit the ability to make changes to onsite work.	1	85	4.16	77.44		
Increases the complexity of maintenance.	0	50	3.10	73.76	1737	0.098
	1	83	2.76	62.93		
Offsite construction requires a reduction in construction waste.	0	50	2.78	64.94	1972	0.609
	1	83	2.88	68.24		
Offsite construction increases the market value of the property.	0	50	2.90	73.85	1732.5	0.090
	1	83	2.63	62.87		
Offsite construction lacks available codes and standards.	0	49	3.20	66.42	2029.5	0.984
	1	83	3.20	66.55		
Using offsite construction requires a high level of use of IT in a construction industry	0	50	2.94	84.42	1304	0.000
	1	85	2.25	58.34		

4.6.3 Satisfaction with Offsite Techniques

This section is concerned with the relationship between satisfaction with offsite construction techniques (e.g. offsite preassembly; hybrid system; panelised system; modular building) and factors affecting offsite construction techniques (i.e. 19 items) and offsite construction in Saudi Arabia (i.e. 5 items). Both variables are measured on a 5-

points Likert scale, one reflecting satisfaction (from 1=not satisfied at all, to 5= very satisfied) and agreement (from 1=strongly disagree, to 5=strongly agree). A suitable test in relation to this section is Spearman's rho correlation coefficient, which measures the relationship between any 2 interval (scale) variables. The table below demonstrates the significant relationship between the satisfaction with each of the offsite construction techniques and factors affecting offsite construction techniques.

4.6.3.1 Satisfaction with Offsite Preassembly

The use of Spearman's rho correlation coefficient established a significant negative relationship between satisfaction with offsite preassembly and a reduction of the overall project schedule, rho(121)=-0.188, p=0.039; transportation restraints, rho(121)=-0.467, p=0.000; increases the complexity of maintenance, rho(121)=-0.200, p=0.031. There was, however, a significant negative relationship with increases the market value of property, rho(121)=0.194, p=0.037. Furthermore, a significant positive correlation was established with "increases overall labour productivity, rho(121)=0.519, p=0.000; increases project design efficiency, rho(121)=0.333, p=0.000; increases initial costs, rho(121)=0.225, p=0.013; and decreases the overall project cost, rho(121)=0.331, p=0.000.

4.6.3.2 Satisfaction with the Hybrid system

The use of Spearman's rho correlation coefficient established a significant negative relationship between satisfaction with a hybrid system and "a reduction of the overall project schedule, rho (121) =-0.200, p=0.028; increases product quality, rho (121) =-0.182, p=0.046; increases overall labour productivity, rho (121) =-0.302, p=0.001." A significant negative correlation was established with "increases initial cost, rho (121) =-0.414, p=0.000. The remainder of the questions established no significant relationship in relation to satisfaction with the hybrid system.

4.6.3.3 Satisfaction with the Panelised system

The use of Spearman's rho correlation coefficient established a significant negative correlation between satisfaction with a panelised system and transportation limitations, rho(121)=-0.256, p=0.005; and a significant negative correlation with the increase of complexity of maintenance, rho(121)=-0.217, p=0.0.019. This indicates that the higher the satisfaction of the participants, the more likely it is they will disagree that both transportation limitations and complexity of maintenance form barriers. A significant positive relationship was also established between satisfaction with the panelised system and the "increase in product quality, rho(121)=0.465, p=0.000; increase in safety performance, rho(121)=0.306, p=0.001; increased sustainability, rho(121)=0.302, p=0.001; reduction in the environmental impact of construction operations, rho(121)=0.399, p=0.000; increase in project design efficiency, rho(121)=0.452, p=0.000; decrease in the overall project cost, rho(121)=0.608, p=0.000". This indicates that that the greater the satisfaction with the panelised system, the greater the likelihood of agreement concerning the importance of such factors.

4.6.3.4 Satisfaction with Modular building

The Spearman's rho correlation coefficient revealed a significant negative relationship between satisfaction with the modular building technique and "increases product quality, rho(121)=-0.223, p=0.014; increase in overall labour productivity, rho(121)=-0.263, p=0.003; increase in safety performance, rho(121)=-0.296, p=0.001; reduction in environmental impact of construction operations, rho(120)=-0.194, p=0.033; increase in project design efficiency, rho(121)=-0.340, p=0.000; increase in initial cost, rho(121)=-

0.235, p=0.010; decrease in overall project cost, rho(121)=-0.499, p=0.000. Thus the greater the satisfaction of participants with the modular building, the more likely they are to disagree with previously noted factors concerning OCT. Finally, a positive correlation with transportation restraints, rho(121)=0.376, p=0.000, indicates that the greater the satisfaction with modular building, the lower the agreement with the existence of transportation restraints when using OCT. The remaining questions demonstrated no significant relationships with satisfaction in relation to modular building.

Table 4-11: The correlation coefficient between the satisfaction with the offsite techniques and the offsite construction techniques and their use in Saudi.

Spearman's rho Correlation					
		Q7O	Q7H	Q7P	Q7M
Offsite construction techniques reduce the overall project schedule.	Correlation Coefficient	-.188*	-.200*	.029	-.022
	Sig. (2-tailed)	.039	.028	.749	.808
	N	121	121	121	121
Offsite construction techniques reduce the need for more skilled craft workers onsite.	Correlation Coefficient	.119	-.111	.064	.029
	Sig. (2-tailed)	.194	.224	.483	.748
	N	121	121	121	121
Offsite construction techniques increase product quality.	Correlation Coefficient	.145	-.182*	.465**	-.223*
	Sig. (2-tailed)	.112	.046	.000	.014

	N	121	121	121	121
Offsite construction techniques increase overall labour productivity.	Correlation Coefficient	.519**	-.302**	.035	-.263**
	Sig. (2-tailed)	.000	.001	.705	.003
	N	121	121	121	121
Offsite construction techniques limit design options.	Correlation Coefficient	.090	-.156	.117	-.119
	Sig. (2-tailed)	.328	.088	.203	.196
	N	120	120	120	120
Offsite construction techniques increase safety performance.	Correlation Coefficient	.083	.113	.306**	-.296**
	Sig. (2-tailed)	.364	.218	.001	.001
	N	121	121	121	121
Offsite construction techniques increase sustainability.	Correlation Coefficient	.021	.079	.302**	-.091
	Sig. (2-tailed)	.819	.391	.001	.323
	N	121	121	121	121
Offsite construction techniques reduce the environmental impact of construction operations.	Correlation Coefficient	.142	.104	.399**	-.194*
	Sig. (2-tailed)	.123	.258	.000	.033
	N	120	120	120	120

Offsite construction techniques increase project design efficiency.	Correlation Coefficient	.333**	-.075	.452**	-.340**
	Sig. (2-tailed)	.000	.413	.000	.000
	N	121	121	121	121
Offsite construction techniques increase initial costs.	Correlation Coefficient	.225*	-.414**	.023	-.235**
	Sig. (2-tailed)	.013	.000	.803	.010
	N	121	121	121	121
Offsite construction techniques decrease the overall project cost.	Correlation Coefficient	.331**	-.074	.608**	-.499**
	Sig. (2-tailed)	.000	.417	.000	.000
	N	121	121	121	121
Transportation limitations.	Correlation Coefficient	-.467**	.128	-.256**	.376**
	Sig. (2-tailed)	.000	.162	.005	.000
	N	121	121	121	121
The owner's negative perception of offsite construction techniques places limitations on their use.	Correlation Coefficient	-.065	.120	.072	.056
	Sig. (2-tailed)	.478	.193	.436	.545
	N	120	120	120	120
Offsite construction techniques limit the ability to make changes to onsite	Correlation Coefficient	.027	.080	-.034	.076

work.	Sig. (2-tailed)	.770	.386	.714	.409
	N	120	120	120	120
Offsite construction techniques increase the complexity of maintenance.	Correlation Coefficient	-.200*	-.052	-.217*	.128
	Sig. (2-tailed)	.031	.582	.019	.172
	N	116	116	116	116
Offsite construction requires a reduction in construction waste.	Correlation Coefficient	-.125	-.039	-.108	.028
	Sig. (2-tailed)	.183	.681	.249	.768
	N	116	116	116	116
Offsite construction increases the market value of property.	Correlation Coefficient	-.194*	.119	-.020	.174
	Sig. (2-tailed)	.037	.202	.833	.062
	N	116	116	116	116
Offsite construction lacks available codes and standards.	Correlation Coefficient	-.013	.069	-.029	-.023
	Sig. (2-tailed)	.887	.462	.758	.811
	N	115	115	115	115
Use of offsite construction requires a higher level of use of IT in a construction industry.	Correlation Coefficient	-.142	.008	.010	.027
	Sig. (2-tailed)	.126	.934	.918	.768
	N	118	118	118	118

**. Correlation is significant at the level of 0.01 (2-tailed).
*. Correlation is significant at the level of 0.05 (2-tailed).

**Q7O= offsite preassembly; Q7H=hybrid System; Q7P= panelised System; Q7M=modular building*

4.6.4 Summary of Inferential Statistics

The main aim of this thesis is to examine the development of a strategy for the implementation of offsite construction in Saudi Arabia. In order to achieve this outcome, it was vital to first study the current use of offsite construction in the country, while studying its advantages, disadvantages, and participants' satisfaction with the techniques, along with and possible barriers hindering the use of offsite construction and its techniques. This research focuses on 4 offsite construction techniques (i.e. offsite preassembly; hybrid system; panelised system; and modular building) as independent variables, along with 19 factors related to offsite construction (i.e. dependent factors) identified as a result of the extensive literature review. The previous chapter summarised and described the main characteristics of offsite construction, while examining the effect of offsite construction techniques on the 19 factors. Furthermore, such factors were correlated with the satisfaction of participants in relation to the offsite construction techniques. This led to the predetermined hypotheses being answered, leading to the acceptance of some and the rejection of others. In this chapter, the researcher will provide a brief description of the research outcomes, while focusing on the main significant results with the potential to assist in designing the implementation strategy of offsite construction in Saudi Arabia during the subsequent stage of this research.

The study relied on semi-structured interviews with 6 expert participants in order to analyse the main variables associated with offsite construction in Saudi Arabia. The analysis of the interviews has established the use of 4 offsite construction techniques (as noted in the paragraph above). Furthermore, it has been established that the majority reflected a positive experience and satisfaction with all 4 techniques, stating that this type of construction is primarily relevant for government buildings. It was highlighted that offsite construction requires an increased number of skilled workers in comparison to traditional methods, and, while it leads to improved quality, it was demonstrated to: (1) shorten the project schedule; (2) enhance safety and performance; (3) decrease onsite disruptions; (4) increase productivity. It was demonstrated that the primary barrier concerns the complexity offsite projects. The need for support from planning and code departments was highlighted. Further barriers include the inflexibility of offsite construction, (although it was also established that there is reduction in errors in this type of construction). A final barrier is the lack of transportation that hinders the completion of such projects. The adoption of offsite construction requires sufficient budget, time, design and flexibility. It was noted that such resources are required to be in place in order to fully adopt offsite construction.

The study was conducted amongst 136 participants from different backgrounds. It was established that all 4 offsite construction techniques were employed, although the most frequently used technique was found to be offsite preassembly, closely followed by the remainder of the techniques. It was also evident that participants agree that the barriers and advantages were highlighted in the results chapter, alongside the advantages of offsite construction. The primary advantages were established as the productivity of labour and the quality of the resulting product.

The use of **offsite preassembly** was found to have a significant beneficial effect in favour of users in relation to the main factors of offsite construction (19). Those using the technique agreed that offsite construction: (1) reduces the need for skilled craft workers onsite; (2) increases overall onsite labour productivity; (3) increases the initial cost; (4) limits the ability to make changes to work onsite; (5) increases the market value of the property; (6) lacks available codes and standards. Further examination revealed that those who did not use offsite preassembly were more strongly of the opinion that the Saudi market is not yet ready for offsite construction, and that there is poor perception and an image of low quality in relation to prefabricated buildings.

It was established that participants using the **hybrid system** agree that offsite-construction: reduces the overall project schedule; reduces the need for skilled craft workers onsite; increases overall onsite labour productivity; increases sustainability; increases the initial cost; limits the ability to make changes to work onsite; increases the market value of the property; lacks available codes and standards. Those who do not use the hybrid system agree that offsite construction: increases the schedule of a project; reduces the environmental impact of construction operations, and agree that it is not suitable for use in Saudi Arabia.

Thirdly, participants employing the **panelised system** agree that offsite construction: reduces the need for skilled craft workers onsite; increases the quality of the project product; increases overall onsite labour productivity; increases safety performance; increases sustainability; increases initial costs; limits the ability to make changes to work onsite; increases the market value of the property; lacks available codes and standards. Participants who do not use the panelised system had a greater tendency to agree that offsite construction reduces the environmental impact of construction operations, and that the Saudi market is not yet ready for offsite construction.

Participants employing **modular building** technique believe that offsite construction: increases overall onsite labour productivity; increases safety performance; increases sustainability; increases initial costs; limits the ability to make changes to work onsite; lacks available codes and standards. However, participants who do not employ modular building believe that offsite construction: reduces the overall project schedule; increases safety performance; believe there is a poor perception and low quality image in relation to prefabricated buildings.

Following the assessment of the effect of offsite construction techniques, it was also essential to examine the ways in which satisfaction with these techniques correlate in an individual manner with participants' rating of factors related to offsite construction in Saudi Arabia. The satisfaction with **offsite preassembly** was found to be positively correlated with: increases overall onsite labour productivity; increases design efficiency; decreases overall project cost; increases initial costs. This implies that an increase in the satisfaction level in relation to the use of offsite preassembly leads to higher agreement concerning the correlated factors. On the other hand, the use of this technique was negatively correlated with: a reduction in the project schedule; transportation limitations; an increase in the complexity of maintenance; increase in the market value of the property. This clearly demonstrates that higher satisfaction with offsite preassembly leads to a reduction in agreement in relation to these factors.

Satisfaction with the **hybrid system** technique was found to have no positive correlation with any of the factors. However, it was found to negatively correlate with factors explaining that offsite construction: (1) reduces the overall project schedule; (2) increases project product quality; (3) increases the initial cost; (4) increases the overall productivity of onsite labour. The correlation here justifies an increase in the satisfaction leading to a decrease in the agreement regarding these factors.

The satisfaction with the **panelised systems** was found to have a positive correlation with: (1) increases project product quality; (2) increases safety performance; (3) reduces onsite disruption of other adjacent operations; (4) increases sustainability; (5) decreases the overall project cost; (6) increases design efficiency. Thus higher satisfaction with the panelised systems results in increased agreement with the correlated factors. Negative correlation was found with: (1) transportation limitations; (2) increase the complexity for maintenance. Thus, the higher the satisfaction, the lower the agreement with these factors.

Finally, the satisfaction with the **modular building** demonstrated a positive correlation with the transportation limitations in offsite construction, implying that the higher the satisfaction, the increased level of agreement that transportation is indeed a limitation. On the other hand, modular building was negatively correlated with: (1) the increase of overall productivity; (2) increase in project product quality; (3) increase in overall onsite labour productivity; (4) decrease in the overall project cost; (5) increased sustainability increases design efficiency; (6) increased initial costs; (7) increased safety performance. This correlation implies that the higher the satisfaction with the modular building, the less agreement in relation to these factors.

The table below demonstrates a summary of the effects of OCT use on impacts (items) and the relationship between impacts (items) and satisfaction with OCT. 'X' indicates a significant effect, while +/- refers to significant positive and negative correlations.

Table 4-12: a summary of the effects of OCT use on impacts

Effect				Impacts	Satisfaction			
Preassembly	Hybrid	Panelised	Modular		Preassembly	Hybrid	Panelised	Modular
	X			The use of offsite construction techniques reduces the overall project schedule.	-	-		
X	X	X		The use of offsite construction techniques reduces the need for skilled craft workers onsite.				
		X		The use of offsite construction techniques increases the quality of the project product.		-	+	-
X	X	X	X	The use of offsite construction techniques increases overall onsite labour productivity.	+	-		-
				The use of offsite construction techniques limits design options.				
		X	X	The use of offsite construction techniques increases safety performance.			+	-
				The use of offsite construction techniques reduces onsite disruption of adjacent operations.			+	
	X	X	X	The use of offsite construction techniques increases sustainability.			+	-
				The use of offsite construction techniques increases design efficiency.	+		+	-
X	X	X	X	The use of offsite construction techniques increases initial costs.	+	-		-

				The use of offsite construction techniques decreases the overall project cost.	+		+	-
				Transportation limitations (i.e. size constraints; transportation cost; impact on building structures) limit the use of offsite construction techniques.	-		-	+
				The owner's negative perception of offsite construction techniques limits the use of such techniques.				
X	X	X	X	The use of offsite construction techniques limits the ability to make changes to the work onsite.				
				Increases the complexity of maintenance.	-		-	
				The use of offsite construction reduces construction waste.				
X	X	X		Increases the market value of the property.	-			
				The use of offsite construction requires a higher level of use of IT.				
X	X	X	X	Lack of available codes and standards.				

4.7 OCT Anticipation and Benefits/Barriers of OCT

The questionnaire included 2 open–ended questions (Q.27 & Q.28). Question 27 asked participants if they anticipated an increased use of offsite construction techniques in the future: 86% stated that they did and 14% stated that they did not. Those who answered in the positive had 5 reasons in common: (1) the most frequent was that OCT reduces construction time; (2) this was followed by the lower cost of OCT compared to conventional techniques; (3) the quality of OCT; (4) the reduction of the construction schedule; (5) the use of OCT reducing the need for skilled workers on the construction site. Participants who stated that the use of OCT would not increase in the near future noted that this was due to: (1) the high initial cost of OCT; (2) issues concerning implementation; (3) inflexibility concerning the design; (4) a negative perception of OCT.

4.8 Interview Analysis

The researcher arranged to meet interviewees in quiet and familiar locations conducive to reflective thought. All interviewees possessed previous knowledge of OCT. Following a brief introduction concerning the research background and its primary goals, the researcher commenced the interviews, which were also audio-recorded. All interviews were then transcribed and analysed based on (Content Analysis). The researcher then read all interviews a number of times, analysing the scripts by extracting a number of themes that arose from the commonly-held ideas and opinions of the interviewees. The themes were generated by creating codes based on the answers, enabling an examination and combination of results to form a theme relevant to the questions asked. There were a total of 6 participants holding various positions and with varying levels of experience. A list of the participants is provided (initials are used to ensure confidentiality).

4.8.1 Profile of Interviewees

The following table outlines information concerning the company and the interviewees who took part in the 6 case studies, in which semi-structured face-to-face interviews were undertaken with various levels of management.

Table 4-13: Profile of Interviewees

Company	Job	Background Information
H University	Professor	Professor of Construction Management and Process Management. His current areas of research are Lean Production and Offsite construction.
A	Engineer	Engineering and environmental consultancy, providing support services. Core expertise in: project management; construction contracts; cost management; engineering; architecture; risk management.
AI	Project Manager	Offers a range of development management, project management and construction services. Is in possession of the systems and processes to provide solutions according to the client's specific requirements.
M	Assistant Manager	Specialises in delivering ambitious and innovative construction projects, delivering to both clients and the communities who use them on a daily basis.
J	Project Manager	Consultant in engineering design. Principle disciplines include: civil; structural; geo-technical; and geo-environmental engineering. Also complementary services, such as: development planning; traffic and highways engineering; conservation; project management.
MH	Project Manager	Interdisciplinary practice of architects, designers, and engineers. Combines expertise across disciplines, locations, sectors and all major building types.

After extensive reading of the interview scripts, the researcher analysed the details of the responses, relating them to current applications and understanding of OCT. The analysis is broken into 4 sections, as follows: (1) current application of OCT; (2) benefits of OCT; (3) barriers to OCT; (4) opportunities provided by OCT (accompanied by recommendations).

4.9 Current Application of Offsite construction Techniques (OCT)

This section concerns the general knowledge and use of OCT among participants. The following points reflect the main answers provided by participants in relation to OCT.

Utilising OCT

Based on the interviews with the participants, it was evident that 5 possess a **reasonable** level of experience of using OCT during previous projects. However one (H) had observed its application in projects for which he had no direct responsibility. Participants were asked to specify the kinds of buildings and the categories (or offsite construction methods) in which they had gained experience. It was clear that participants had worked on a variety of construction projects, the vast majority of which were **publicly funded building projects** (e.g. multiple story buildings, bridges and tunnels and one university), using volumetric **pre-assembled units** (i.e. factory finished units that enclose usable space within a completed structure, but do not form part of the building's structure, including kitchens and bathrooms). One participant did not provide any construction category.

Level of OCT Use

The participants stated the percentage of OCT in use by the construction firms with which they had been involved. All participants (apart from H) stated that they had experienced a high level of OCT in their work, or in the companies for which they work. All participants work for the same company, hence reported a similar percentage of use: A, AI, M, J, MH stated that OCT is used in over 70% of the company's construction projects, e.g. Participant Pm stated that: "most of the projects that I work in involve OCT. I would say that this is the case for 75% of the projects I am involved in."

Techniques used

Furthermore, participants were asked to specify the type of OCT techniques used in their work. They all stated an awareness of the use 4 main offsite construction techniques in Saudi Arabia, these being: (1) hybrid system; (2) panelised systems; (3) modular building; (4) offsite pre-assembly. However, they all stated that offsite assembly forms the most frequently used technique. Participant A stated:

> *through my work as an engineer, I am aware that, as a company, we use all types of OCT, whether it is panelised systems, hybrid system, modular building or offsite pre-assembly. But, I also know that we mainly use offsite pre-assembly as the main OCT, as it is not as complex as the others.*

Experience of OCT:

2 participants (A, MH) described their experience as positive (i.e. very good and good, respectively). Other participants provided mixed experience, for example one participant (H) explained: "I think OCT is a necessity in some big projects, however it is difficult to justify its use in small residential buildings". A further 2 participants (M, J) explained that working offsite kept them in more **comfortable conditions**, away from the heat of the sun. Participant J commented on the more organised, and less chaotic **conditions** within the factory. When prompted, they agreed that OCT is more suited to buildings in **urban locations**, due to the fact that (despite the difficulties in transporting loads) it cuts down on onsite building time and avoids the need to close down local areas difficult to access and a high density of population.

Customer Satisfaction

5 participants stated that the use of OCT as the principal means of construction has generally resulted in customer satisfaction. However, H noted that satisfaction is not

always achieved. Participants M, J reflected that:

> *the disadvantages of the OCT are more likely to arise at the beginning of the project which can have an initial negative effect on satisfaction. However, many of the customers who show initial scepticism at the start of the project are later reassured and satisfaction is generally achieved.*

Participant J stated:

> *I always had the idea that OCT is not suited for Saudi Arabia, until I got involved, now I am satisfied with it but sometimes it is hard to transfer satisfaction to customers and others.*

Building Sectors and OCT

Participants were asked to state which particular projects they considered most suited to the application of OCT. Of the 4 responses received to this question, 3 (H, A, AI) were of the opinion that OCT is most suited to government projects (e.g. schools; hospitals; universities; bridges; projects on a considerable scale). One participant (J) concluded that, in general, OCT is suitable for all Saudi construction projects, due to fact that the extreme onsite temperatures could "ruin the concrete", and render onsite working conditions uncomfortable, particularly during the summer months.

4.10 Benefits of Utilising OCT

The second section relates the main benefits of using OCT, as described by the participants. The main benefits and the views of participants are listed below.

Quality and Speed

Participants noted the reasons for using OCT in their projects. The most commonly reported being that OCT improves both the quality and speed of production (H, M, J, MH). Participant MH stated that:

> *using OCT guarantees quality and speed in production, and that what appeals to us as a company and to the customers, the quality is always high, especially if we are replicating material and not producing new designs. What takes a year in traditional construction can be built in half of the period, if not less.*

Reduction of Wastage

A further reason for the use of OCT concerns the reduction in wastage. Participants H, A, AI stated that (unlike traditional construction) fewer materials are used in an environment capable of being controlled, thus leading to a reduction in waste. Participant A also noted that reducing wastage increases profits and ensures delivery of less costly products.

Requires Fewer Workers

One of the clear advantages stated by participants H, AI, J, MH concerns the fact that OCT involves fewer workers in comparison to traditional construction methods, and that, furthermore, fewer skilled workers are needed, and can thus be easily trained. Participant H commented that the construction company decides when it is used, but, when prompted, added that the lack of skilled labour in traditional construction formed a positive reason for its use. He stated that:

> *traditional construction needs many workers with high level of skills, however OCT involves less workers, although skilful. I can say that OCT needs fewer workers and that gives it an advantage.*

Increased Productivity

Increased productivity was cited by 4 participants (H, AI, J). They were of the opinion that OCT increases the productivity of a company, enabling it to undertake a large number of projects in short space of time, resulting in improved profits and project completion rates. Participant J stated that:

> *using OCT we are, as a company, more productive, I used to work in a construction company before that never used OCT and I know from my experience that OCT allows more productivity.*

Shorter Schedules and Reduction of Costs

All participants agreed that OCT is both time and cost efficient. It was noted that construction time is generally shorter than that of traditional construction, and hence not so costly. Furthermore, the cost to the consumer is significantly less, and is generally delivered and built within a pre-specified timeframe. Participant AM stated that: “OCT is unique; it helps everyone, the company, the consumer in terms of costs and timing”. However, participants MH and AI stressed that, although OCT forms a cheaper option than traditional construction, it involves high costs at the beginning of the project, becoming cheaper by the end, particularly when it comes to large construction projects.

Parallel work: Manufacturing and Site Construction

Participants AI and MH stated that, unlike traditional construction, where the site is the only location that can be used, OCT gives the company the facility to work simultaneously onsite and offsite for both manufacture and construction. Participant A stated:

> *Sometimes as an engineer I can be onsite and I would be calling my colleague to manufacture more construction parts that I will use during the next day. That can only be done when using OCT.*

Replications/Repetition

Participants H, A, M stated that an advantage of OCT is that it is replicable or repeatable, i.e. the same construction can be undertaken multiple times in multiple places, according to demand. Hence, it is easier for the company to produce identical designs and constructions to ones previously produced. H stated that this further stresses the efficiency and delivery of OCT. Participant M noted that*:*

> *OCT allows us to replicate our work, and that makes it easier. The second time is usually easier and allows for better efficiency than the first time and then it becomes even easier.*

Safety and Performance

All participants indicted that OCT is safer than traditional construction, both onsite and during construction. Participant H stated that the:

> *safety of OCT should not go unnoticed when talking about Saudi Arabia, and that there is a big difference between working long shifts onsite (traditional construction) where the safety measures are often poor as compared to offsite, where the conditions are better. The less time spent onsite, the better safety for workers*.

In terms of project *safety and performance*, 4 participants (AI, M, MH) believed that OCT improves both performance and safety. Participant MH noted that there is no direct causal relationship, and that the *safety and performance* outcomes depend on a consistent implementation of policy, including which safety issues are prioritised and implemented on a consistent basis.

OCT and Quality

4 participants (H, A, AI, M) agreed that that the use of OCT could increase the quality of

a project and also ensure that project outcomes are more predictable. One participant (M) added that "in the factory, a core of highly skilled labour can be trained and retained to achieve quality, whereas onsite, skilled labour is dispersed and cannot be guaranteed".

Other benefits

Finally, participants were asked if they had experienced further benefits through the use of OCT. Participant H noted: "I think other benefits include increased quality assurance, modularity and relative ease in producing complicated designs", 2 further participants (A, J) also noted that OCT is a contributory factor in reducing construction time. Participant J added that it further reduces noise, and less waste is produced onsite.

4.11 Barriers to Utilising OCT

The third section addresses the main barriers facing OCT and the participants who use it. The researcher investigated and analysed the points outlined below.

Increased complexity

4 participants (H, AI, M, J) considered the main barriers to using OCT to be: project complexity, choice and implementation of planning systems. One participant (A) believed that these difficulties could generally be overcome, reflecting that these were "not so important when complicated issues were learnt through repetition". The complexity is understood to arise at the start of a new design, or when using OCT in a project for the first time. However, all were in agreement that such complexity disappears with increased use of OCT in different projects.

Resistance to the Use of OCT

The participants do not appear to have experienced resistance from union organisations or other local construction organisations within their company in relation to their work. However, 2 participants (M, J) stated that companies demanding construction can resist OCT. M also stated that: “I work for a big company that uses OCT in many projects, so there is no resistance there, but other, smaller, companies might resist its use.”

Local Zoning Ordinance Restrictions of OCT

Participant J believed that some local planning and building departments could offer more support for OCT and that uniformly high standards would be difficult to achieve without this support. Other participants explained that obtaining planning permission can be difficult at times (H, J), due to the lack of acceptance (or awareness of) OCT by those in local zoning ordinance, and which might pose additional difficulties for smaller companies.

The Restrictions of Financial institutions in Relation to OCT

Despite the fact that all participants stated that their companies (A, MI, M, J, MH) are well equipped to deal with the financial demands of OCT, participants H and A stated that (due to a lack of awareness and acceptance) banks and financial institutions can work as a barrier against OCT, rejecting loans to customers and to companies. Participant A stated that: “although OCT is generally used in government projects, this might not be a big problem, but for the ordinary private companies and individuals this could be a main obstacle”. He referred to the initial cost of OCT as an obstacle, as the bank views it as an expensive option.

The Resistance of Companies due to Cost

The initial cost of OCT (MH, AI, A) is generally high, thus leading to potential resistance from companies and customers. They view it as an expensive option compared to the construction methods to which they are accustomed. Companies appear to avoid taking risks working with OCT. The participants acknowledged that such risk is needed and that high costs are only incurred at the commencement of the project. Participant MH stated that:

> *OCT is perceived to be costly to the companies and the customers, however that could be true at the beginning of projects, but not when completed and when considering the time saved. Also, when constructions are replicated it becomes even cheaper for the manufacturing companies.*

Lack of Awareness of OCT

All participants stated that OCT is relatively new in Saudi Arabia, leading to a lack of awareness among individuals, companies, and banks. Participants A and M stated that many construction companies are not aware of OCT and its benefits. Participant H highlighted the fact that a number of companies use OCT without realising it. Furthermore, participant A stated that: “financial institutions and policy makers should be more aware of OCT in order to make full use of it”.

Inflexibility of Design

3 participants (H, AI, M) viewed a lack of flexibility in design as a challenge. Participant AI stated that: “this is one of the problems in residential buildings, where walls are prefabricated with reinforced concrete, which restricts any changes in plans”. Furthermore, (H) stated that, despite the efficiency of OCT, it offers less flexibility,

leading to some designs being unable to be changed and thus often repeated, leading to companies repeatedly producing identical items. He explained that, when it comes to flexibility in designs, OCT is less effective than traditional construction methods.

Offsite Construction Errors

Participant A stated that OCT is inclined to incur more construction errors compared to conventional techniques at the start, but that some manufacturing errors can lead to long delays: "I have experienced errors in OCT leading to long delays, but once we got it right there were fewer consecutive errors". On the other hand, 3 participants (H, AI, M) stated that OCTs suffer fewer construction errors in comparison to conventional techniques, agreeing that quality is not one of the primary challenges facing OCT. One participant (J) had no experience of failure caused by manufacturing delays or poor quality.

Risk

Participants H, M and J stressed an unwillingness to take risks as a major barrier for OCT. They stated that many companies are unwilling to take risks and start operating and offering OCT. For example, J stated:

> *I don't think companies here in Saudi are willing to take risks. They generally try to stick to their traditional methods, and I see that taking a risk and trying OCT will eventually help its success in Saudi. Many are scared of failure, as they do not have enough experience.*

Further Specific Barriers

Finally, participants were given the opportunity to include further specific barriers they might have experienced in the past. 3 participants (A, J, MH) stated that the main barrier concerns the cost of OCT (particularly for private individuals). 2 participants (H, AI) believed that a major barrier concerns the lack of public knowledge and awareness. They both also stated that this area did not receive great deal of research, and that there are insufficient factories to produce prefabricated units. Participant A stated that the supply chain is inadequate. Participant M raised the issue of transportation, noting an issue in constructing large projects onsite. Participant J noted, "OCT is not well marketed and the government has not adopted it to the full". Participant MH added that there is a particular issue with unrepeated designs and the inability to make changes onsite during construction.

4.11 Opportunities Provided by OCT

In the final section, participants provided their opinions concerning the opportunities provided by OCT.

Use of OCT along with Design Flexibility

3 participants (H, A, AI) agreed that they wish to see increased use of OCT in conjunction with increased design flexibility. However, 2 participants (M, MH) disagreed, both stating that there is a need for the design to be consistent.

4.12 Main Factors for the Use of OCT

When asked to list the main factors that they believed to contribute to the use of OCT, 2 participants (H, AI) stated budget, time, design flexibility, and client response. Participant A agreed with the factors of budget and time. It was clear that the budget (i.e. cost) is one of the main factors, due to the time spent in construction. Participant A stated that: "time is money, the less time we spend onsite the better for us and the less budget involved from the company."

Competitor Adoption

Participants were asked whether they would use OCT if they knew it was being used by a competitor. All participants stated that they would definitely adopt OCT. Participant AI stated: "we live in a market where you have to compete on all fronts, so we have to show flexibility in our services to attract more projects". However, participant J stated:

> *although I would use OCT, I have to decide based on the demands. I know that OCT suits big projects, but if my company deals with smaller projects (such as houses), then I would have to avoid it, as many people still lack awareness of OCT.*

Adoption Based on Resources

Participants were asked if they might adopt OCT more widely if the resources were available within their areas of operation. All participants agreed that they would adopt OCT if the resources were available. Participant H stated that:

> *when talking about resources, I mean planning permission, regulations, finance. If they are all available, then I don't see any reason not to adopt OCT.*

Future Popularity of OCT

5 participants (H, A, AI, M, MH) believed that the use of OCT would grow during the following decade. Participant AI stated:

> *it will increase because more big projects are going to be built. Industry will be more developed and construction time will required to be as short as possible*.

Participants M and MH stated that it will increase, but that this will require both time and skill.

4.13 Recommendations

Educating all Parties

A number of recommendations have been suggested by the participants. One refers to a need to educate all the parties involved in offsite construction to **improve levels of knowledge**. They felt that this would encourage contracting companies to adopt OCT (H, A). Respondent H recommended **government support** as a catalyst to 'kick-start' the application of OCT.

Raising awareness

5 respondents (A, H, AI, M, J) suggested a marketing/advertising approach to **raising awareness of OCT**. Participant J stated: "marketing is weak. If we improve it, greater awareness could increase demand for OCT". Participant M stated that:

> *awareness needs to be raised among all companies, workers, students or even customers. Only then we can successfully implement and use OCT in small and big projects to the level of other countries, such as Japan.*

OCT and Skilled labour

When questioned if it was possible to resolve the issue of a lack of skilled labour in relation to OCT, 2 participants (A, AI) stated 'no'. Participant A stated that he acknowledged that over-reliance on imported skilled labour and larger pools of an unskilled workforce could interrupt the necessary transfer of skills to Saudi nationals, a measure that will be necessary for the development of OCT in Saudi Arabia. 2 participants (H and M) believed that concentrating skilled labour in factory locations could, to some extent, resolve the issue of shortages. However, both admitted the need for training, particularly at the beginning, when many workers must come to terms with unfamiliar techniques, along with their application under a stricter cultural regime in relation to meeting deadlines and achieving pinpoint accuracy in measurements. One of the distinctive features of the Saudi construction industry concerns its dependence on low skilled foreign workers. A number of contractors employ workers with little (or no) experience in modern methods of construction. Despite their existing construction skills, it could take some time to reach the stage where they could effortlessly apply and implement the knowledge gained through experience gained during earlier stages of the process.

Taking an in Depth Conclusive Perspective

Participant H (as an academic) suggested that a deeper understanding of the constraints impacting on OCT requires a perspective embracing a wider perspective, including the mix of factors preventing its implementation. Participant H states that alleviating these factors individually is both problematic and inefficient, as they are all interrelated within the wider organisational culture. Organisational-level initiatives must simultaneously confront and deal with interrelated systemic constraints. Viewing them in isolation does not provide organisations and project teams with the context to formulate effective strategies. The core challenges facing the industry are knowledge-related. When it comes to individual restraints (be they themes related to the supply-chain, quality, and cost or customer satisfaction) the common factor is collaborative knowledge. Collaborative knowledge covers the complete process from beginning to end, due to the fact that each of the constraints related to these themes is affected by knowledge.

Chapter 5: The Conceptualisation of the OCT Strategy

5.1 Introduction

This study examines OCT in the context of Saudi Arabia, with the aim of investigating its impact and benefits, the reasons for choosing it, and the challenges facing its adoption and implementation in Saudi Arabia. The results from the analysis of the questionnaires and semi-structured interviews indicated a similar pattern. Overall, the use of OCT appeared common among the participants, and most of them have experience of using it. When analysing the impact of adopting or using OCT, the findings suggested that people consider that it leads to good labour productivity and that workers are more productive when using OCT, achieving their targets off-site in a comfortable environment. Furthermore it was also explained that OCT improves the quality and sustainability of construction compared to traditional building methods, and that this quality is also accompanied by decreased production time (schedule) for OCT projects. However, OCT faces a challenge: it lacks the ability to make changes toon-site work (inflexibility), although it also requires less skilled workers. Such factors were also mentioned in the semi-structured interviews along with the risks associated with OCT.

On the other hand, and as another research objective, the participants were asked to indicate the reasons for choosing OCT over traditional methods. In doing so, and in line with the previously provided factors related to the impact of OCT, the participants referred to the fact that OCT reduces the construction duration (time) and schedule, and alsothe cost of the project. Such factors were also accompanied by aspects like product quality and labour productivity. The results from the interviews also indicated a similar pattern of results.

When discussing the challenges facing OCT in Saudi Arabia, the participants indicated that the major challenges reside in OCT's inability to allow changes to be made on-site (inflexibility), and also the fact that it offers limited design options while it requires special computer software to operate it. The high cost of OCT designs are also stated as a challenge. The interviews reveal that other factors, such as a lack of awareness and education, are major obstacles to the use of OCT, along with resistance among certain companies, local authorities and planning departments. Several cultural aspects were also reported as a factor hindering the adoption of OCT in Saudi Arabia.

Keeping the above findings in mind, the following discussion will incorporate the outcomes of this study and examine what might be called a 'success story' for OCT; the building of temporary artistic urban structures which challenge the perception that OCT produces low quality, unsuitable public buildings. It then isolates and discusses systemic features common to the sustained, successful application of OCT. Examples include: an application of the collaborative process, a willingness to implement knowledge gained through experience and the capacity to overcome policy resistance. The chapter then considers the impact of cost, schedule and scope and their relationship with labour, quality and risk. Finally, it examines several systemic fault lines associated with traditional construction and OCT in Saudi Arabia, such as the Saudi government's central role in procuring construction, before conceptualising a strategy for OCT's successful implementation.

5.1.1 The Significance of OCT

It was evident from this study that the quality of OCT is a major benefit, and over half of the participants indicated that they had used at least one level of OCT or another, but it was also judged that OCT remains in its infancy in Saudi Arabia and that the demand comes mainly from big governmental projects (49%) and large residential ones (50%). Although it may appear self-evident, Smith's (2011) observation that buildings that rely upon OCT are only as good as the demands placed upon them is worth repeating. OCT must be employed intentionally and with a high degree of planning. One such example is re-locatable modular or temporary modular OCT. Warren describes OCT in an urban aesthetic context as "the delivery of temporary artistic urban structures incorporating an original architectural design solution delivering the set objectives of portability, adaptability and sustainability" (Warren, 2010, p.57). Well-known examples of successful, intentional and meticulously-planned projects are the pre-fabricated London Eye (perfectly situated to surmount the problems of transportation as its components were delivered to the site by sea and river) and the pre-fabricated viewing tower planned for Brighton, known as the i360. The London Eye provides a good example of how OCT can be used as a solution to a specific construction problem, and also illustrates the viability of using OCT as a method for manufacturing and erecting practical, safe, affordable semi-permanent artistic structures in a specifically urban environment.

Warren's design is appealing because it helps to rescue OCT from an association with shoddiness or disrepair, links it to innovation and aesthetic values, and successfully matches quality and design to purpose. Warren claims a "wider significance" for temporary artistic urban structures because they demonstrate that the traditional "prejudice towards pre-fabricated systems as cheap, short-term and unsuitable public buildings, is unjust" (Warren, 2010). This might explain why culture in Saudi Arabia was considered (by the interviewees) as a barrier to the adoption and use of OCT. In Warren's example, we have a niche application – in this case a pre-fabricated, "multi-use public pavilion", which he convincingly argues is not only "practical, safe and affordable", but that can also "inhabit and therefore enhance" a variety of urban locations, and meet a wide range of uses, as well as being "resource-autonomous and environmentally friendly" (Warren, 2010). Admittedly, because his study involves an examination of aesthetic structures with a limited lifespan, it does not apply to more utilitarian applications and may be dismissed by some on that account. Such constructions are viable partly because they are free from the complicating factors associated with more conventional projects, such as the price and availability of land, planning considerations, and (in the case of house building) the availability of mortgages and affordable deposits but, just as the approach to OCT, in a sense, relies upon 'thinking outside the box', our approach to the use of urban architecture should also not be limited by convention. Warren's approach constitutes an exception to the industry-wide attitude which considers "innovation as a poor competitive instrument for direct profits"(Pan and Sidwell, 201,1 p.1082).

Warren's "portable, fully adaptable and sustainable public events venue" is surely a new way of enhancing a city's architectural and aesthetic appeal, altering through its "temporary" presence the "urban profile of the city", while simultaneously insinuating itself into the "miscellaneous context of modern-day London" (Warren 2010).

5.2 Challenges and getting the most out of the benefits of OCT

OCT exploits the use of factory locations to design and manufacture modules incorporating pre-fabrication and pre-assembly, and to install and complete the finished building at the site. At first glance, the adoption of the construction industry's version of mechanised assembly line processes, successfully exploited by the aerospace and motor industries, appears to have a wide application. However, despite its well-documented benefits, the adoption of OCT in countries such as the UK, the US, Hong Kong and Saudi Arabia remains low. Despite the inflated claims made by certain researchers in relation to the realizable cost and time savings (as reported in this study), and their confidence in its potential, why, at a time of technological advancement, is the use of this technique not more widespread? How can we explain this failure to capitalise on the benefits of technology and automation? The literature takes a variety of perspectives into account when responding to this question. Negative attitudes, the need for high levels of initial investment and the lack of a skilled workforce are some of the explanations that have been proposed. Aburas (2011) offers two technical reasons and one attitudinal reason to explain why OCT has not been employed commonly or efficiently in Saudi Arabia's construction industry:

- technical limitations specifically to do with modular and volumetric construction;
- the material used in construction in Saudi Arabia being primarily brick and concrete;

- Negative perceptions about OCT.

As in the current study, it was evident from Aburas' study that OCT suffers from several technical limitations, such as inflexibility (the difficulty in making on-site changes). It was also mentioned that there is a negative perception (59%) among owners; on the other hand, there appears to be a good level of satisfaction among the participants when using OCT. In theory, any or all of these reasons might have been offered as barriers to OCT in the context of many countries. This study attempts to adopt a more contextual approach, looking beyond aspects related to access to technology and placing greater emphasis on less easily-observed attitudinal barriers. Too often, OCT is referred to as mere technology, as if its simple application would make OCT viable.

However, a more thorough reading of the literature reveals that this set of conditions is one of several layers of influence. A deeper systemic account references certain key terms; experience, integration, 'lead users' and collaboration are several of the terms used throughout the literature. We must examine how OCT requires an application of the collaborative process; technology on its own is not enough, as it will not, by itself, design or build pre-fabricated units. As one of the interviewees (a university professor) pointed out, the success of OCT is best achieved when combining all factors, as they are inter-related. Smith (2010, p.336) refers to technology as the capability that is "embodied knowledge in an artefact, method or process". He describes technology transfer as the "exchange of capability from one party to another to the mutual benefit of both" (ibid). This transfer of capability takes place between governments, universities and industry. A particularly relevant point in the context of this research is that OCT demands the fast appropriation of technology by industries for which it was not originally intended (ibid).

Pan et al. (2007), referring to the social housing sector, also prioritise the role of shared knowledge in the success of innovative modern manufactured housing schemes. The contribution of architects, developers, contractors and sub-contractors to the development and decision making process must be collaborative and open if it is to have a significant impact. Williams and Gibson (1990) describe four different means of technology transfer; some will be more amenable or adaptable to Saudi modes of operation than others. Firstly, there is Appropriation, which refers to quality, research and development; it assumes that, when an idea has been tested or proven and is of acceptable quality, it will sell itself. Thus, one would assume that, the better the quality of OCT in Saudi, the more likely it is that it will be accepted. Secondly, Dissemination refers to the flow of knowledge once linkages have been secured. A knowledge of OCT was identified as an obstacle in this study and therefore knowledge should be improved (as the interviews show). Thirdly, Utilisation emphasises an important and demanding linkage in the case of Saudi construction, that of an "interpersonal community between technology researchers", by identifying the facilitators and barriers existing within the transfer process. Finally, Communication, again a potentially challenging process for Saudi construction (the participants reflected on the benefits of positive communication), sees the transfer process as interactive, a "continuous exchange of ideas", requiring an open collaborative model of working but it should be noted that Abdul-Hadi et al (2005) refer to the poor level of communication within the Saudi construction industry.

Technology is transferred not only from the aerospace and motor industries to architectural practice but also from business and other collaborative models. This should not be seen as a transfer of theories or tools, but rather understood as a sharing of process model to achieve effective integration (Smith, 2010, p.336). For architects to participate in technological development – including predicting, forecasting and projecting both materials and digital technologies into the construction market – they must also be competent and open to sharing knowledge that is mutually beneficial. Engineers must also have both component knowledge of the core design concepts, in addition to architectural knowledge about how these components are linked. The view that information technology plays a pivotal role in OCT was supported by only 44% of the respondents, while 26% disagreed and 30% were undecided.

So, all of the principal stakeholders (engineers, project managers and architects) must possess component knowledge. No single field of expertise can have sufficient knowledge to the extent that each player is unable further to improve or extend their contribution to the team. An educated workforce is full of people who know more about their job than their supervisor.

How they integrate into the collaborative construction process is what counts. Off-site construction must integrate all of the disciplines and specialty groups into a team effort, thereby forming a structured development process that proceeds from concept to production to operation. It must consider both the business and technical needs of its customers with the goal of providing a quality product that meets user needs. The interaction between the independent parts has become critical for organisations (Sterman, 2002). The final key player in the process of innovation is the subcontractor, who fabricates, manufactures and buys and sells a project (Smith 2010 pg 337). He must be capable of focusing on the right level of detail.

Pan and Sidwell (2011, p.1097) also emphasise (in the UK context) the importance of collaborative working and how developing positive relationships between the developer and off-site suppliers can reduce costs and improve design efficiency. Their findings highlight the logic of the "learning curve or experience curve" and its influence on cost reduction. To emphasise this point, several authors go beyond the standard call for 'further research'. Mohammed (2012) calls for an identification of the issues associated with the related cultural, societal, economic, and business models, if OCT is to make a significant contribution to construction. Abdul-Hadi et al (2005) note that forward thinking 'lead users' and other innovators, who anticipate market forces before their competitors, cannot work alone in a market that is as technologically diverse as construction, and call for a major investment in the collaborative process to promote long-term quality. To achieve this in Saudi Arabia, knowledge and experience must be shared and transferred amongst Saudis themselves, and channels must be found to "standardize experience capture" and "implement knowledge gained through experience in earlier process stages" (Johnsson and Meiling, 2009, p.679). If product quality is to be tackled in-house, this research is in agreement with the findings of Johnsson and Meiling (2009), who conclude that defects in OCT, or its components, point to a "need for learning in the organization" rather than to a need to identify technical and economic fault lines. Such an approach would help to reduce the costs related to poor quality and improve production efficiency and customer satisfaction, thus avoiding poorly-targeted investment. To take advantage of quality management, companies applying OCT must redirect their focus from "project-based, to process-based production" (Johnsson and Meiling, 2009, p.679).

Pan et al. reacha similar conclusion; their findings emphasise the importance of engaging all of the industry players in delivering a housing supply in both wide quantity and of high quality (Pan et al., 2007, p.192). Referring to house builders in the UK, Pan et al. (2007, p.188) found that partnering is a concept that has not been fully understood by the industry. The degree of cooperation between house builders and manufacturers and suppliers was weak in many cases (Pan et al., 2007, p.188). In the current study, it was explained that the backing of local zoning and building is necessary, as these can ease OCT use. The point is well made that all off-site strategies are interrelated and require the commitment of government and the industry, but changing people's perceptions is fundamental (Pan et al., 2007, p.188). It remains to be seen whether the outside agencies involved in Saudi off-site construction – this usually means Western subcontractors – and the Saudis themselves can collaborate over technological development, and whether the personalised nature of successful Saudi business relations, with delays related to the sometimes too patient search for a consensus, can successfully adapt to the time sensitive demands of OCT. Although Saudi Arabia has improved its educational approach to academic leadership, teamwork and problem solving skills, it is difficult to measure its progress in fostering the kind of academic values which would provide the pool of skilled labour which OCT demands.

The nature of the skills that would emerge from such educational institutions would be expected to relate to, and apply, Business Process Re-engineering (BPR), which describes the analysis and redesign of workflows within and between enterprises, so that end-to-end processes are streamlined or optimised, and non-value-added tasks automated. Hammer and Champy (1993) define BPR as "the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical contemporary measures of performance, such as cost, quality, service, and speed" (Abdul-Hadi et al, 2005).

Referring to the Saudi construction industry, Abdul-Hadi et al. reference poor communication, the conservative culture of construction firms, conflict arising from the use of external consultants, poorly-defined core processes, and resistance to change as the most important barriers to successful BPR (Adul-Hadi et al., 2005).

5.3 Which factors affect and enhance OCT in Saudi Arabia?

5.3.1 Performance Factors and Policy Resistance

Resistance to OCT use was reported by the interviewees from local zoning and building. Policy resistance arises because our understanding of the world is unable to match its complexity. The system of learning we use to judge causal relationships systematically leads to cognitive maps that ignore feedback, nonlinearity, time delays, and other elements of dynamic complexity. Why do so many attempts to improve programmes fail? It may be because the continual crisis fosters a short-term orientation that avoids the risk associated with innovation and prevents investment in organisational capabilities that could prevent the repetition of crises associated, in Saudi construction, with delays and the rewriting of contract details.

Time delays between the taking of a decision and its implementation are another common cause of policy resistance. Research shows that people commonly ignore time delays, even when the existence and contents of these delays are known and reported to them, leading to instability. It is not a lack of resources, technical knowledge, or a genuine commitment to change that prevents us from overcoming policy resistance. If we could see inter-relationships rather than linear cause-and-effect chains, and see processes of change rather than snapshots, there might be fewer obstacles to overcoming policy resistance and achieving high performance.

OCT is not a one-size-fits-all solution. No single off-site system can provide an appropriate solution to every building problem. The factors of cost, schedule, labour, scope, quality, and risk (all of which are considered important in this research when using OCT) are factored into an equation which balances them, and measures them against opportunity, purpose and possible outcomes but OCT – particularly when it is a pre-planned response to an identified need, like inner city social housing in a dense urban environment, where land is scarce and housing required urgently –offers a solution to balancing competing performance goals.

Capitalising on the increased efficiency through off-site construction must take account of and resolve several issues. Cost, schedule and scope are interrelated with labour, quality and risk. Although the relative impact of these factors will depend upon the circumstances of any given project, they are generally related. As previously stated, at the very least, the workforce, the architect, and teams for quality control and design must develop sound communicative relationships, and implicitly share problem-solving values aimed not just at maximising profit, but also at achieving quality and therefore customer satisfaction.

5.3.2 The Cost of OCT:

Reflecting the views expressed in the literature, questionnaire and interview responses, it was clear that OCT can reduce the time required to complete a project, and also reduce the need for skilled craft workers on-site, incidents of on-site disruption by other adjacent operations and, ultimately, costs. Again, reflecting the lack of consensus expressed in the literature, the questionnaire and interview responses were undecided about the issue of cost. 51% agreed with the statement “off-site construction techniques decrease the overall project cost”, while 29% disagreed and 21% were undecided. General, across-the-board judgments about the perceived cost barriers and cost savings of OCT must account for too many variables to be conclusive.

The cost of the project is always a major consideration; the lowest bid usually wins the contract, and innovative technology is associated with a higher initial capital cost. This research concludes that OCT should continue to reconsider the commercial balance between cost, value and quality, impressing on the mind of the consumer that the issue of cost effectiveness does not always prevail over aesthetic considerations.

A 2013 review of the housing market in England (for the Department for Communities and Local Government and the Department for Business, Innovation and Skills) examined the potentially significant role of off-site construction methods in future house building. Its approach, for the reasons explained below, was to define OCT as a process in which the on-site added value is less than 40% of the final construction value at completion (Miles and Whitehouse, 2013, p.20).

As a rough guide, it estimated the typical cost of land and the cost of construction of an average new build property to be approximately 40% of the overall property sale price. Sales, marketing costs and profit accounted for the remaining 20%. “Of the 40%

construction costs, some 15% is spent on site-wide infrastructure and landscaping, leaving only about 25% for the actual construction cost of the house itself'(Miles and Whitehouse, 2013, p.17). Although subject to regional variation, this analysis of costs is significant because, in the specific context of the UK housing market, it isolates the element of the overall cost that the use of off-site methods can influence as only 25% of the total development cost.

The 2013 Government sponsored review of the housing market in England reports the complex market forces which have a unique application with regard to the off-site construction market in the UK. This housing market has an "almost complete disconnect with consumer choice", without "an obvious parallel in any other modern manufacturing industry". The report's conclusions validate the findings of this research that generalised statements, particularly relating to cost and speed of construction. For example, the statement that OCT increases the speed of construction, as reported by four of the interviewees, is generally true, but must be located within a context in order to have real value. A reduction in time is a clear benefit of OCT in Saudi Arabia, where the shorter the time taken, the better a project is considered to be. However it would appear that, in a different context (the UK), house-builders are generally "not interested in increasing the speed of construction" (Miles and Whitehouse, 2013, p.17). It is axiomatic that their business model is "based on building new homes only at the rate they can be sold". Therefore, in a demand-led market, it is generally more cost effective for contractors to use traditional methods. The market requires strong local demand for "builders to build homes only after the sales have been agreed" (Miles and Whitehouse, 2013, p.17). Currently, house-builders have "no commercial interest in the performance of the homes they sell beyond the obligations that apply to them for the first two years of the free-standing 10 year structural warranties that apply to the majority of new homes. This means that issues relating to durability, maintenance, cost of ownership and performance in use, all fall to the property owner or occupier" (Miles and Whitehouse, 2013, p.17).

5.3.3 Skilled labour:

Based on this research, productivity and skilled workers are necessary for OCT, although fewer workers are required. In the context of this study, more than 50% of the participants had experience of OCT. As we have seen, the successful implementation of OCT is a context-specific adaptation to circumstances. Nevertheless, some basic principles driving its use can be deduced. Keeping teams intact is an idea that has brought success to design-built entities. Designers or builders who continually engage with the same engineers, contractors, and subcontractors benefit from the experience curve in improving cost efficiency. OCT has the capacity to retain skilled labour by controlling the workflow. Experienced design team members and contractors will build the confidence and the skills to succeed and improve productivity. In the case of OCT and the use of skilled workers, "off-site construction increases overall labour productivity" (agreed by 79% of the participants).

One interview respondent referred to the problem of the high turnover of subcontractors, thus denying the factory prefabrication the skill pools it requires in order to function efficiently; he acknowledged that the over-reliance on imported skilled labour and larger pools of an unskilled workforce could interrupt the necessary transfer of skills to Saudi nationals which is necessary for the development of OCT.

A team working closely together on multiple projects, sharing the same core values and repeating the same processes also builds trust with the stakeholders. Stakeholders who work with a single manufacturer on a sequence of projects will produce a continuous workflow and repeat processes of decision-making, roles and responsibility.

Eastman et al (2008) refer to a labour market barrier in the US which is also relevant to Saudi Arabia. As real wages, benefit packages and job security have stagnated, the use of cheaper immigrant labour has increased. American contractors are not motivated to search out labour saving innovations available through OCT and risk employing them (Eastman et al, 2008, p.8).According to the basic laws of supply and demand, and the understandable aversion to risk in an industry that is wedded to familiar practices, the widespread availability of cheap but mainly unskilled foreign labour in Saudi Arabia will have a similar dampening effect on unfamiliar construction practices.

According to the literature, traditional construction is suffering from declining skills for a wide variety of reasons, some of which are specific to individual countries. For example, in Western counties but not Saudi Arabia, the ageing work force and limited supply of new trainees have proved problematic. In both Western counties and Saudi Arabia, seasonal or peaked demand has attracted an unstable supply of foreign workers, but OCT requires new skills in design, process efficiency and project integration. A skilled workforce will be one of the drivers of a future successful off-site industry in Saudi Arabia. The Saudi Government has responded by sponsoring a reduction in foreign labour, aimed at reducing the number of expatriates and opening more positions for locals in the private sector but, because of the inflated wages offered to government employees, private-sector employment is generally not sought after, and suitably qualified Saudi nationals are not always available.

By enforcing quota requirements relative to the size of an industry, the Nitaqat programme in Saudi Arabia attempts to modernise the Saudi-isation process, relating it to company size and the supply of Saudi talent available for the jobs required. However, the Nitaqat programme has met with a mixed response; the Saudi Labour Ministry linked it to a fall in unemployment among Saudi workers. However, the Saudi press quoted a critical response from Shoura Council members, who stated that “companies manipulate the system to give the impression that they have helped Saudis get employed”. A policy which abandons foreign-worker quotas to encourage business investment or, as in the case of Saudi Arabia, attempts to “replace blunt quotas with more nuanced rules” (which are sensitive to the skills available in specific industries, such as construction) could be a means of overcoming skills shortages (The Economist Intelligence Unit, 2014).

5.3.4 Sustainability:

OCT appear to be offer sustainability and productivity in the context of Saudi Arabia. Hence this section will talk about their scope, suitability and importance. Scope refers to the breadth, size and complexity, and the size and quality of the team involved in a project. To extend scope, retain quality and improve sustainability, pre-fabrication must be vertically and horizontally integrated. Integration at the physical and organisational levels demands that teams consciously share the same goals and that contractors should be involved in the building planning process at the design stage, so they understand design goals and feed information to the design team at an early stage. Establishing a design intent – recorded in the design documents – and construction intent – centred on manufacture, delivery and installation – with two-way communication, means that decision making and the product outputs are properly integrated. One difficulty with fledgling or inexperienced pre-fabrication industries is the absence of a supply chain management network; in other words, a chain of interconnected businesses dedicated to providing product and service packages to the end-customer is absent. The development of internet-based collaborative databases makes it possible to track raw materials from the point of origin to the point of consumption, thereby adding value, increasing quality and reducing cost (Smith, 2011, p.89).

Although 86% of participants agreed that the use of OCT will increase in the years to come, none cited sustainability as a factor contributing to its future success. On the other hand, 66% of the participants indicated that, on the whole, OCT increases sustainability in Saudi Arabia. However, the literature states that OCT outperforms traditional construction when it comes to reducing environmental degradation and waste during building design and construction processes (Poon and Jaillon, 2010; Tam et al., 2005, 2007a; Jaillon et al., 2009; Fong et al. 2003). The non-value adding activities associated with traditional construction are not compensated, whereas a higher proportion of OCT activities add value. Modular pre-fabricated construction can remove waste, and also increase value and appeal to the environmentalist lobby. In the current study, only 30% of the questionnaire respondents agreed that “off-site construction reduces construction waste”, while 44% disagreed and 26% were undecided, suggesting that the respondents feel that waste has little impact on the development of OCT in Saudi Arabia. Therefore it must be considered a driver for OCT use in developed countries at least, as well as a potential driver of Saudi OCT.

5.3.5 Quality

Quality in OCT refers to the quality of production and the quality of design. The participants in this study clearly referred to the high quality of OCT. When examining this in greater depth, quality can be seen to require the creative contributions of both architects and contractors to ensure that desirable attributes complement rather than compete against each other. Regulatory codes must be both devised and enforced, preferably by independent agencies, to ensure compliance.

Jaillon and Poon (2010) argue that OCT products have rarely have structural or quality defects because it is easier to achieve an efficient quality control system in the factory environment than on-site; thus OCT increases product precision. Indeed, 78% of the questionnaire respondents agreed with the statement that "off-site construction techniques increase product quality", 17% disagreed and 5% were undecided, and yet, in relation to public housing stock in particular, the literature has referred to OCT's negative image, based on reports of poor quality materials. How can we explain this inconsistency? One of the shortcomings associated with using the quantitative methodology of a questionnaire is that it presents opinion as fact, observable, measurable and divorced from the context that gives the response validity (Glesne and Peshkin, 1992, p.6). The discrepancy between the questionnaire responses and perceptions about the poor quality of the materials and the completed work arises from the context; OCT is not, as a rule, associated with one-off, high-end or luxury dwellings, and therefore does not generally make use of the more expensive products available. Low cost materials are used to increase profitability, but are subject to quality control tests in a factory environment. However, OCT in a controlled environment permits greater control over the quality of the components and the off-site finished product. This is because corrective intervention disrupts the schedule less when performed off-site, and manufacturers, who tend to focus on one particular type of construction to maximise factory efficiency, become experts at seeking out imperfections. What can be said with confidence is that OCT generally delivers higher-quality finishes because defects are eliminated prior to completion.

Based on the study results, 86% of the participants indicated that OCT will increase in Saudi Arabia in the coming years. When examining the data carefully, it was evident that design inflexibility was seen as a major factor that will hinder OCT development, although overall only 37% identified this as a challenge. It was explained that there was an inability to make changes in the field when using OCT. However, judgements on this topic made in isolation require further investigation. Where, and at what stage, errors in the process are exposed will determine whether they can be corrected more easily than errors occurring in a traditional construction context. Mistakes occurring on-site in scope or schedule can result in weeks of delays. An error which comes to light off-site in the design phase can be dealt with by realignment and rescheduling in the factory environment, which is more controlled and flexible. An error which comes to light after the design phase, but while the raw materials remain off-site, is still within the control of a workforce who are familiar with project challenges. Problems of inflexibility arise when goods leave the factory and faults are discovered which cannot be rectified on-site. When almost complete modules must be returned to the factory location for readjustment, serious disruption and costs result. It is when the product is transported on-site that inflexibility becomes an issue and the costs linked to correcting faults begin to soar (Smith, 2011, p.90).

Perhaps this clarification of the quality issue informs a 59% agreement with the statement that "the negative perception of off-site construction techniques limits the use of those techniques". Notably, 30% of the participants were undecided and 11% disagreed. The issues of quality, schedule, and budget are as inter-related as are skilled labour, the architect and the financial stakeholder. Any single change in one element will affect all of the other elements. The issue of quality, discussed previously, is a case in point. If, for example, the architect or financial stakeholder selects a lower quality material to save costs or achieve a timely completion, all of the stakeholders must be informed of the risk.

With regard to the impact of codes and standards, the opinion of Saudi respondents reflects the views of those in the US and UK. Only 15% agreed that a lack of codes and standards impedes the use of OCT, while 55% disagreed and 30% were undecided. Each country will implement laws according to the resources available although, generally, the International Building Code requirements apply to the construction of new buildings and alterations or additions to existing buildings. Many US states have third party inspection systems that are responsible for standards in the factory, while local inspectors verify the standards on-site (Smith, 2011, .90). In the UK, there are "no significant regulatory or other barriers from the housing sector for off-site construction methods"(Miles and Whitehouse, 2013, p.31)

5.3.6 OCT and Risk

Risk is one of the factors associated with OCT according to the interview participants. In one sense, on-site and off-site construction methods are competing against one another for scarce resources. In another sense, in a risk averse and slow to change industry, OCT acts as a barrier to innovation. For example, traditional contracts and practices rigidly apportion responsibility in a way that incentivises caution by punishing the consequences of failure. This context reinforces risk-avoidance behaviour, causing project teams to protect themselves by looking inward and avoiding collaborative processes.

The fragmentation caused by the adversarial culture of traditional construction does not encourage architects and engineers to risk innovative designs (Smith, 2011, p.53). The rejection of new designs and innovation in traditional construction is a well-known phenomenon, which clearly demonstrates that views regarding a new technique (e.g. OCT) are likely to be even less supportive.

Any variation from the standard in construction presents potential financial vulnerability for the owner, designers and contractors. The negative image attached to residential construction can make lending institutions such as banks reluctant to provide finance; this might also explain why, according to the interview results, the financial institutions could resist OCT. Specialised pre-fabricated elements of a building may be perceived as risky by the investor and contractor, but professionals with experience on-site believe that coordinating, delivering and installing specialised units on-site presents an added risk (Smith, 2011, p.94).As explained previously in this discussion and the Literature Review, construction companies themselves resist innovation, with an attitude of 'If it's not broken, why fix it?'

Under these conditions, an off-site construction firm must recognise project risk and develop a risk mapping framework and strategy so that projects are delivered on time and on budget. The aspects of OCT – cost, schedule, labour, quality, and risk – do not represent definitive answers to a broad range of construction dilemmas. Instead, the evidence suggests that OCT is implemented according to context and the specific conditions of place, time and capability, and that this implementation represents a sliding scale of opportunities and trade-offs rather than the uncomplicated application of technology.

We can partly attribute conflicting judgements about OCT to the failure to clarify which of the many OCT applications is being discussed; we can also attribute this conflict to the failure to contextualise the application in a particular time and place. Some discussions refer to the building of social housing, others to the supply of modular kitchens and bathrooms, while yet others, in a variety of contexts and cultures, refer to the use of OCT in the concrete and steel sectors of civil engineering.

The statement that OCT reduces the required on-site construction time is uncontested, but the statement that "off-site construction techniques reduce the overall project schedule", with which 77% of the questionnaire respondents agreed (8% disagreed, and 15% were undecided) requires qualification; this outcome is subject to access by an experienced set of skilled workers and the coordination of activities both on-site and off-site by project managers in the supply chain. Similarly, factory conditions generally result in an improved working environment, although workers may resent an increase in control and surveillance.

The issue of sustainability must also be placed in context. 66% of the questionnaire respondents agreed that "off-site construction techniques increase sustainability" (7% disagreed, and 27% were undecided); this conclusion begs the question – what did the respondents understand by sustainability, and what, more generally, is meant by sustainability? The definition adopted by the World Business Council describes sustainability as involving the “simultaneous pursuit of economic prosperity, environmental quality and social equity” (Miles and Whitehouse, 2013, p.20). However, the construction industry, like other industries, exists to create profit for its shareholders, and is not generally associated with a concern for social equity. It is the role of the government and regulatory bodies to monitor the industry and enforce outcomes which meet social needs. Unless required to do so by legislation, the construction industry will regard sustainability issues as incidental by-products, unless they possess a commercial value. On this basis, it seems logical to argue that OCT has no direct causal link with sustainability.

When a set of economic and technical drivers rewards the industry for investing in OCT, commercial imperatives will no doubt change “the negative perception of off-site construction techniques” (59% of the questionnaire respondents agreed, 11% disagreed and 30% were undecided that there are indeed negative perceptions) and negative perceptions will cease to restrict OCT use.

5.4 What techniques affect and enhance OCT in Saudi Arabia?

It should be clear that OCT does not offer a construction panacea, and that each single off-site system must be applied to meet a specific building problem. The evidence from the literature review suggests that OCT is best suited to certain niche type buildings in specific locations; these may be inner city sites where space is restricted and inconvenience to the inhabitants is a factor. The building of one-off urban structures delivering set objectives of portability, adaptability and sustainability may be another consideration. More typically, in Saudi Arabia, modularisation is used within the building’s superstructure, as well as when installing a variety of mechanical, electrical and plumbing systems. Offsite pre-assembly is used in volumetric construction: cellular systems are used for repetitive designs, hybrid construction using precast elements to provide a permanent formwork for *insitu* concrete, and steel structural elements fabricated to exact tolerances before being delivered to the site.

Generally speaking, repetitive projects such as near identical offices, modular kitchens and bathroom pods, or civil engineering projects using pre-fabricated steel and concrete when the replication of process is involved, are the drivers of OCT. High-cost, prestige projects which employ unique forms using individual craftsmen are less suited to OCT. Warehouses and projects for building five to eight storey high public housing exploit the replication of box forms which are relatively undemanding in terms of design complexity, whereas one-off projects can be more unique in terms of their geometric specifications and are generally beyond the capability that OCT can provide.

Resorting to OCT for projects such as large buildings can alleviate social disruption in terms of hindering traffic flow and imposing a temporary economic and social cost on local communities. Under these conditions, OCT offers designers and contractors significant advantages in terms of construction time, safety and environmental-friendliness. The questionnaire and interview respondents working off-site reported their involvement in residential, commercial, and government buildings; some were involved in the construction of high buildings and temporary structures, such as site offices, using repeated units to achieve good quality components and economies of scale. From the evidence from the questionnaire and interviews, we can conclude that, in Saudi Arabia, OCT is the most widely-used form of off-site construction in building and in the many civil engineering projects throughout the Kingdom.

In any setting, regardless of the climatic conditions, basic procedures are pivotal to the success of the project. Procedures such as pouring concrete to the correct consistency are difficult under any condition. Activities like moulding concrete components on site, and timing and testing the delivery of wet concrete to the site location before it hardens are made more difficult by the heat of Saudi Arabia. Particularly when the replication of a process is involved, a factory setting allows the pouring of concrete sections so that moulds can be re-used.

When mixing concrete off-site, the precision required for the job is not compromised by the stress involved in time management related to activities such as transportation or pumping wet concrete on a congested, over-heated construction site. In the context of Saudi Arabia, weather and climate did not appear to be a major obstacle to OCT (for 3%), despite the hot climate in Saudi. In civil engineering projects, pre-fabrication in a factory-based setting saves time at the construction site. Other weather-related challenges associated with on-site construction, such as extreme heat or cold, which permit only brief periods when outside construction is feasible, can be reduced by employing OCT. In addition to removing weather delays, properly mapped out OCT can reduce the delays associated with sequencing the participation of multiple subcontractors.

23% of the participants agreed that “general contractors do not have sufficient expertise to assemble pre-fabricated building components on-site”. This study has emphasised the importance of collaborative working and how developing positive relationships between the workers in any given OCT project can reduce costs and improve design efficiency. It has also emphasised the indispensability of an upwards experience curve in setting the conditions which give confidence and impetus to financiers and contractors who prioritise cost reduction.

The access to tools and mechanisation and the concentration of skilled craft workers at the factory enable more rapid cutting, moulding or framing than would be possible on-site. However, the questionnaire respondents felt that the severe heat of the Saudi climate was not an influential factor in resorting to OCT. There are several possible explanations for this opinion. The respondents may have become accustomed to working in high temperatures, or it may be that unskilled foreign workers are more exposed then the respondents to intensive work outdoors. It is also possible that the more demanding physical tasks are performed early in the day or postponed to the cooler hours later on. If the latter is the case, the avoidance of severe climate conditions becomes a compelling argument for the use of OCT in the Saudi construction industry. Moreover, it is indisputable that OCT reduces the need to cut and weld steel sections on-site. In doing so, it not only reduces costs but also removes safety hazards associated with the high midday Saudi temperatures.

Saudi stakeholders intending to implement successful OCT would be advised to make the following enquiries across the typical project phases, as outlined by Smith (2011).

Pre-design: Context, experience, market demand for the installation, culture and environment will all play a part in preparing the ground for OCT. Do these drivers contribute towards meeting the costs, time, labour, site conditions and objectives of the project?

Design: Is the project designed in integration with stakeholders for off-site manufacture, transport, assembly and disassembly, if required?

Development: Is the design of the project developed so that a spirit of open enquiry prevails and there is a seamless structure between on-site work and what is manufactured in the factory?

Detail: were the redesign details developed in collaboration with the architect, general contractor, fabricator and installer so that knowledge gained through experience in the earlier process stages is implemented?

Order: Are design changes kept to a minimum and orders anticipated in advance to reduce costs?

Fabrication: Is fabrication performed using up-to-date moulds and prototypes so that lead times are reduced in an open collaborative model of working to coordinate with the project team?

Delivery: Are site deliveries made just-in-time, loaded and delivered to minimise handling?

Assembly: Are assembly operations continuous, and designed collaboratively to reduce the delays associated with sequencing the participation of multiple subcontractors to ensure that the safety, quality, time and cost parameters are met? (Smith, 2011)

5.5 What main factors will contribute to the implementation of a successful OCT strategy in Saudi Arabia?

There are two fundamental responses to this question: a macro approach which takes a broad based view of the systemic failings, and a micro approach which isolates single characteristics or causes that act as barriers.

When asked to describe the barriers to OCT, the respondents predictably isolated individual characteristics in this regard. A deeper understanding of the constraints that impact on OCT requires a perspective based on a bigger picture of a mix of factors preventing OCT implementation. Alleviating these individual factors is both demanding and requires efficiency, as these factors are all intricately related within the wider organisational culture. Organisational-level initiatives must confront and deal with groups of systemic constraints (Blismas, Pendlebury, Gibb and Pasquire, 2005).

The literature sets out the shortcomings of the traditional Saudi construction techniques, particularly their failure to comply with time schedules (thus increasing costs), and describes them as having the poorest quality among Saudi's manufacturing and service sectors (Alotaibi et al, 2013). The questionnaire and interview respondents acknowledged that, on account of the unavoidable fixed cost of asset procurement, OCT increases the initial costs; however, they were clear that, once applied, OCT decreases the overall project cost and increases the project's design efficiency.

Resistance to change is, arguably, typical of human behaviour and is certainly typical of the construction industry. For example, tradition often favours building by hand. The application of the core theory underlying OCT – that a shared and open collaborative culture will produce time and cost savings – is subject to satisfying various conditions that are specific to time and place. Some examples of these conditional, context-bound qualifications would be: if the stakeholders respond early to problems arising from an imperfect design; if complementary construction tasks are grouped together; if skilled labour can exploit assembly line techniques; and if congestion at the assembly site can be avoided. Over time, and with experience, the Saudi construction industry, with government backing, has the capability to overcome these barriers.

The literature has described some of these systemic barriers: poor communication between the client and consultant (in the Saudi context, the government is frequently the client); unfamiliarity with the personalities and abilities of the technical staff; and interference by the owner, i.e. the government, in construction operations. Another example of the generic or cultural barriers is the unpreparedness of the Saudi educational curriculum, which does not focus sufficiently on problem solving and critical thinking. Another broad-based factor which arguably discourages innovation in business in Saudi Arabia is the 'rentier' state of mind induced by an over-reliance on foreign labour, and the incompatibility between the traditional values of the patrimonial state and the demands of the commercial markets.

The challenge facing off-site construction in Saudi Arabia and other countries is how to move beyond well-meaning slogans about enhancing learning towards adopting the tools that will help us to understand complexity, design better operating systems and policies, and make effective changes. System dynamics is a method to accelerate learning in complex systems and to help companies to learn about dynamic complexity, understand the sources of policy resistance, and design more effective policies (Sterman, 2002). BPR (the fundamental rethinking of business processes to improve performance relating to cost, quality, service, and speed) analyses and redesigns workflows within and between enterprises. Saudi researchers have identified the conservative culture of construction firms and their resistance to change as barriers restricting the engagement of Saudi construction companies with dynamic forward thinking and innovative business processes. It is this capacity to adapt as a strategic choice, in advance of changing circumstances, that sets up the intentional pre-planning for allowing OCT a wider application.

Successful intervention in complex dynamic systems requires more than technical tools and mathematical models. Although change is endemic in the business world, perhaps policy resistance (the tendency for interventions to be defeated by the response of the system to the intervention itself) can only be overcome by seeing the world as a complex system, in which ‘everything is connected to everything else’(Sterman, 2002).

The 1998 Egan Report characterised OCT as lacking in capital investment. It also described OCT as disjointed, underachieving and suffering from inadequate training (Egan,1998). It is paradoxical that the very environment and culture that OCT has been “promoted as being able to change”, are themselves “inhibiting its adoption and its success” (Blismas, Pendlebury, Gibb and Pasquire 2005).

Policy resistance arises because our understanding of the world cannot match its complexity. Why do so many attempts to improve programs fail? It may be because continual crisis fosters a short-term orientation that prevents investment in organizational capabilities that could prevent these crises (Sterman, 2002).

OCT can be applied to a variety of building and construction types. When the technical complexities and collaborative culture have been understood and adopted enthusiastically by all of the stakeholders, and when experience is matched with the repeated replication of components, the stage is set for OCT to become viable and successful. However, more is required than the establishment of a technocratic culture. Forward thinking project planning, upfront investment to meet high fixed costs and the tight control of project schedules and budgets must be combined to increase the quality and reduce the financial risk and environmental impact. OCT is often applied to shorten building cycles. The implementation of OCT suits repetitious projects such as the manufacture and rapid installation of motorway gantries to avoid traffic congestion, or unique projects such as a commercial warehouse which must be set up to trade as soon as possible.

In addition to the factors set out above, there are several systemic factors peculiar to Saudi Arabia which will influence the successful implementation of OCT. They are: the building up of a skilled and experienced workforce, the encouragement and targeting of investment; and the integration of supply chain capability.

Industry must be aware of the market and how it is likely to change over the next ten years. In Western countries, governments intervene to meet a social need or to deliver a declared policy aim, to ameliorate the risk associated with new products related to innovative systems, and to help create certainty in the market. Governments will incentivise investment in the development of systems like OCT, particularly when the by-product of such development is the meeting of a desirable social outcome such as sustainability and the alleviation of carbon and energy-related environmental anxieties. Western governments use fiscal policy to offer tax breaks to promote capital investment in the design and development of new OCT production systems (Miles and Whitehouse, 2013, p.32). The complementary role of private industry is to respond by investing in research and development.

The drivers of a future successful off-site industry in Saudi Arabia are reciprocal and mutually related. Taken together, they would lay down the conditions for innovation. One driver is the encouragement and targeting of investment. In Europe, the private sector is the driver of industrialisation and business innovation. However, Saudi Arabia, operating under a different set of circumstances to Western countries, will continue to rely upon the resources of the state to fund large construction projects (Zuhur, 2011, p.161).Therefore, when it comes to targeted investment in Saudi, the role of the government is pivotal; it both decides upon policy and executes it.

The Saudi government's central role in procuring construction projects is relevant for two reasons. Firstly, its influence as the ultimate paymaster, and sometimes its interference in projects, influences the organisational culture which tolerates the financial cost of project delay, which is regarded as "one of the most serious and frequent problems in the Saudi Arabian construction industry". Secondly, because they provide the finance and, with the assistance of the design team, choose the delivery method, the clients provide much of the impetus behind choosing a building project. In Saudi, the client is often the government. As we have seen, other factors, such as project type, time pressure and the exploitation of economies of scale, are also influential when deciding whether or not OCT is the most suitable delivery method. Nevertheless, its investment resources, and its influence when awarding contracts, put the Saudi government in a powerful position to determine when and whether OCT is used.

Regarding investment, although increasing openness to foreign ownership has been a feature of economic liberalisation, the OECD's Foreign Direct Investment Index of 56 developed and developing countries ranks Saudi Arabia second from the bottom for regulation (Investing across Borders 2010).

The Middle East is the region with the most restrictions on the use of ownership contracts by foreign investors; Saudi Arabia has restrictions on the size of land which can be purchased, and on foreign companies purchasing land for subdividing and using as collateral (Investing across Borders 2010). The reasons for balancing commercial openness with local cultural needs have been discussed at length elsewhere in this study. It is the role of the Saudi government to control the restrictions on foreign investment because regulations can have the effect of discouraging investment. A 2011 investment report found that "the private sector perceives the restrictions to foreign ownership and approval requirements as key obstacles" to Foreign Direct Investment (FDI) (The Economist Intelligence Unit, 2014).

However, Saudi Arabia may hold an advantage over more conventional capitalist societies when capital costs drive the selection of whether a project is built on-site or off-site. In capitalist societies, high initial investment is difficult to justify to speculators looking for a quick low cost investment for a high return. The Saudi government's investment decisions are not subject to short-term considerations.

Chapter 6: Validation

6.1. Introduction

Once the findings of a research project have been compiled, they should be tested. In the case of this research, although these findings should be validated by more research in a broader sample of countries and cases, this section introduces validation approaches to test the strategy for OCT in Saudi Arabia. As previously confirmed, the aim of this research was to investigate the viability of OCT in Saudi Arabia and to develop an implementation strategy for its application. This research employed a multiphase mixed-methods approach by collecting quantitative data (questionnaire surveys) from 136 participants (Phase 1), and qualitative data (semi-structured interviews) from 6 experienced OCT managers (Phase 2). It also used the validation methods (ISM) to analyse the findings of qualitative data collected from 6 experienced OCT managers (Phase 3) to validate the findings.

In Chapter 4, both the quantitative and qualitative methods were tested for validity and reliability separately. In this chapter, the researcher employs ISM to validate the strategies of OCT in Saudi Arabia:

6.2. ISM Methodology

Interpretive Structural Modelling (ISM) can be used for identifying and summarising the relationships among specific variables, which define a problem or issue (Warfield 1974, Sage 1977). It provides us with a means by which order can be imposed on the complexity of such variables (Jharkharia, Shankar 2005; Singh, Shankar, Narain, Agarwal 2003).

After reviewing the literature on OCT and the opinions of experts, both from the construction industry and the expert, 14 important impacts of OCT factors have been identified. The literature review, together with the experts' opinions, was used to develop the relationship matrix, which was later used as the basis for developing an ISM model.

The main objectives of this section are:

I. To identify and rank the challenges, impacts and reasons related to OCT.
II. To explore the interaction among the identified challenges, impacts and reasons related to the use of ISM.
III. To discuss the managerial implications of this research.
IV. For ISM to be successful, it is necessary to identify the variables in the focus group and to develop a Structural Self-Interaction Matrix (SSIM) to identify the relationship between each variable horizontally.

6.3. ISM and the Development of the Implementation Model

The methodology of ISM is an interactive learning process. In this process, a set of different and directly-related variables affecting the system under consideration is structured into a comprehensive systemic model. The beauty of the ISM model is that it portrays the structure of a complex issue of the problem under study, in a carefully designed pattern employing graphics as well as words. The methodology of ISM can act as a tool for imposing order and direction on the complexity of the relationships among the elements of a system (Sage 1977, Jharkharia, Shankar 2005).

The ISM methodology is interpretive due the fact that the judgment of the group decides whether and how the variables are related. It is structural too, as an overall relational structure is extracted from the complex set of variables. ISM is a modelling technique in which the specific relationships of the variables and the overall structure of the system under consideration are portrayed in a digraph model. ISM is primarily intended as a group learning process, but it can also be used for individuals. The various steps involved in the ISM methodology are as follows:

8. Variables affecting the system under consideration are listed, which can be Objectives, Actions, Individuals, etc.
9. From the variables identified in Step 1, a contextual relationship is established among the variables with respect to which pairs will be examined.
10. A Structural Self-Interaction Matrix (SSIM) is developed for variables, which indicates pair-wise relationships among the variables within the system under consideration.
11. A reach ability matrix is developed from the SSIM and this matrix is checked for transitivity. The transitivity of the contextual relation is a basic assumption made in ISM. It states that, if a variable A is related to variable B and variable B is related to variable C, then variable A is necessarily related to variable C.
12. The reachability matrix obtained in Step 4 is partitioned into different levels.
13. Based on the relationships given above in the reachability matrix, a directed graph is drawn and the transitive links are removed.
14. The resultant digraph is converted into an ISM, by replacing variable nodes with statements.

15. The ISM model developed in Step 7 is reviewed to check for conceptual inconsistency and the necessary modifications are made.

6.4. Challenges related to OCT

1. The project owners do not allow the use of OCT
2. General contractors do not have expertise of assembling OCT-built components on-site
3. The local zoning ordinance restricts the use of OCT
4. The local building regulations restrict the use of OCT
5. The financial institution restricts the use of OCT
6. Designing OCT components requires special computer software
7. Skilled assembly craft is unavailable locally
8. Using OCT will increase the design cost
9. Using OCT will increase the construction cost
10. There are transportation restraints
11. There are limited design options for OCT use
12. It is difficult or impossible to make changes in the field when using OCT

The following four symbols are used to denote the direction of the relationship between two factors (i and j):

- V for the relation from factor i to factor
- A for the relation from factor j to factor i (c)
- X for both direction relations actors i and j will influence each other
- O for no relation between the factors.

Table 6-1: Structural Self-Interaction Matrix (SSIM)

		1	2	3	4	5	6	7	8	9	10	11	12
1	The project owners do not allow the use of OCT	X	A	A	A	A	O	O	A	A	O	X	A
2	General contractors do not have expertise in using OCT		X	A	A	O	A	A	O	V	V	X	A
3	The local zoning ordinance restricts the use of OCT			X	X	O	O	O	O	O	X	O	O
4	The local building regulation restricts the use of OCT				X	O	O	O	O	O	O	V	O
5	The financial institution restricts the use of OCT					X	O	O	O	A	O	O	O
6	Designing OCT components requires special computer software						X	O	V	O	O	V	V
7	Skilled assembly is unavailable locally							X	O	V	O	O	V
8	Using OCT will increase the design cost								X	V	O	A	O
9	Using OCT will increase the construction cost									X	X	X	X
10	Transportation restraints										X	A	X
11	Limited design options when using OCT											X	X
12	Inability to make changes in the field when using OCT												X

Table 6-2: Reachability Matrix (Initial and Final)

		1	2	3	4	5	6	7	8	9	10	11	12
1	The project owners do not allow the use of OCT	X	A	A	A	A	O	O	A	A	O	X	A
2	General contractors do not have expertise in using OCT	V	X	A	A	O	A	A	O	V	V	X	A
3	The local zoning ordinance restricts the use of OCT	V	V	X	X	O	O	O	O	O	X	O	O
4	The local building regulation restricts the use of OCT	V	V	X	X	O	O	O	O	O	O	V	O
5	The financial institution restricts the use of OCT	V	O	O	O	X	O	O	O	A	O	O	O
6	Designing OCT components requires special computer software	O	V	O	O	O	X	O	V	O	O	V	V
7	Skilled assembly is unavailable locally	O	V	O	O	O	O	X	O	V	O	O	V
8	Using OCT will increase the design cost	V	O	O	O	O	A	O	X	V	O	A	O
9	Using OCT will increase the construction cost	V	A	O	O	V	O	A	A	X	X	X	X
10	Transportation restraints	O	A	X	O	O	O	O	O	X	X	A	X
11	Limited design options when using OCT	X	X	O	A	O	A	O	V	X	V	X	X
12	Inability to make changes in the field when using OCT	V	V	O	O	O	A	A	O	X	X	X	X

Table 6-3: Initial Reachability Matrix

		1	2	3	4	5	6	7	8	9	10	11	12
1	The project owners do not allow the use of OCT	1	0	0	0	0	0	0	0	0	0	1	0
2	General contractors do not have expertise in using OCT	1	1	0	0	0	0	0	0	1	1	1	0
3	The local zoning ordinance restricts the use of OCT	1	1	1	1	0	0	0	0	0	1	0	0
4	The local building regulation restricts the use of OCT	1	1	1	1	0	0	0	0	0	0	1	0
5	The financial institution restricts the use of OCT	1	1	0	0	1	0	0	0	0	0	0	0
6	Designing OCT components requires special computer software	1	1	0	0	0	1	0	1	0	0	1	1
7	Skilled assembly is unavailable locally	1	1	0	0	0	0	1	0	1	0	0	1
8	Using OCT will increase the design cost	1	1	1	0	1	0	0	1	1	0	0	0
9	Using OCT will increase the construction cost	1	0	0	0	1	1	0	0	1	1	1	1
10	Transportation restraints	1	0	1	0	0	0	0	0	1	1	0	1
11	Limited design options when using OCT	1	1	0	0	1	0	0	1	1	1	1	1
12	Inability to make changes in the field when using OCT	1	1	0	0	1	0	0	0	1	1	1	1

Table 6-4: Final Reachability Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	
1	The project owners do not allow the use of OCT	1	0	0	0	0	0	0	0	0	0	1	0	**2**
2	General contractors do not have expertise in using OCT	1	1	0	0	0	0	0	0	1	1	1	0	**5**
3	The local zoning ordinance restricts the use of OCT	1	1	1	1	0	0	0	0	0	1	0	0	**4**
4	The local building regulation restricts the use of OCT	1	1	1	1	0	0	0	0	0	0	1	0	**5**
5	The financial institution restricts the use of OCT	1	1	0	0	1	0	0	0	0	0	0	0	**3**
6	Designing OCT components requires special computer software	1	1	0	0	0	1	0	1	0	0	1	1	**6**
7	Skilled assembly is unavailable locally	1	1	0	0	0	0	1	0	1	0	0	1	**5**
8	Using OCT will increase the design cost	1	1	1	0	1	0	0	1	1	0	0	0	**6**
9	Using OCT will increase the construction cost	1	0	0	0	1	1	0	0	1	1	1	1	**7**
10	Transportation restraints	1	0	1	0	0	0	0	0	1	1	0	1	**5**
11	Limited design options when using OCT	1	1	0	0	1	0	0	1	1	1	1	1	**8**
12	Inability to make changes in the field when using OCT	1	1	0	0	1	0	0	0	1	1	1	1	**7**

6.4.1. Building the ISM-based model (Digraph): Factors' Levels

To validate the challenges facing OCT, the researcher compared the results generated from the focus group and compared them with those generated from the questionnaire. Some similarities were found in the results. For example "limited design options using OCT" was equally rated as the most important in both the focus group and the questionnaire. Although the "inability to make changes in the field using OCT" was ranked second in the focus group, it was rated first in the questionnaire. Also "using OCT will increase the construction cost" was rated at level two in the focus group and ranked third in the questionnaire. These three factors appeared similar in terms of levels of importance. Other challenges such as "the project owners do not allow the use of OCT" were the least important in the focus group, but ranked 8th in the questionnaire; while "transportation restraints" was at level 4 in the focus group, but ranked ninth in the questionnaire.

Table 6-5: Item Levels

Level	Item	
1	**1**	The project owners do not allow the use of OCT
2	**5**	The financial institution restricts the use of OCT
3	**3**	The local zoning ordinance restricts the use of OCT
4	**10**	Transportation restraints
	7	Lack of skilled assembly craftworks locally
	2	General contractors do not have expertise in the use of OCT
	4	The local building regulation restricts the use of OCT
5	**6**	Designing OCT components requires special computer software
	8	Using OCT will increase the design cost
6	**9**	Using OCT will increase the construction cost
	12	Inability to make changes in the field when using OCT
7	**11**	Limited design options when using OCT

6.5. Reasons for OCT

1. Project owners require the use of OCT
2. To compensate for the shortage of skilled craft workers
3. To compensate for the local weather conditions
4. To reduce the design duration
5. To reduce the construction duration
6. To reduce the overall project schedule
7. To reduce the overall project cost
8. To increase product quality
9. To enhance the company's reputation
10. To compensate for the restricted working space on-site
11. To reduce the environmental impact
12. To improve the project's safety performance
13. To increase the company's profit margin
14. To increase the overall labour productivity

Table 6-6: Structural Self-Interaction Matrix (SSIM)

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Project owners require the use of OCT	X	O	O	A	A	A	A	A	O	O	O	A	A	A
2	To compensate for the shortage of skilled craft workers		X	O	V	V	V	O	V	X	A	A	A	V	O
3	To compensate for the local weather conditions			X	O	V	O	O	O	V	V	V	O	O	V
4	To reduce the design duration				X	X	X	X	A	A	O	O	O	V	V
5	To reduce the construction duration					X	X	V	V	A	A	V	O	V	A
6	To reduce the overall project schedule						X	X	V	X	X	V	O	V	O
7	To reduce the overall project cost							X	V	X	O	O	A	V	A
8	To increase product quality								X	A	A	V	V	O	O
9	To increase the overall labour productivity									X	X	A	A	V	V
10	To compensate for the restricted working space on-site										X	X	V	O	X
11	To reduce the environmental impact											X	O	O	O
12	To improve the project's safety performance												X	O	O

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
13	To increase the company’s profit margin													X	O
14	To enhance the company’s reputation														X

Table 6-7: Reachability Matrix (Initial and Final)

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Project owners require the use of OCT	X	O	O	A	A	A	A	A	O	O	O	A	A	A
2	To compensate for the shortage of skilled craft workers	O	X	O	V	V	V	O	V	X	A	A	A	V	O
3	To compensate for the local weather conditions	O	O	X	O	V	O	O	O	V	V	V	O	O	V
4	To reduce the design duration	V	A	A	X	X	X	X	A	A	O	O	O	V	V
5	To reduce the construction duration	V	A	A	X	X	X	V	V	A	A	V	O	V	A
6	To reduce the overall project schedule	V	A	V	X	X	X	X	V	X	X	V	O	V	O
7	To reduce the overall project cost	V	V	V	X	A	X	X	V	X	O	O	A	V	A
8	To increase product quality	V	A	V	V	A	A	A	X	A	A	V	V	O	O
9	To increase the overall labour productivity	O	X	A	V	V	X	X	V	X	X	A	A	V	V
10	To compensate for the restricted working space on-site	O	V	A	O	V	X	O	V	X	X	X	V	O	X
11	To reduce the environmental impact	O	V	A	O	A	A	O	A	V	X	X	O	O	O
12	To improve the project’s safety performance	V	V	O	O	O	O	V	A	V	A	O	X	O	O
13	To increase the company’s profit margin	V	A	O	A	A	A	A	O	A	O	O	O	X	O
14	To enhance the company’s reputation	V	O	A	A	V	O	V	O	A	X	O	O	O	X

Table 6-8: Initial Reachability Matrix

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Project owners require the use of OCT	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	To compensate for the shortage of skilled craft workers	0	1	0	1	1	1	0	1	1	0	0	0	1	0
3	To compensate for the local weather conditions	0	0	1	0	1	0	0	0	1	1	1	0	0	1
4	To reduce the design duration	1	0	0	1	1	1	1	0	0	0	0	0	1	1

5	To reduce the construction duration	1	0	0	1	1	1	1	1	0	0	1	0	1	0
6	To reduce overall project schedule	1	0	1	1	1	1	1	1	1	1	1	0	1	0
7	To reduce the overall project cost	1	1	1	1	0	1	1	1	1	0	0	0	1	0
8	To increase product quality	1	0	1	1	0	0	0	1	0	0	1	1	0	0
9	To increase the overall labour productivity	0	1	0	1	1	1	1	1	1	1	0	0	1	1
10	To compensate for the restricted working space on-site	0	1	0	0	1	1	0	1	1	1	1	1	0	1
11	To reduce the environmental impact	0	1	0	0	0	0	0	0	1	1	1	0	0	0
12	To improve the project's safety performance	1	1	0	0	0	0	1	0	1	0	0	1	0	0
13	To increase the company's profit margin	1	0	0	0	0	0	0	0	0	0	0	0	1	0
14	To enhance the company's reputation	1	0	0	0	1	0	1	0	0	1	0	0	0	1

Table 6-9: Final Reachability Matrix

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	
1	Project owners require the use of OCT	1	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
2	To compensate for the shortage of skilled craft workers	0	1	0	1	1	1	0	1	1	0	0	0	1	0	**7**
3	To compensate for the local weather conditions	0	0	1	0	1	0	0	0	1	1	1	0	0	1	**6**
4	To reduce the design duration	1	0	0	1	1	1	1	0	0	0	0	0	1	1	**7**
5	To reduce the construction duration	1	0	0	1	1	1	1	1	0	0	1	0	1	0	**8**
6	To reduce the overall project schedule	1	0	1	1	1	1	1	1	1	1	1	0	1	0	**11**
7	To reduce the overall project cost	1	1	1	1	0	1	1	1	1	0	0	0	1	0	**9**
8	To increase product quality	1	0	1	1	0	0	0	1	0	0	1	1	0	0	**6**
9	To increase the overall labour productivity	0	1	0	1	1	1	1	1	1	1	0	0	1	1	**11**
10	To compensate for the restricted working space on-site	0	1	0	0	1	1	0	1	1	1	1	1	0	1	**9**
11	To reduce the environmental impact	0	1	0	0	0	0	0	0	1	1	1	0	0	0	**4**
12	To improve the project's safety performance	1	1	0	0	0	0	1	0	1	0	0	1	0	0	**5**
13	To increase the company's profit margin	1	0	0	0	0	0	0	0	0	0	0	0	1	0	**2**
14	To enhance the company's reputation	1	0	0	0	1	0	1	0	0	1	0	0	0	1	**5**

6.5.1 Building the ISM-based model (Digraph): Factors' Levels

To validate the reasons for using OCT, the focus group showed that "to reduce the project's overall schedule" was the most important along with "to increase overall labour productivity"; both were rated first and third respectively in the questionnaire. Also "to reduce the project's overall schedule" was placed second in importance by the focus group and by the questionnaire too, whereas the focus group ranked "to compensate for the restricted working space on-site" as second but this was ranked fifth in the questionnaire. At leve1 1 (least important) was "project owners require the use of OCT techniques" and that was ranked in ninth place, towards the end of the list, in the questionnaire. Overall, the three most important reasons appeared to be similar, and others showed similarities too. As a result, it can be concluded that that the outcomes are relatively valid.

Table 6-10: Item Levels

Level	Item
1	**1** Project owners require the use of OCT
2	**13** To increase the company's profit margin
3	11 To reduce the environmental impact-
4	12 To improve the project's safety performance
	14 To enhance the company's reputation
5	3 To compensate for the local weather conditions
	8To increase product quality
6	2 To compensate for the shortage of skilled craft workers
	4 To reduce the design duration
7	5 To reduce the construction duration
8	**10** To compensate for the restricted working space on-site
	7 To reduce the overall project's cost

9	**6** To reduce the project’s overall schedule
	9 To increase overall labour productivity

6.6. Impact of OCT

1. Overall project schedule
2. Skilled craft workers on-site
3. Product quality
4. Overall labour productivity
5. Initial cost.
6. Safety performance
7. Sustainability
8. Project design efficiency
9. Overall project cost
10. The owner’s negative perception
11. Transportation restraints
12. Design options
13. The ability to make changes to on-site work
14. Onsite disruption of other adjacent operations.

Table 6-11: Structural Self-Interaction Matrix (SSIM)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Overall project schedule	X	X	X	X	V	O	A	V	V	O	A	O	A	V
2	Skilled craft workers on-site.		X	V	X	O	O	O	O	O	A	O	O	A	O
3	Product quality			X	X	X	V	V	X	V	O	O	O	X	V
4	Overall labour productivity				X	V	V	V	V	X	X	O	V	X	V
5	Initial cost					X	O	O	A	X	O	O	O	A	O
6	Safety performance						X	V	A	O	A	O	O	A	O
7	Sustainability							X	A	O	A	O	O	A	O
8	Project design efficiency								X	V	X	X	X	A	O
9	Overall project cost									X	O	A	O	A	V
10	Onsite disruption of other adjacent operations										X	X	O	X	O
11	Transportation restraints											X	X	O	O
12	Design options												X	O	O
13	The ability to change on-site work													X	O
14	The owner’s negative perception														X

Table 6-12: Reachability Matrix (Initial and Final)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Overall project schedule	X	X	X	X	V	O	A	V	V	O	A	V	A	V
2	Skilled craft workers on-site.	X	X	V	X	O	O	O	O	O	A	O	O	A	O
3	Product quality	X	A	X	X	X	V	V	X	V	O	O	O	X	V
4	Overall labour productivity	X	X	X	X	A	V	V	V	X	X	O	V	X	V
5	Initial cost.	A	O	X	V	X	O	O	A	X	O	O	O	A	O
6	Safety performance	O	O	A	A	O	X	V	A	O	A	O	A	A	O
7	Sustainability	V	O	A	A	O	A	X	A	O	O	O	A	A	O
8	Project design efficiency	A	O	X	A	V	V	V	X	V	X	X	V	A	O
9	Overall project cost	A	O	A	X	X	O	O	A	X	O	A	O	A	V
10	Onsite disruption of other adjacent operations	O	V	O	X	O	V	O	X	O	X	X	O	X	O
11	Transportation restraints	V	O	O	O	O	O	O	X	V	X	X	X	O	V
12	Design options	A	O	O	A	O	V	V	A	O	O	X	X	O	O
13	The ability to make changes to on-site work	V	V	X	X	V	V	V	V	V	X	O	O	X	O
14	The owner’s negative perception	A	O	A	A	O	O	O	O	A	O	A	O	O	X

Table 6-13: Initial Reachability Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Overall project schedule	1	1	1	1	1	0	0	1	1	0	0	1	0	1
2	Skilled craft workers on-site.	1	1	1	1	0	0	0	0	0	0	0	0	0	0
3	Product quality	1	0	1	1	1	1	1	1	1	0	0	0	1	1
4	Overall labour productivity	1	1	1	1	0	1	1	1	1	1	0	1	1	1
5	Initial cost	0	0	1	1	1	0	0	0	1	0	0	0	0	0
6	safety performance	0	0	0	0	0	1	1	0	0	0	0	0	0	0
7	Sustainability	1	0	0	0	0	0	1	0	0	0	0	0	0	0
8	Project design efficiency	0	0	1	0	1	1	1	1	1	1	1	1	0	0
9	Overall project cost	0	0	0	1	1	0	0	0	1	0	0	0	0	1
10	Onsite disruption of other adjacent operations	0	1	0	1	0	1	0	1	0	1	1	0	1	0
11	Transportation restraints	1	0	0	0	0	0	0	1	1	1	1	1	0	1
12	Design options	0	0	0	0	0	1	1	0	0	0	1	1	0	0
13	The ability to make changes to on-site work	1	1	1	1	1	1	1	1	1	1	0	0	1	0
14	The owner’s negative perception	A	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 6-14: Final Reachability Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	Overall project schedule	1	1	1	1	1	0	0	1	1	0	0	1	0	1	9

2	Skilled craft workers on-site	1	1	1	1	0	0	0	0	0	0	0	0	0	0	4
3	Product quality	1	0	1	1	1	1	1	1	1	0	0	0	1	1	10
4	Overall labour productivity	1	1	1	1	0	1	1	1	1	1	0	1	1	1	12
5	Initial cost	0	0	1	1	1	0	0	0	1	0	0	0	0	0	4
6	Safety performance	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2
7	Sustainability	1	0	0	0	0	0	1	0	0	0	0	0	0	0	2
8	Project design efficiency	0	0	1	0	1	1	1	1	1	1	1	1	0	0	9
9	Overall project cost	0	0	0	1	1	0	0	0	1	0	0	0	0	1	4
10	Onsite disruption of other adjacent operations	0	1	0	1	0	1	0	1	0	1	1	0	1	0	7
11	Transportation restraints	1	0	0	0	0	0	0	1	1	1	1	1	0	1	7
12	Design options	0	0	0	0	0	1	1	0	0	0	1	1	0	0	4
13	The ability to make changes to on-site work	1	1	1	1	1	1	1	1	1	1	0	0	1	0	11
14	The owner's negative perception	A	0	0	0	0	0	0	0	0	0	0	0	0	1	1

6.6.1 Building the ISM-based model (Digraph): Factors' Levels

It was found that "overall productivity" was most the important factor for the focus group and the questionnaire respondents. This was followed by "the inability to make changes to on-site work", which, however, came fourth when looking at the questionnaire results. Also, "product quality" was important in the focus group, coming third; it was ranked second in the questionnaire. The least important for the focus group was "the owner's negative perception" and it was ranked eleventh in the questionnaire. Again, and in common with the other sections, there seems to be consistency on the most important factors; hence validation can be assumed.

Table 6-15: Item Levels

Level	Item
1	14 The owner's negative perception
2	6 Safety performance
	7 Sustainability
3	9 Overall project cost

	2	Skilled craft workers on-site
	5	Initial cost
	12	Design options
4	11	Transportation restraints
	10	On-site disruption of other adjacent operations
5	8	Project design efficiency
	1	Overall project schedule
6	3	Product quality
7	13	The ability to make changes to on-site work
8	4	Overall labour productivity

6.6.2. ISM-based model for the impact of OCT

The diagram below represents 8 levels that are considered important for the successful implementation of OCT in Saudi Arabia. The ISM showed that the main factor that is considered to be of the greatest importance, at level 8, is "overall productivity". This factor showed that it has significant association with "the ability to make changes to on-site work", with both factors complementing each other. "The ability to make changes to on-site work" (level 7) when using OCT is also associated with "product quality" (level6), both affecting each other. Companies need to place a special emphasis on product quality as it affects the overall schedule of an OCT project, and will also affect the initial cost of the project and the efficiency of the product design.

When studying and trying to improve product efficiency, it is important to consider that it is affected by the project schedule too. Further importance should be given to "the on-site disruption of other adjacent operations" as it correlates with "project design efficiency". Transportation restraints are shown to be correlated with project design efficiency. Companies should also consider that transportation restraints lead to an increase in the overall project cost; while online disruption of other adjacent operations affects the likelihood of having skilled craft workers on-site. At level 3 of the ISM diagram, the design options of OCT are likely to affect overall OCT sustainability and safety performance in level 2, keeping in mind the owners' (companies') negative perception of OCT. Overall, the strategy of successful OCT implementation will come from focusing on the important factors and working through to the least important ones. Improvements across all levels are required to ensure a successful strategy for effective OCT implementation in Saudi Arabia.

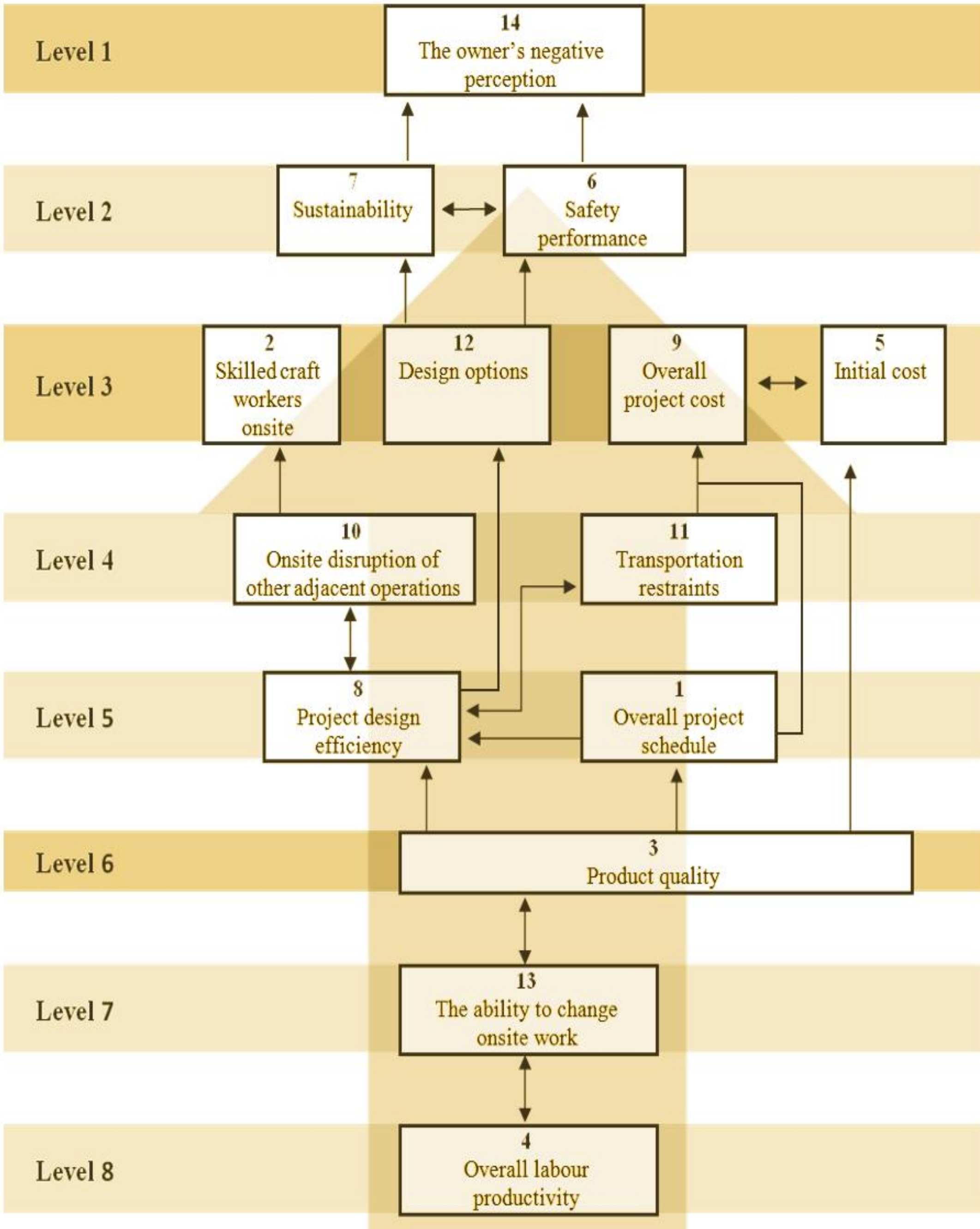

Figure 6-1: ISM-based model for the Impact of OCT

Chapter 7: Conclusion

7.1 Overview

OCT is considered to be a new phenomenon in Saudi Arabia since it has not yet been utilised to the maximum and faces a lot of challenges. The main aim of this research was to study how OCT is utilised, what the participants view as the positive or negative impacts of OCT, the reasons behind its use and the challenges it faces. This study is mainly concerned with the objectives which will be summarised in this chapter with the associated findings. This study had 5 objectives, all of which are listed below, followed by explanations of the main results related to them.

7.2 Achieving the Research Objectives

Objective 1: To describe and analyse the drivers and barriers related to using OCT in the construction industry in a selection of developed countries and to extrapolate the sets of conditions which contribute to the success of OCT.

Objective 2: To investigate and analyse the barriers and drivers to the use OCT in the construction industry in Saudi Arabia.

Objective 3: To establish the relationships between the impact on OCT and the satisfaction among practitioners with the current implementation of OCT in Saudi Arabia.

Objective 4: To conceptualise a strategy for the successful implementation of OCT in Saudi Arabia.

Objective 5: To validate an implementation strategy and adoption process.

The following subsections examine, in turn, how each objective has been met. A recommendation section follows the objectives.

Objective 1: To describe and analyse the drivers and barriers related to using OCT in the construction industry in a selection of developed countries and to extrapolate the sets of conditions which contribute to the success of OCT.

This research objective was met by extensively reviewing the OCT literature. It was crucial to generate more knowledge from the current research in this field and from the field of construction in general. From a review of the literature, it was evident that the current study could offer a unique perspective on the use of OCT in Saudi Arabia. After thoroughly examining the literature review, the researcher specified the research objective and identified a number of factors that could be influential in the context of Saudi Arabia (overall project schedule, skilled craft workers on-site, project product quality, the negative environmental impact of construction operations, design efficiency, safety performance, design options, transportation restraints, use of IT, the ability to make changes to work on-site, the owner's negative perception, overall project cost, initial costs, the property marketing value, OCT codes and standards and the on-site disruption of other adjacent operations). These factors were then incorporated into the questionnaire and the interviews used to gather the data. The questionnaire was administered among 136 participants and the semi-structured interviews were conducted among 6 interviewees. Achieving this objective enabled the researcher to meet the following objective.

Objective 2: To investigate and analyse the barriers and drivers to the use OCT in the construction industry in Saudi Arabia.

This is the main objective in this study, in order to understand OCT in the context of Saudi Arabia. The results from the analysis of the questionnaires and the interviews related to participants in the construction industry can be arranged in the following manner.

Firstly, the participants were required to provide their views on the impact of using OCT. The results have led to the identification of a number of factors. There was a clear focus on labour productivity as a critical factor, indicating that there seems to be better productivity when using OCT than when using traditional construction techniques; reference was made to the advantage of working off-site (e.g. in a factory) as a way of ensuring that the workers are productive. Along with productivity, quality was also associated with the use of OCT, thus favouring the argument that OCT can provide high quality construction while also ensuring sustainability. Time as a crucial aspect in construction came up often when talking about OCT, and there was agreement among the participants and interviewees that OCT reduces the duration of work. Also, when compared to traditional construction, OCT does not require many skilled workers. Conversely, it was mentioned that problems such as product inflexibility (i.e. being unable to make changes on-site) as well as risk, could be barriers. It was explained that OCT in the context of Saudi Arabia needs to be tried and companies ought to take risks in order fully to adopt it.

Secondly, the participants were asked to indicate their reasons for choosing OCT over traditional construction techniques. In line with the previous paragraph, it was shown that time is the main reason (schedule), as OCT leads to less construction time and hence to a shorter schedule. Cost was another factor: it was agreed that, overall, OCT can be cheaper than traditional construction techniques. Although it was acknowledged by the interviewees that some perceive it as an expensive option, which is only the case at the beginning of a project. There was also a focus on the quality of OCT, explaining that this technique can ensure good quality construction. Furthermore, and very importantly, labour productivity seems to be another reason for choosing OCT; as explained earlier, working in a comfortable environment (off-site) can ensure better quality and better productivity.

***Thirdly*,** there was a focus on the barriers to the use of OCT. As mentioned earlier, design inflexibility was shown to be a major problem. Off-site construction offers less flexibility to make changes onsite. Along with inflexibility, design limitations were also mentioned as a barrier; OCT only offers few repeated designs which require special computer software. Although lower costs could be an advantage of OCT, some have reported that it can be costly too, especially in the early stages. In the interviews, it was explained that, when considering a successfully-completed completed project, OCT is generally less costly than traditional construction techniques, especially with regard to the aspect of time being money. Mention was made in the interviews that a lack of awareness about OCT and insufficient education in this field could be major obstacles, as many seem to be resisting its adoption. Another major factor in such resistance is culture, where OCT is viewed as a cheap option.

Objective 3: To establish the relationships between the impact on OCT and the satisfaction among practitioners with the current implementations of OCT in Saudi Arabia.

This objective was statistically met using a correlation test (Spearman’s rho). Overall, the impacts of OCT (19 items) were correlated with the participants’ satisfaction with the use of Modular Building, Panelised System, Hybrid System and Preassembly. Overall, it was found that satisfaction with modular building was mainly negative with the impact items (7 items) showing a negative relationship with: "the use of OCT decreases the overall project cost"; "the use of OCT increases the overall on-site labour productivity"; "the use of OCT increases safety performance"; the use of OCT increases sustainability"; "the use of OCT increases design efficiency"; "the use of OCT increases the initial cost"; and "the use of OCT increases project product quality". This indicates that, the higher the score or agreement with the impacts, the less satisfaction there is with modular building. "Satisfaction with modular building" was only positively correlated with "transportation restraints" (i.e. size constraints, transportation cost, and impact on building structures) that limit the use of OCT.

Satisfaction with a Panelised System was positively related to: "the use of OCT increases project product quality"; "the use of OCT increases safety performance"; "the use of OCT reduces the on-site disruption of other adjacent operations"; "the use of OCT increases sustainability"; "the use of OCT increases design efficiency"; and "the use of OCT decreases the overall project cost". This means that, the more satisfied the participants are with Panelised System, the more they agree with the impacts. On the other hand, a Panelised System was negatively correlated with "transportation restraints" (i.e. size constraints, transportation cost, impact on building structures) that limit the use of OCT and increase the complexity of maintenance. This indicates that, the higher the satisfaction with a Panelised System, the less the participants agree with these items.

Satisfaction with a Hybrid System showed a negative correlation with: "the use of OCT reduces the overall project schedule"; "the use of OCT increases the project product quality”, and “the use of OCTs increases the over-all onsite labour productivity”. These results indicate that, the higher the satisfaction, the lower the agreement with these items.

Finally, a significant positive correlation was found between Preassembly as a technique and: “the use of OCT increases the overall on-site labour productivity”; “the use of OCT increases design efficiency”; “the use of OCT increases the initial costs”; and “the use of OCT decreases the overall project cost”. Better satisfaction with Preassembly leads to more agreement with the impact items. On the other hand, Preassembly was found to be negatively correlated with: “the use of OCT reduces the overall project schedule”; “transportation restraints (i.e. size constraints, transportation cost, impact on building structures) limit the use of OCT”; “the use of OCT increases the complexity of the maintenance”; and “the use of OCT increases the property marketing value”. This shows that, the higher the participants’ satisfaction with Preassembly, the less they are in agreement with these items.

The results here are mixed, with some negative and others positive; these results require further study and such relationships need to be addressed in future research and when delivering training or educational seminars.

Objective 4: To conceptualise a strategy(s) for the successful implementation of OCT in Saudi Arabia.

This objective has been met by choosing a number of factors impacting on OCT in Saudi Arabia; 19 impacts were investigated but only items that generated 50% or more agreement where chosen as the most important (14 items). On the other hand, all of the reasons for using OCT and the related challenges were chosen to be important. The chosen impacts, reasons and challenges were then validated using ISM to establish the levels of importance of each of the factors; this also helped to demonstrate the relationship between the factors/items. The result of the ISM can be used for the future direction of how to implement OCT successfully in Saudi Arabia; it also allows a map for future research training. Further to that, and when conceptualising a strategy for the successful implementation of OCT, it is essential to look at the relationship between the use of OCT (Modular Building, Panelised System, Hybrid System and Preassembly) and the satisfaction with them. Negative and positive relationships (see Objective 3) need to be explored.

Objective 5: To validate an implementation strategy and adoption process.

To meet this objective, the researcher designed three models using ISM (Interpretive Structural Modelling). The first section is concerned with the drivers behind OCT; the second concentrates on the challenges facing OCT in Saudi Arabia followed by the third model concentrating on the impact facing OCT in Saudi Arabia.

1-*Drivers*

Using ISM, the results provided have ranked the drivers of OCT in the following order: "to increase the overall labour productivity"; "to reduce the project's overall schedule"; "to reduce the overall project cost"; "to compensate for the restricted working space on-site"; "to reduce the construction duration"; "to reduce the design duration"; "to compensate for the shortage of skilled craft workers"; "to increase the product quality"; "to compensate for the local weather conditions"; "to enhance the company's reputation"; "to improve the project's safety performance"; "to reduce the environmental impact"; "to increase the company's profit margin"; and "project owners require the use of OCT".

2-*Challenges*

The third ISM section resulted in different levels of challenges, which have the following levels of importance: Limited design options when using OCT; Inability to make changes in the field using OCT; Using OCT will increase the construction cost; Using OCT will increase the design cost; Designing off-site construction components requires special computer software; The local building regulation restricts the use of OCT; General contractors do not have expertise in using OCT; The lack of skilled assembly craft workers locally; Transportation restraints; The local zoning ordinance restricts the use of OCT; The financial institution restricts the use of OCT; and The project owners do not allow the use of OCT.

3- *Impact*

In the second model, ISM resulted in the impacts falling into the following order in terms of importance. It was shown that OCT impacts on: Overall labour productivity; The ability to make changes on-site work to work; Product quality; Project design efficiency; Overall project schedule; Onsite disruption of other adjacent operations; Transportation restraints; Skilled craft workers onsite; Overall project cost; Initial cost; Design options; Sustainability; Safety performance; and The owner's negative perception.

7.3 Contribution of this Study to Practice and Knowledge

The construction sector in Saudi Arabia is constantly developing, and it still under-researched. The contribution of this study is significant, as it is *considered the first of its* *kind to be conducted in Saudi Arabia, looking at OCT and examining its impact, the reasons for its use and the barriers it may face.* Using questionnaires and interviews as well as a focus group, this study has reached a conclusion with regard to the main factors associated with the implementation of OCT. A number of benefits were associated with OCT: its quality, reduced time and schedule, need for fewer skilled workers and sustainability. Equally, the reasons for adopting OCT were also similar, highlighting duration/time and schedule followed by lower costs, better quality and higher productivity but, when examining the barriers, it was evident that OCT's inflexibility, the limited design options, the high cost, and the design costs were of great importance. However, it was clearly highlighted that the lack of risk taking and low awareness are factors that hinder OCT adoption, leading to resistance towards it.

This research has led to a better understating of OCT, and clarified the main factors that the government, companies, educators and policy makers should take into consideration in order to improve OCT in Saudi Arabia. Equally, this research has provided a solid platform for future research that aims to expand knowledge in this field. The current findings will be published to maximise the utility of this research (e.g. publications, public construction magazines as well as lectures and seminars). It is important that it is translated into Arabic to make it more accessible.

7.4 Recommendations

Based on the literature review and the research findings, this study proposes a number of recommendations that can improve OCT in the context of Saudi Arabia, and perhaps lead to improvements to the construction industry in general. Steps towards increasing the awareness of OCT will certainly help in using OCT to a greater extent, especially when targeting the agents (people) involved in construction.

- A general awareness about OCT is crucial to its successful adoption. There is an urgent need to provide training methods aiming to improve awareness of OCT among manufacturers, architects, engineers, designers and local planning and building personnel. Increased awareness is essential, because only through that can OCT become more accepted in Saudi Arabia with less resistance.
- Saudi universities and technical colleges should teach students (engineers, architects, etc.) about utilising OCT in Saudi Arabia and also about the potential challenges and benefits related to its usage. This will create a new generation of innovative workers who are more likely to experiment with OCT and push the boundaries.
- Manufacturers, contractors, designers, engineers and architects should cooperate in order to increase and maximise the design options for OCT. This would improve OCT's flexibility, and lower the design costs. Clearly, inflexibility, the limited design options and high costs are barriers to this, according to this research.
- Positive, effective communication between workers and their superiors is also essential, as recommended by Pan et al. (2007). When referring to the social housing sector and the construction sector; they pointed out that sharing knowledge and communication as well as collaboration leads to success in construction. The members of a project (architects, developers, contractors and sub-contractors) should collaborate and take decisions together to introduce significant and innovative changes in the construction sector, especially OCT. Clear communication between teams and workers should always be enhanced to improve OCT implementation. Problem solving in the construction sector is

best achieved through positive communication between all of the individuals involved, from the top management and owners to the workers.

- There is also a need to train workers and improve their skills; only then can manufacturers see better productivity and fewer errors. There is also a need to improve the workers' computer skills, which are essential in OCT.
- Construction firms should be encouraged to take calculated risks with OCT, as it is generally considered risky, leading to it being used less. Many financial institutions may avoid financing OCT projects due to the unknowns; the calculated risks that they take will only improve OCT use.
- There is a need for an educated workforce who is knowledgeable in and skilful regarding OCT.
- Special attention should be paid, in the process of innovation, to sub-contractors who fabricate, manufacture and buy products. They could influence the way in which OCT is designed and implemented.
- The Saudi government should be more committed to the construction industry and encourage OCT, since the government is considered a major player in promoting new ideas and plans in construction (e.g. with regard to regulations and codes).
- There needs to be a balance between the cost, value and quality of OCT projects and products. This will give clients or companies more reasons to consider the use of OCT.
- There is a need for experienced members of staff who will improve the confidence of other workers and ultimately the productivity level.

- There is a need to avoid high turnover in the construction sector in general, specifically OCT. Workers should be rewarded (in wages) and companies need to avoid losing skilful workers. Companies should avoid cheap unskilled labour.
- There is a need to encourage Saudi nationals to work in the construction industry in general and in OCT in particular. The employment of Saudis is avoided, at times, because of the availability of cheaper foreign labour; the government also needs to address this.
- A standard code for the use of OCT should be created, and this code should have specific standards which have to be met for a company to use OCT.

7.5. Research Limitation

The research processes were successful in achieving the research objectives and answering the research questions. However, certain difficulties were encountered in the course of the research process. The first obstacle faced the reluctance of certain people to participate in the study. The second was the lack of any significant Saudi-specific literature on the topic.

In terms of data collection, too, there were some difficulties. The collection procedure was to give the questionnaires to the participants by hand and then collect them using the same method after completion to obtain a high response rate. However, some of the questionnaires were not completed.

The research focused on all types of projects (residential/housing, civil engineering, infrastructure, building/industrial building) together and no analysis was made on the bases of individual types. There were fewer respondents to the survey from the public sector than from the private sector. This may lead the results to favour the private sector.

7.6. Further research

- More research needs to be conducted about investing OCT at all levels. There is a need to conduct a similar study using a bigger sample to ensure better generalisability. Furthermore, it is essential to include more expert companies in diverse construction specialisations and seek their views regarding OCT and how it can be used in more projects in Saudi Arabia.
- An increase in the number of case studies to investigate the activities related to off-site manufacture would provide a larger database and provide further verification of the results of this study.

- The research could be extended to cover the Gulf Cooperation Countries (GCC). The off-site risk situation across Europe and the US would provide a compliment to this study. The data would enhance the OCT strategy and provide a useful additional database as the globalisation of OCT increases.
- The research concentrates on all types of projects together. It would be of interest to study the project's success on the basis of individual types (residential/housing, civil engineering, infrastructure, building/industrial building). This can be achieved by collecting more data on individual project types.

References:

Abdul-Hadi, N. Al-Sudairi, A. and Alqahtani, S. (2005) ‘Prioritizing barriers to successful business process re-engineering (BPR) efforts in Saudi Arabian construction industry’.*Construction Management and Economics*, 23(3), pp. 305-15.

Aburas, H. (2011) ‘Off-Site Construction in Saudi Arabia: The Way Forward’ *J. Archit. Eng.* 17, SPECIAL ISSUE: *Residential Construction*, pp.122-124.

Ahuja, V., Yang, J. and Shankar, R. (2010) ‘IT-enhanced communication protocols for building project management’, *Engineering, Construction and Architectural Management*, 17 (2), pp.159-179.

Akintoye, A., Goulding J.S. and Zawdie, G. (2012) *Construction Innovation and Process Improvement*.Wiley-Blackwell.

Alhwairini, A. andFoley, A. (2012) ‘Working towards total quality management in Saudi Arabia",*Education, Business and Society: Contemporary Middle Eastern Issues*, 5 (3), pp.187 – 199.

Al-Khalil, M. and Al-Ghafly, M. (1999a) ‘Delay in public utility projects in Saudi Arabia’, *International Journal of Project Management* 17 (2), pp.101-106.

Al-Khalil, M. and Al-Ghafly M. (1999b) ‘Important causes of delay in public utility projects in Saudi Arabia’, *Construction Management and Economics* 17 (5), pp.647-655.

Al-Kharashi, A and Skitmore, M. (2009) ‘Causes of delays in Saudi Arabian public sector construction projects’, *Construction Management and Economics*, 27 (1), pp.3-23.

Al-Khatam, J.A., (2003) *Building Maintenance Cost*.(Master report), King Fahd University of Petroleum and Minerals.

Almatawa, M. S.,Elmualim, A. &Essah, E.(2012) *Passive and active hybrid approach to buildings design in Saudi Arabia*.in: Eco-Architecture,pp: 5-7 Sept, Kos, Greece.

Alotaibi, F.,Yusoff.F, and Islam.R, (2013) ‘Assessing the impact of total quality management practices and quality culture with competitiveness of Saudi contractors’. *American Journal of Applied Sciences*, 10 (6), pp. 638-645.

Al-Saqer, K. M. (2001) An investigation into the development processes and project management practices of government construction projects in Saudi Arabia.*PhD thesis, University of Birmingham, UK.*

Alshawi, M. (2007) Rethinking IT in Construction and Engineering*: Organisational Readiness*. Taylor & Francis.

Al-Rasheed.M,(2006) *Contesting the Saudi State: Islamic Voices from a New Generation.* Cambridge, UK.

Al-Sultan, A. (1989) Determination of Construction Contract Duration for Public Projects in Saudi Arabia.*Master's thesis submitted to the King Fahad University of Petroleum and Minerals,* Saudi Arabia.

Alwatan (2009) Local newspaper report about King Abdullah University of Science and Technology.Available at www.alwatan.com.sa, (Accessed 22 September 2009 and 12 October 2009).

AMA (2002) *The UK Prefabricated Buildings Market Report 2002*. Cheltenham: AMA Research.

Amaratunga, D., Braldry, D., Sarshar, M. and Newton, R. (2002) 'Quantitative and Qualitative Research in the Built Environment: Application of "Mixed" Research Approach'. *Work Study*, 51(1), pp.17-31.

Arabian Business (2007).Available at www.arabianbusiness.com (Accessed 10 September 2009).

Arif, M. (2009) 'Editorial – Special issue on offsite manufacturing', *Construction Innovation*, 9 (1), pp.5-6.

Arif, M. and Egbu, C. (2010) 'Making a Case for Offsite Construction in China', *Engineering, Construction and Architectural Management*, 17 (6), pp.536-548.

Assaf, A. and Al-Hejji, S. (2006) 'Causes of delay in large construction projects in Saudi Arabia', *International Journal of Project Management* 24 (4), pp.349-357.

Assaf, S. A., Al-Khalil, M, and Al-Hazmi, M. (1995), "Causes of Delay in Large Building Projects". *Journal of Management in Engineering*, 11(2), pp.45-50.

Azman, M.N.A., Ahamad, M.S.S., Majid, T.A. and Hanafi, M.H. (2010) 'The Common Approach in Off-site Construction Industry', *Australian Journal of Basic and Applied Sciences*

Ball, M. (1998) 'Chasing a snail: innovation and housebuilding firms' strategies', *Housing Studies*, 14 (1), pp.9-22.

Barker, K. (2003) *Review of Housing Supply: Securing our Future Housing Needs, Interim Report – Analysis.* London: HMSO.

Barlow, J. (1999) ‘From craft production to mass customization. Innovation requirements for the UK house building industry’, *Housing Studies*, 14 (1), pp.23-42.

Barret, J. and Weidmann, T. (2007) *A Comparative Carbon Footprint Analysis of On-Site Construction and an Off-Site Manufactured House*. Stockholm, Sweden: Stockholm Environment Institute.

BDA (2005) ‘Brick is back’. *Brick Development Association (BDA), Windsor*.Available at www. brick.org.uk

Becker, P. (2005) *StepChange – Innovation, Attitude and Business Benefits*. London, UK: DTI & TRADA.

Bell, P. (2009) *Kiwi Prefab: Prefabricated Housing in New Zealand*. Masters Dissertation.Victoria University of Wellington.

Belli, G. (2008). *Non experimental Quantitative Research*. Available from: http://media.wiley.com/product_data/excerpt/95/04701810/0470181095-1.pdf

Ben Mansur.A, (2013).*How Trust Factors Affect Business Relationships in Saudi-Arabian Companies*. (PhD Thesis**),** University of Salford. UK.

Berg, B. (2004) *Qualitative Research Methods for the Social Sciences*.5th edition. London: Allyn and Bacon.

Blismas, N. (2007) *Off-site manufacture in Australia: Current state and future directions*. Brisbane: Cooperative Research Centre for Construction Innovation.

Blismas, N. and Wakefield, R. (2009) ‘Drivers, Constraints and the Future of Offsite Manufacture in Australia’, *Construction Innovation*, 9 (1), pp.72-83.

Blismas, N., Pasquire, C. and Gibb, A. (2006) ‘Benefit evaluation for off-site production in construction’, *Construction Management and Economics*, 24 (2), pp.121-130.

Blismas, N.G., Pendlebury, M., Gibb, A. and Pasquire, C. (2005) ‘Constraints to the Use of Off-site Production on Construction Projects’, *Architectural Engineering and Design Management*, 1, (3), pp.153-162.

Brewer, G. and Runeson, G. (2009) ‘Innovation and Attitude: Mapping the profiles of ICT decision-makers in architectural, engineering and construction firms’, *International Journal of Managing Projects in Business*, 2 (4), pp.599-610.

Bryman, A. (2008) *Social Research Methods*.3rd edition.Oxford University Press.

Bryman, A. and Bell, E. (2007) *Business Research Methods*.2nd edition. New York:

Oxford University Press Inc.

Build Offsite (2006) Leaflet of Build Offsite: ‘Promoting Construction Offsite’, London: Build Offsite.

CACPUCI (2009) *Advancing the Competitiveness and Efficiency of the U.S. Construction Industry*. Washington DC: National Research Council.

Cera, C.D., Regli, W.C., Braude, I., Shapirstein, Y. and Foster, C.V. (2002) ‘A Collaborative 3D Environment for Authoring Design Semantics’, *IEEE Computer Graphics and Applications*, 22 (3), pp.43-55.

Chen, W. S., and Hirschheim, R. (2004). "A paradigmatic and methodological examination of information systems research from 1991 to 2001". *Information Systems Journal*, 14(3), 197-235.

Chiang, Y.H., Chan, E.H.W. and Lok, L.K.L. (2006) ‘Prefabrication and Barriers to Entry – A Case Study of Public Housing and Institutional Buildings in Hong Kong’.*Habitat International*, 30 pp.482-499.

Chidambaram, R., Narayanan, S. P., &Idrus, A. B. (2012) ‘Construction delays causing risks on time and cost – a critical review’, *Australasian Journal of Construction Economics and Building*, 12 (1), pp. 37-57.

Churchill, G. (1991). *Marketing Research: Methodological Foundations*. The Dryden Press, Fort Worth, TX.

Churchill, G.A. and Iacobucci, D. (2002), *Marketing Research: Methodological Foundations*. Harcourt College Publishers, Forth Worth, TX.

CIDB (2013) Construction Industry Development Board Malaysia.Available at http://www.cidb.gov.my/cidbweb/index.php?lang=en (Accessed April 2013).

Creswell, J. W. (2009). *Research design: Qualitative, Quantitative, and Mixed Methods Approach*, 3rd ed. SAGE Publications. London.

Coaldrake, William H. (1996) *Architecture and Authority in Japan.* London & New York: Routledge.

Collis, J. and Hussey, R. (2009) *Business research: A practical guide for undergraduate and postgraduate students*. Basingstoke: Palgrave Macmillan.

Construction Industry Council (CIC) (2013) *Offsite Housing Review*. February 2013, Miles, J. and Whitehouse, N. (eds.), London: CIC.

Construction Industry Training Board (CITB) (2011) *Training and Skills in the Construction Sector*. Available at http://www.citb.co.uk/Documents/research/Training-Skills-Survey-Reports_tcm17-27270.pdf (Accessed April 2012).

Construction Skills (2008) *2020 Vision – The Future of UK Construction*. London: CITB.

CRC (2007a).*Off-site Manufacture in Australia: Current State and Future Directions*. CRC Construction Innovation. Canberra, Australia: Cooperative Research Centres.

CRC (2007b) *'Offsite Manufacture in Australia – Final Report', in Fussell*, T. (ed.). Canberra, Australia: Cooperative Research Centre for Construction Innovation (CRC).

Creswell, J. (1994) *Research Design: Qualitative and Quantitative Approaches*. Thousand Oaks, CA: Sage Publications.

Creswell, J.W. (2009) *Research Design: Qualitative, Quantitative, and Mixed Methods Approach*. 3rd edition. London: SAGE Publications.

Crotty, M. (1998) *The Foundations of Social Research: Meaning and Perspective in the Research Process*. London: Sage Publications.

Dai, X.C. (2001). *The role of the project management office in achieving project success*. W. G. Wells, Jr. United States -- District of Columbia, The George Washington University.

De Vries, B., Verhagen, S. and Jessurun, A. J. (2004) 'Building Management Simulation Centre', *Automation in Construction*, 13 (5): pp.679-687.

Denscombe M. (1998). *The Good Research Guide: For Small-scale Social Research Projects*. Buckingham: Open University Press.

Denzin, N. and Lincoln, Y. (2000) *Handbook of Qualitative Research*, 2nd edition. London: Sage

Dillman, D.A. (2007) *Mail and Internet Survey: The Tailored Design Method*. 2nd edition.Hoboeken, NJ: Wiley.

Driver, M. (2005) Brick Bulletin, (Autumn),London, UK.

DTI (2003) *Innovation Report – Competing in the Global Economy: The Innovation Challenge*. London: HMSO.

Easterby-Smith, M., Thorpe, R. and Lowe, A. (2002) *Management Research: An Introduction*.4th edition. London: Sage.

Easterby-Smith, M., Thorpe, R. and Lowe, A. (2008) *Management Research*.3rd edition.Sage Publications Ltd.

Eastman.C, Teicholz.P, Sacks.R, Liston.K, (2008) *BIM Handbook, A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors.* John Wiley & Sons, Hoboken, New Jersey, USA

Edge, Martin, *et al.* (2002) *Overcoming client and market resistance to prefabrication and standardisation in housing*.Research report of department of trade and industry, UK.

Egan, J. (1998) *Rethinking Construction: The Report of the Construction Task Force to the Deputy Prime Minister*. London: DTI.

Eickmann, J.A. (1999) *Prefabrication and preassembly trends and effects on the construction workforce*.M.S.thesis, The University of Texas at Austin.

Falqi, I. (2004) *Delays in Project Completion: A comparative study of construction delay factors in Saudi Arabia and the United Kingdom*, Masters dissertation. Heriot-Watt University, Edinburgh, UK.

Faso, B., d'Ivoire, C., Macedonia, F. Y. R., Federation, R., Leone, S., Islands, S., & Venezuela, R. B. (2010) Investing Across Borders. Retrieved from http://iab.worldbank.org/~/media/FPDKM/IAB/Documents/IAB-report.pdf

Fellows, R. and Liu, A. (2008) *Research Methods for Construction*.4th edition.Blackwell Science.

Fernandez,J (2005) *Material Architecture; Emergent Materials for Innovative Buildings and Ecological Construction,* Routledge.

Field, A. (2009) *Discovering Statistics Using SPSS*. 3rd edition. London: SAGE Publications Inc.

Finnimore, B. (1989) *Houses from the Factory: System Building and the Welfare State 1942-74*. London: Rivers Oram Press.

Forbes, L.H. and Ahmed, S.M. (2010) *Modern Construction: Lean Project Delivery and Integrated Practices*. Florida: CRC Press, Taylor & Francis Group.

Fruchter, R. (1998) 'Internet-based Web Mediated Collaborative Design and Learning Environment', in *Artificial Intelligence in Structural Engineering Lecture Notes in Artificial Intelligence*.Ed.Smith, I., Springer, 1454, pp.133-145.

Gann, David M. (1996) 'Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan', *Construction Management and Economics*, 14, pp.437-450.

Gann, D. and Senker, P. (1993) 'International trends in construction technologies and the future of housebuilding', *Future*, January/ February.

Gelo, O., Braakmaan, D. and Benetka, G. (2008). "Quantitative and qualitative research: Beyond the debate". *Integrative Psychological and Behavioral Science*, 42(3), 266-290.

Gibb, A and Pendlebury, M. (2005) *Build offsite – promoting construction offsite: glossary of terms*. Version 1.2, Build Offsite, June 2005, UK.

Gibb, A.G.F. (1999) *Off-site Fabrication: Prefabrication, Pre-assembly and Modularisation*. Caithness: Whittles Publishing.

Gibb, A.G.F (2001) *Off-site fabrication: Prefabrication, Pre-assembly and Modularization*. Whittles Publishing.

Gibb, A.G.F. and Isack, F. (2003) 'Re-engineering through Pre-assembly: Client Expectations and Drivers', *Building Research and Information*, 31 (2), pp.146-160.

Gilbert, N. (2008) *Researching Social Life*. 3rd edition. SAGE Publications Ltd.

Glesne, C., &Peshkin, A. (1992) *Becoming Qualitative Researchers: An Introduction*. White Plains, NY: Longman

Goodier, C., Gibb, A., Ashley, D. and Taylor, M. (2005) *Build Offsite Glossary of Terms*, Version 1.2, May, London: Build Offsite.

Goodier, C.I. and Gibb, A.G.F. (2007) 'Future opportunities for offsite in the UK'.*Construction Management and Economics*, 25(10), pp. 585–95.

Goulding, J.S. and Lou, E.C.W. (2013) 'E-Readiness in Construction: An Incongruous Paradigm of Variables', *Journal of Architectural Engineering and Design Management*, 9 (2)

Goulding, J.S. and Pour Rahimian, F. (2012) 'Industry Preparedness: Advanced Learning Paradigms for Exploitation', in Akintoye, A., Goulding, J.S. and Zawdie, G. (eds.), *Construction Innovation and Process Improvement*. Wiley-Blackwell, pp.409-433.

Goulding, J., Nadim, W., Petridis, P. and Alshawi, M. (2012) 'Construction Industry Offsite Production: A Virtual Reality Interactive Training Environment Prototype', *Advanced Engineering Informatics*, 26 (1), pp.103-116.

Goulding, J., Sexton, M., Zhang, X., Kagioglou, M., Aouad, G.F. and Barrett, P. (2007) 'Technology adoption: breaking down barriers using a virtual reality design support tool for hybrid concrete', *Construction Management and Economics*, 25 (12), pp.1239-1250.

Gu, N. and London, K. (2010) ‘Understanding and facilitating BIM adoption in the AEC industry’, *Automation in Construction*, 19 (8), pp.988-999.

Gummesson, E. (2000) *Qualitative Methods in Management Research*.2nd Edition. Thousand Oaks, CA: Sage.

Haas, Carl. T. (2000) *Prefabrication and preassembly trends and effects on the construction workforce*.Center for Construction Industry Studies, Report No.14.

Haas, C. and Fagerlund, W.R. (2002) *Preliminary Research on Prefabrication, Pre-assembly, Modularization and Off-site Fabrication in Construction*. Austin, USA: University of Texas at Austin.

Haas, C., O’Connor, J.T., Eickmann, J.A. and Fagerlund, W.R. (2000) *Prefabrication and Preassembly Trends and Effects on the Construction Workforce*. Austin, USA: Center for Construction Industry Studies, The University of Texas at Austin.

HAC (2011) *Preserving Affordable Manufactured Home Communities in Rural America: A Case Study*. Washington, USA: Housing Assistance Council.

Hair, J., Anderson, R., Tatham, R. and Black, W. (2003) *Multivariate Data Analysis*, 6th edition. Upper Saddle River: Prentice-Hall.

Hair, J., Black, W., Babin, B., and Anderson, R. (2009). *Multivariate Data Analysis*. Prentice Hall.

Hair, J, F., Celsi, M.W., Money, A.H., Samouel, P. and Page, M.J. (2011) *Essentials of Business Research Methods*.2nd edition. New York: M. E. Sharpe.

Hampson, K. and Brandon, P. (2004).*Construction 2020: A vision for Australia’s Property and Construction Industry*. Brisbane, Australia: Cooperative Research Centres (CRC).

Hollensen, S. and Schmidt, M. (2006) *Marketing Research: an International Approach*. Essex: Pearson Education Ltd.

Höök, M. and Stehn, L. (2008) ‘Applicability of lean principles and practices in industrialised housing production’, *Construction Management and Economics*, 26 (10), pp.1091-1100.

Howard, K. and Sharp, J.A. (1996) *The Management Of A Student Research Project*. 2nd edition. Aldershot: Gower.

Huang.H.J, Dastmalchian.A, (2006) "Implications of trust and distrust for organizations: Role of customer orientation in a four-nation study", *Personnel Review*, 35 (4), pp.361 –

377.

Hussey J. and Hussey R. (1997) *Business Research: A practical guide for undergraduate and postgraduate students*. London: Macmillan.

Isikdag, U., Underwood, J. and Kuruoglu, M. (2012) 'Building Information Modelling', in Akintoye, A., Goulding, J.S., and Zawdie, G. (eds.), *Construction Innovation and Process Improvement*.Wiley-Blackwell.

Jaillon, L. and Poon, C. S. (2010) Design Issues of Using Prefabrication in Hong Kong Building Construction, *Construction Management and Economics*, 28, pp. 1025- 1042.

Jaillon, L and Poon, C.S. (2008) Sustainable Construction Aspects of using Prefabrication in Dense Urban Environment: a Hong Kong case study', *Construction Management and Economics*, 26,pp. 953–966.

Jaillon, L. and Poon, C.S. (2009) 'The Evolution of Prefabricated Residential Building Systems in Hong Kong: A Review of the Public and Private Sector', *Automation in Construction*, 18 pp.239-248.

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

Jharkharia, S., & Shankar, R. (2005) 'IT-enablement of supply chains: understanding the barriers', *Journal of Enterprise Information Management*, 18(1), pp:11-27.

Johnson, B. (2001). "Toward a new classification of nonexperimental quantitative research". *Educational Researcher,* 30(2), 3-13.

Johnsson.H, Meiling .J, (2007) ' Defects in offsite construction: timber module prefabrication'. *Construction Management and Economics,* 27 (7), pp. 667-681.

Joint Practice Notes, (2001) Hong Kong. Retrieved from http://www.bd.gov.hk/english/documents/joint/JPN01.pdf)

Jones.A.E, Bussell.M.N, (2010), 'Robustness and the relevance of Ronan Point today', *The Structural Engineer*.88 (23/24).Retrieved from www.thenbs.com/nbsTV/studyNotes/313261RES.pdf

Kelly, R. (2009) 'Your Guide to Specifying Off-site Manufacture. Maximising Value and Minimising Risk',

Kerlinger, F.N. (1986). *Foundations of behavioral research* (3rd ed.). New York: Holt, Rinehart & Winston.

Koskela, L. and Vrijhoef, R. (2001) 'Is the current theory of construction a hindrance to innovation?',*Building Research & Innovation*, 29 (3), pp.197-207.

Krar, S. and Gill, A. (2003) *Exploring Advanced Manufacturing Technologies*. New York: Industrial Press Inc.

Kumar, R. (2005) *Research Methodology*, 2nd edition. SAGE Publications Ltd.

Latham, M. (1994) *Constructing the Team*. London: HSMO.

Leedy, P.D. and Ormrod, J.E. (2001) *Practical Research: Planning and Design*. 7th edition. New Jersey: Pearson Educational International and Prentice Hall.

Lim.J, Schultmann,.F, Ofori .G, (2010)'Tailoring Competitive Advantages Derived from Innovation to the Needs of Construction Firm's', *Journal of Construction Engineering and Management*, 136 (5), pp:568-580.

Lim, S., Buswell, R.A., Le, T.T., Austin, S.A., Gibb, A.G.F. and Thorpe, T. (2012) 'Developments in construction-scale additive manufacturing processes', *Automation in Construction*, 21 pp.262-268.

Ling, F.Y.Y. (2003) 'Managing the implementation of construction innovations', *Construction Management and Economics*, 21 (6), pp.635-649.

Lincoln, Y.S. and Guba, E.G. (1985). *Naturalistic Inquiry*. Beverly Hills, CA: Sage Publications.

Liska, Roger W. and Piper, Christine (1999) *Attracting and maintaining a skilled workforce.* Construction Industry Institute, University of Texas at Austin.

Long, D (2005) *Culture and Customs of Saudi Arabia.*.Penn State Press.

Lopez, Liliana.(2013) Induction And Deduction As Entry Points Into Qualitative Data Analysis: How Can Early Analytical Choices Affect The Theorizing Process?.Retrieved from http://aisel.aisnet.org/cgi/viewcontent.cgi?article=1171&context=amcis2013

Love, P.E.D. and Irani, Z. (2004) 'An Exploratory Study of Information Technology Evaluation and Benefits Management Practices of SMEs in the Construction Industry', *Information & Management*, 42 pp.227-242.

Lu, N. (2009) 'The Current Use of Offsite Construction Techniques in the United States Construction Industry'. In Seattle, WA: pp.946-955.

Luo, Y. (2008) *Decision support for prefabrication strategy selection on building* *systems*.PhD.The Pennsylvania State University.

Lusby-Taylor, P., Morrison, S., Ainger, C. and Ogden, R. (2004) *Design and Modern Methods of Construction*. London: The Commission for Architecture and the Built Environment (CABE).

Mahamid, , I. (2014)'Micro and macro level of dispute causes in residential building projects: Studies of Saudi Arabia' *Civil Engineering Department, Hail University, Hail, Saudi Arabia*.doi:10.1016/.

Malhotra, K.N. and Birks, F.D. (2007) *Marketing Research: An applied approach*. 3rd edition. Harlow: Pearson Education Limited.

Mandal, A. S.G. (1994) 'Deshmukh, Vendor selection using interpretive structural modeling (ISM)', *Int. J. Oper. Prod. Manage*. 14 (6), pp. 52-59.

Mayan, M. (2001) *An Introduction to Qualitative Methods: A Training Module for Students and Professionals*. Edmonton: International Institute for Qualitative Methodology.

Mbachu, J. (2009). *Improving Construction Project Delivery Through Automation and Robotics*. 6th International Conference on Construction Project Management (ICCPM), Jeju, Korea.

MBI (2010a) *Improving Construction Efficiency & Productivity with Modular Construction*. Charlottesville, USA.

McCutcheon, R. (1989) 'Industrialised House Building in the UK, 1965-1977', *Habitat International*, 13 (l), pp.33-63.

McDaniel, Carl Jr. and Gates, Roger (1998), *Marketing Research Essentials*, Minneapolis,MN: West Publishers.

McKay, L.J. (2010) *The effect of offsite construction on occupational health and safety*.

Meiling, J. (2010) *Continuous improvement and experience feedback in off-site construction.*Doctoral dissertation, Doctoral thesis.Luleå University of Technology.Department of Civil and Environmental Engineering.Division of Structural Engineering. Timber Structures.

Merlan.A,. Village Voice Architecture. (21.Augest.13) Retrieved from http://blogs.villagevoice.com/runninscared/architecture/

Meyer, J. (2003) 'Questioning design and method: Exploring the value of action research in relation to R&D in primary care', *Primary Health Care Research and Development* 4

(2), pp.99-108.

Middle East Finance and Economy (2005) Available at: www.ameinfo.com.

Miles, M. and Huberman, A. (1994b) *Qualitative Data Analysis: A Sourcebook of New Methods*. London: Sage.

MoC&I (2001) *Kingdom of Saudi Arabia: History, Civilisation, Development*. Saudi Ministry of Culture & Information, Saudi Arabia.

Mohammed.A, (2012) 'Special issue on off-site Construction', *Journal of Architectural Engineering*, 18 (2), pp.67-68.

MOM, MND, (1999) 'Ministry of Manpower', *Ministry of National Development of Singapore Construction*, 21 ,pp: 43.

MOP (1997) *Kingdom of Saudi Arabia: History, Civilisation, Development*. Ministry of Planning, Saudi Arabia.

MOP (2008) *Achievement of the Development Plans: Facts and Figures*. Ministry of Planning, Saudi Arabia.

MOP (2009a) *Saudi Economy Indicators*.Available at http://www.mep.gov.sa.(Accessed 10 September 2009).

MOP (2009b) *Eighteenth Development Plan*. Ministry of Planning.Available at http://www.mep.gov.sa.

MOT (2009) *Railways in Saudi Arabia*.Ministry of Transportation.Available at www.mot.gov.sa.

Morris, N, O, (2011) Using technology in the EFL classroom in Saudi Arabia .(Master report), MA TESOL Collection.Paper 516.Retrieved fromhttp://digitalcollections.sit.edu/ipp_collection/516

Murray, N., Terrence, F. and Aouad, G. (2003) 'A Virtual Environment for the Design and Simulated Construction of Prefabricated Buildings', *Virtual Reality*, 6 pp.244-256.

Na, Lu. (2007) *Investigation of the designers' and general contractors' perceptions of offsite construction techniques in the United States construction industry*.Dissertation.Clemson University.

Nachmias, C. and Nachmias, D., (1992), *Research Methods in the Social Sciences*, London: Edward Arnold.

Nadim, W. (2012) ‘Modern Methods of Construction’, in Akintoye, A., Goulding, J.S. and Zawdie, G. (eds.), *Construction Innovation and Process Improvement*, Wiley-Blackwell.

Nadim, W. and Goulding, J.S. (2009) ‘Offsite Production in the UK: The Construction Industry and Academia’, *Architectural Engineering and Design Management*, 5 pp.136-152.

Nadim, W. and Goulding, J.S. (2011) ‘Offsite Production: A Model for Building Down Barriers: A European Construction Industry Perspective’, *Journal of Engineering, Construction and Architectural Management*, 18 (1), pp.82-101.

Nahmens, I. and Ikuma, L.H. (2012) ‘Effects of Lean Construction on Sustainability of Modular Homebuilding’, *Journal of Architectural Engineering*, 18 (2), pp.155-163.

Naoum, S.G. (1998) *Dissertation research and writing for construction students*, 1st edition. Oxford: Butterworth-Heinemann.

Nawari, N. (2012) ‘BIM Standard in Off-Site Construction’, *Journal of Architectural Engineering*, 18 (2), pp.107-113.

NCB Economist (2003) *Annual Report*.National Commercial Bank, Saudi Arabia.

Newland,P., (2008) *The Cultural Construction of London's East End: Urban Iconography, Modernity and the Spatialisation of Englishness*,Rodopi.

Neuman, W. (2005) *Social research methods: Quantitative and qualitative approach*.6th edition.Allyn& Bacon.

Newland, P., (2008) *The Cultural Construction of London's East End : Urban Iconography, Modernity and the Spatialisation of Englishness*,Rodopi .

Ngowi, A.B., Pienaar, E. and Mbachu, J. (2005) ‘The Globalisation of the Construction Industry – A Review’, *Building and Environment*, 40 pp.135-141.

Ng, S. T., Cheng, K. P., & Skitmore, R. M. (2005). A framework for evaluating the safety performance of construction contractors. Building and Environment,40(10), 1347-1355.

NHBC (2006) *A guide to modern methods of construction*. Amersham: NHBC Foundation.

Niblock.T, (2006) *Saudi Arabia: Power,* Legitimacy and Survival, London and New York.

Noor, K.B.M. (2008) ‘Case Study: A strategic Research Methodology’, *American Journal of Applied Science*, 5 (11), pp.1602-1604.

Nunnally, J.C., and Bernstein, I.H. (1994). *Psychometric theory*. New York: McGraw-Hill.

O'Brien M., Wakefied, R. and Beliveau, Y. (2000) *Industrial the residential construction site*.U.S.Department of Housing and Urban Development Office of Policy Development and Research.

O'Leary, Z. (2004) *The Essential Guide to Doing Research*. London: Sage.

ODPM (2003) *Sustainable Communities: Building for the Future*. London: ODPM.

ODPM (2005a) *Government Response to the House of Commons Environmental Audit Committee Report – Housing: Building a Sustainable Future*. London: The Stationery Office.

Offsite Housing Review (2013), Miles, J. and Whitehouse, N. (eds.), London: Construction Industry Council.

Oppenheim, A.N. (2000) *Questionnaire Design, Interviewing and Attitude Measurement*. London: Print Pub Ltd.

OWBC (2001) *Market Research: Types, Methods and Techniques*. Online Women's Business Centre. Available at http://www.onlinewbc.gov/docs/market/mk_research_types.html#quantitative.

Pan, W. (2006) *Cost Effective and Innovative Solutions Using Offsite Techniques*. Construction Productivity Network (CPN) Members' Report E6103, London: CIRIA.

Pan, W., Gibb, A. and Dainty, A. (2004) *Offsite-MMC in Housebuilding – Perspectives and Practices of Leading UK Housebuilders*. Loughborough: Loughborough University.

Pan, W., Gibb, A.G.F. and Dainty, A.R.J. (2007) 'Perspectives of UK housebuilders on the use of offsite modern methods of construction'.*Construction Management and Economics*, 25, pp.183–94.

Pan, W, &Sidwell, R.(2011) 'Demystifying the cost barriers to offsite construction in the UK', *Construction Management & Economics,* 29(11), pp:1081-1099.

Panuwatwanich, K., Stewart, R.A. and Mohamed, S. (2009) 'Validation of an empirical model for innovation diffusion in Australian design firms', *Construction Innovation: Information, Process, Management,* 9 (4), pp.449-467.

Partington, D. (2000) 'Building grounded theories of management action', *British Journal of Management* 11 (2), pp.91-102.

Pasquire, C., Gibb, A., &Blismas, N. (2004). 'Off-site Production: Evaluating the drivers and constraints'. International Group for Lean Construction, Denmark.

Pasquire, C.L., and Gibb, A.G.F. (2002) 'Considerations for assessing the benefits of standardization and pre-assembly in construction', *Journal of Financial Management of Property and Construction*, 7 (3), pp.151-161

Patton, M.Q. (2002) *Qualitative Research and Evaluation Methods*, (3rd ed.), Thousand Oaks, CA: Sage.

Payne, G. and Payne, J. (2004) *Key Conceptions in Social Research*. London: Sage.

Peterson, C.E. (1948) 'Early American prefabrication', *Gazette des beaux-Arts*, XXXIII .

Phillipson, M. (2003) *Defining the Sustainability of Prefabrication and Modular Process in Construction: Current Practice and Potential Uses of Prefabrication*. Department of Trade and Industry.

POST, P.O.O.S.a.T. (2003) *Modern Methods of House Building*. London, UK: Parliamentary Office of Science and Technology POST.

Pour Rahimian, F. (2012) 'Design Innovation: Advanced Visualisation Futures', in Akintoye, A., Goulding, J.S. and Zawdie, G. (eds.), *Construction Innovation and Process Improvement.*Wiley-Blackwell.

Powell, S.G., Baker, K.R. and Lawson, B. (2008) 'A critical Review of the Literature on Spreadsheet Errors', *Decision Support Systems*, 46 (1), pp.128-138.

Prasad, B. (1996) *Concurrent Engineering Fundamentals: Integrated Products and Process Organization*. Prentice Hall.

Richards, L. (1993) 'Writing a qualitative thesis or grant application', in Beattie, K. (ed.) *So where's your research profile.*

Rivard, H. (2000). 'A Survey on the Impact of Information Technology on the Canadian Architecture, Engineering and Construction Industry'.*Electronic journal of information technology in construction*, 5, pp:37-56.

Riyadh Chamber of Commerce (2004) *Report on construction in the private and public sectors*. Hard copy.

Robson, C. (2002) *Real World Research.*2nd edition.Blackwell publishers.

Russell, B. (1981) *Building Systems, Industrialization and Architecture*. London: John Wiley & Sons.

SAAB (2007) Saudi Arabia Economy, *Thinking Big*.Quarter 4.

Sadafi, N., Zain, M., and Jamil, M. (2012) 'Adaptable Industrial Building System: Construction Industry Perspective', *Journal of Architectural Engineering*, 18 (2), pp.140-147.

SAGIA (2005) *Report on Economic Cities*. Saudi Arabian General Investment Authority. Available at www.sagia.gov.sa.

Sage, A.P, (1977) 'Interpretive Structural Modeling: Methodology for Large Scale Systems', *McGraw-Hill, New York, NY*, pp. 91-164.

Saudi Arabia Economy (2009).Available at www.looklex.com (Accessed 28 September 2009).

Saudi Council of Chambers of Commerce and Industry (1998).Available at http://www.saudichambers.org.sa.

Saudi Arabia Ministry of Municipal and Rural Affairs.(2013). Contractor's Classification. Riyadh: The Ministry's Agency for Contractor's Classification

Saunders, M., Lewis, P. and Thornhill, A. (2003) *Research Methods for Business Students*.3rd edition. Harlow: Financial Times Prentice Hall.

Saunders M., Lewis P. and Thornhill, A. (2007) *Research Methods for Business Students*.4th Edition. Harlow: Financial Times Prentice Hall.

Saunders, M., Lewis, P. and Thornhill, A. (2009) *Research Methods for Business Students*.5th edition. Harlow: FT Prentice Hall.

Sawyer, T. (2006) Demand drives homebuilders to build fast and innovate. ENR, January, 2/9.

Sekaran, U. (2003) *Research Methods for Business*.4th edition. Hoboken, NJ: John Wiley & Sons.

Sexton, M. and Barrett, P. (2003) 'Performance-based building and innovation: balancing client and industry Needs', *Building Research and Information,* 33 (2), pp.142-148.

Shahzad, W.M. (2011) *Offsite manufacturing as a means of improving productivity in New Zealand construction industry: key barriers to adoption and improvement measures*. (Masters report). Massey University, Albany, New Zealand.

Singh, M. D., Shankar, R., Narain, R., &Agarwal, A. (2003)'An interpretive structural modeling of knowledge management in engineering industries', *Journal of Advances in Management Research*, *1*(1), pp:28-40.

Slaughter, E.S. (1998) 'Models of construction innovation', *Journal of Construction*

Engineering and Management, 124 (3), pp.226- 232.

Smith, R.E., (2011) *Prefab Architecture: A Guide to Modular Design and Construction*, John Wiley & Sons, New Jersey, USA

Stephens,(2013). 'The Kingdom of No Surprises', Foreign Policy. Retrieved from http://foreignpolicy.com/2013/02/19/the-kingdom-of-no-surprises/

Stewart, I. and Fenn, P. (2006) 'Strategy: The motivation for innovation', *Construction Innovation*, 6 (3), pp.173-185.

Stewart, R.A., Miller, C., Mohamed, S. and Packham, G. (2003) *Sustainable development of construction small and medium enterprises (SMEs): IT impediments focus*. W78 International Conference on Information Technology in Construction – Construction IT Bridging the Distance, Auckland, New Zealand.

Sterman, J. D. (2002). "System Dynamics Modeling: Tools for Learning in a Complex World."IEEE'.*Engineering Management Review*. 30(1):pp. 42-52.

Straub, D. W. (1989). "Validating Instruments in MIS Research", *MIS Quarterly* (13) 2, pp. 147-169.

Sullivan, K., (2012), In Saudi Arabia, unemployment and booming population drive growing poverty, (03.December.12).The Washington Post. Retrieved from http://articles.washingtonpost.com/2012-12-03/world/35623000_1_saudi-arabia-poverty-rate-royals

Tah, J.H.M. (2012) 'Virtual Planning and Knowledge-based Decision Support', in Akintoye, A., Goulding, J.S. and Zawdie, G. (eds.), *Construction Innovation and Process Improvement*.Wiley-Blackwell.

Tam, V.W.Y., Tam, C.M., Zeng, S.X. and Ng, W.C.Y. (2007) 'Towards Adoption of Prefabrication in Construction', *Building and Environment*, 42 (10), pp.3642-3654.

Tashakkori, A. and Teddlie, C. (2003) *Handbook of Mixed Methods in Social and Behavioural Research*. Thousand Oaks, CA: Sage.

Tatum, C.B., Vanegas, J.A. and Williams, J.M. (1986) *Constructability Improvement Using Prefabrication, Pre-assembly and Modularization*. Construction Industry Institute, Stanford University, California, Technical Report No. 297, November.

Tatum, C.B., Vanegas, J.A. and Williams, J.M. (1987) *Constructability Improvement Using Prefabrication, Preassembly and Modularization.* Construction Industry Institute, The University of Texas at Austin.

Taylor, S. (2009) *Offsite Production in the UK Construction Industry, A Brief Overview. London*. Construction Engineering Specialist Team: HSE. Available at http://www.buildoffsite.com/downloads/off-site_production_june09.pdf (Accessed April 2013).

The Economist Intelligence Unit (2014) ;The Business environment in Gulf Co-operation Council countries. Retrieved from http://www.economistinsights.com/sites/default/files/MERCK%20-%20The%20Business%20environment%20in%20GCC%20countries%20WEB_2.pdf

Thuesen, C. and Hvam, L. (2011) 'Efficient on-site construction: learning points from a German platform for housing', *Construction Innovation: Information, Process, Management*, 11 (3), pp.338-355.

Van de Ven, A.H. (1986) 'Central problems in the management of innovation', *Management Science*, 32 (5), pp.590-607.

Where's your Research Profile? A Research Book for Academics. South Melbourne: Union of Australian College Academics.

Warfield, J.W. (1974) 'Developing interconnected matrices in structural modeling', *IEEE Transcr* 4 (1),pp. 51-81.

Warren.M., (2010) *Architecture in Motion: Change We Can Believe.*(Master report), Unitec, New Zealand.

Waskett,P., (2001) 'DTI Construction Industry Directorate Project Report : Current Practice and Potential Uses of Prefabrication, (30 November 2001). BRE Building Research Establishment Ltd.

Whitaker, B.(2009) *What's Really Wrong with the Middle East.*Saqi.

William, F., & Gibson, D. V. (1990).*Technology Transfer: A Communication Perspective,* Sage: Beverly Hills, CA

Wilson, M.W.Y. (2006) *Prefabrication for Hong Kong's Construction Industry: A study of Barriers and Opportunities*. Master of Science.The University of Hong Kong.

Winch, G. (2003) 'Models of manufacturing and the construction process: the genesis of re-engineering construction', *Building Research & Information,* 31 (2), pp.107-118.

Yau, W.M.W. (2006) *Prefabrication for Hong Kong's Construction Industry: A Study of Barriers and Opportunities*. Master's Thesis.The University of Hong Kong.

Yin, R.K. (2003) *Applications for Case Study Research*.2nd edition. London: Sage

Yin, R.K. (2003) *Case Study Research: Design and Methods*, 3rd edition. Beverly Hills: Sage.

Yin, R. K. (2009) *Case study research: Design and Methods*.4th edition. Thousand Oaks, CA: Sage.

Zain Al-Abedien, H. (1983) *About the effect of delay penalty on the construction of projects and modification proposals*, Proceedings of the First Saudi Engineering Conference, Jeddah, May 14–19.

Zainal, Z. (2007) 'Case Study as a Research Method', *Journal Kemanusiaan*, 9 (1), pp.1-6.

Zikmund,W. G. (2003). *Business research methods*. Ohio-USA: Thomson, South-Western.

Zuhur, S, (2012) Saudi Arabia,Nations in Focus, *ABC Clio, United States.*

Appendix One: Ethical Approval

Academic Audit and Governance Committee

College of Science and Technology Research Ethics Panel (CST)

To **Yasir Ammar Almutairi and Prof Mohamed Arif**

cc: **Prof Mike Kagioglou, Head of School of SOBE**

MEMORANDUM

From **Nathalie AudrenHowarth, College Research Support Officer**

Date 13th May 2013

Subject: **Approval of your Project by CST**

Project Title: **Framework for the implementation of Offsite construction in Saudi Arabia**

REP Reference: **CST 13/57**

Following your responses to the Panel's queries, based on the information you provided, I can confirm that they have no objections on ethical grounds to your project.

If there are any changes to the project and/or its methodology, please inform the Panel as soon as possible.

Regards,

Nathalie Audren Howarth

College Research Support Officer

Appendix Two: Interview Guide

Develop implementation strategies of offsite construction techniques in Saudi Arabia.

Section I. Current Application on Off-site Construction Techniques (OCT)

1. Have you utilized the OCT in your previous project recently? In which of the Following construction categories: residential, commercial, industrial or heavy construction?

2. What percent of OCT being utilized accounted for the overall production?

3. What the techniques you have utilized in your project?

4. How would you summaries your experience of OCT?

5, Do you believe utilizing OCT help you (or diminish your ability) to provide a higher level of customer satisfaction?

7. What kind of project or building sectors would be more appropriate for OCT by your understanding?

Section II Benefits of utilizing OCT

1. What are the motivations to use OCT in your project?
2. Did OCT help you solve the lack of skilled labour issue?
3. 3. Did utilizing OCT increase the project quality? Or increase the predictability of project outcomes?
4. Did utilizing OCT greatly reduce the project schedule?
5. Did utilizing OCT greatly improve the project safety performance?
6. Did utilizing OCT reduce onsite disruption of adjacent operations?
7. Did utilizing OCT increase the labour productivity?
8. Are there any other benefits you (your company) have experienced?

Section III Barriers of utilizing OCT

1. Is the increased complexity of project planning system the one of the barriers?

2. Did the local planning department and code department support the OCT or not?

3. Is there any manufacturing company you preferred? Have you (your company) experienced any logistic problem?

4. Have you experienced any resistance from union organization or other local construction organizations?

5. Do you think the design inflexibility is one of the challenges?

6. Does OCT have less construction error tolerance compared to conventional techniques? If yes, is that one of the primary challenges?

7. Have you experience any failure because of the manufacturing delay or bad quality, or transportation issue?

8. Are there any specific barriers you have personally experienced?

<u>Section V Opportunities that OCT provides</u>

1. Would you like to use OCT more along with increased design flexibility?

2. What are the primary determining factors of using OCT or not in a project?

3. Would you adopt the OCT more widespread if your major competitor using it more?

4. Would you adopt the OCT more widely if the resources are available in your operational areas? (Qualified manufacturers, skilled assembling labors, etc)

5. Do you believe the utilizing the OCT will increase or decrease in next decades?

6. Are there any other factors would influence you adopting the OCT?

7. Do you suggest any recommendations to implement OCT in Saudi Arabia?

Appendix Three: Questionnaire

Develop implementation strategies of offsite construction techniques in Saudi Arabia.

The questionnaire is divided into the following sections:

1. Respondent Background
2. The Techniques of Off-Site Construction
3. Factors related to Off-Site Construction Techniques
4. Reasons of using Off-site construction Techniques
5. challenges of using Off-site construction Techniques

This questionnaire has been designed to elicit your opinions on the topic of the implementation of Offsite construction in Saudi Arabia, and the factors that could influence the success of off-site construction. When answering the questions, please think of the last off-site construction project in which you were most recently involved.

Please answer the following questions by putting [X] mark in the boxes.

<table>
<tr><th colspan="2">Part One: Respondent Background</th></tr>
<tr><td>1. Your original field of study:
1.[ ] Engineering
2.[ ]architecture
3.[ ] management
4.[ ] other, specify: ………………….</td><td>2. Your highest educational level:
1.[ ] Below Bachelor
2.[ ] Bachelor
3.[ ] PhD
4.[ ] Master</td></tr>
<tr><td>3. Communication with other workers :
1.[ ] Extremely good
2.[ ] Very good
3.[ ] Good
4.[ ] Not very good
5.[ ] Not at all</td><td>4. Your experience of Offsite construction: (in years)
1.[ ] <5
2.[ ] 5-10
3.[ ] 11-15
4.[ ] 16-20
5.[ ] > 20</td></tr>
<tr><td colspan="2">5. Tick top 3 of your design work
1.[ ] Residential
2.[] commercial
3. [ ] industrial
4. [ ] Institutional
5. [ ] Government
6.[ ] private company
7.[] Others, specify: ....</td></tr>
<tr><th colspan="2">Part Two: The Techniques of Off-Site Construction</th></tr>
</table>

6. **Please indicate the off-site construction technique/s you follow in your workplace.**
1.Off-site preassembly ( )
2.Hybrid system ( )
3.Panelized system ( )
4.Modular Building ( )

7. **Satisfaction of your past experience of using off-site construction techniques.**
Off-site preassembly:
[ ] not satisfied at all [ ] Dissatisfied [ ] Neutral [ ] Satisfied [ ] extremely satisfied
Hybrid system:
[ ] not satisfied at all [ ] Dissatisfied [ ] Neutral [ ] Satisfied [ ] extremely satisfied
Panelized system:
[ ] not satisfied at all [ ] Dissatisfied [ ] Neutral [ ] Satisfied [ ] extremely satisfied
Modular Building
[ ] not satisfied at all [ ] Dissatisfied [ ] Neutral [ ] Satisfied [ ] extremely satisfied

Part Three: Factors related to Off-Site Construction Techniques

8. **Off-site construction techniques reduce the overall project schedule.**
[ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree

9. **Off-site construction techniques reduce the need for more skilled craft workers onsite.**
[ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree

10. **Off-site construction techniques increase product quality.**
[ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree

11. **Off-site construction techniques increases overall labour productivity.**
[ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree

12. **Off-site construction techniques limit design options**
[ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree

13. **Off-site construction techniques increase safety performance.**
[ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree

14. **Off-site construction techniques increased sustainability.**
[ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree

15. **Off-site construction techniques reduce environmental impact of construction operations.**
[ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree

16. Off-site construction techniques increase project design efficiency. [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
17. Off-site construction techniques Increase initial cost.. [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
18. Off-site construction techniques decreases the overall project cost. [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
19. Transportation restraints (i.e. size constraints, transportation cost, impact on building structures) limit the use of off-site construction techniques [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
20. The owner's negative perception of off-site construction techniques limits the use of those techniques. [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
21. Off-Site construction techniques limits the ability to make change onsite work [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
22. Off-Site construction techniques Increase the complexity for maintenance. [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
23.Offsite construction require Reduce the construction waste [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
24 Offsite construction Increase property marketing value [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
25. Using offsite construction required high use of IT in a construction industry. [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
26. Offsite construction has a Lack of available codes and standards [ ] Strongly Disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly Agree
27. Do you expect that using off-site construction techniques will increase in the upcoming years? **Yes. State why (Please by as specific as possible)** **No. State why (Please by as specific as possible)**
28. Please provide any other benefits or barriers of specifying off-site construction techniques that were not listed above.

Part Five: Reasons of using Off-site construction Techniques

29. Please rank top 3 reasons:

Reasons	rank
A. Project owners require using off-site construction techniques	
B. To compensate for the shortage of skilled craft workers	
C. To compensate for the local weather conditions	
D. To reduce design duration	
E. To reduce construction duration	
F. To reduce project overall schedule	
G. To reduce overall project cost	
H. To increase product quality	
I. To increase overall labour productivity	
J. To compensate for the restricted working space onsite	
K. To reduce environmental impact	
L. To improve project safety performance	
M. To increase your company's profit margin	
N. To enhance your company's reputation	
O. Any other reasons:	

Part six: challenges of using Off-site construction Techniques

30. Please rank top 3 challenges:

Challenges	rank
A. The project owners do not allow using off-site construction techniques.	
C. General contractors do not have expertise of assembling prefabricated building components onsite.	
D. The local zoning ordinance restricts the use of off-site construction techniques.	
E. The local building regulation restricts the use of off-site construction techniques.	
F. The financial institution restricts the use of off-site construction techniques.	
G. Designing off-site construction components requires special computer Software.	
H. Lack of skilled assembly craft works locally.	
I. Using off-site construction techniques will increase the design cost.	
J. Using off-site construction techniques will increase the construction cost.	
K. Transportation restraints	
L. Limited design options of using off-site construction techniques.	
M. Inability to make changes in the field by using off-site construction techniques.	
N. Any other reasons:	

Appendix Four: Questionnaire Data

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
R1	1	2	3	5	1, 5	4	O5, H3, P3, M5	5	5	4	3	4	5	4	5	3	2	5	2								E, F, G	E,K,L
R2	1	2	2	1	5	4	O3, H3, P3, M5	4	3	5	3	4	4	3	2	4	3	3	5	4	3	2	3	3	4	4	C, H, N	C,E,G
R3	1	2	1	2	5, 7	1	O5, H4, P5, M4	4	5	4	5	4	5	4	5	2	2	3	4	4	5	4	4	2	5	4	D, F, K	G,J,L
R4	2	4	2	1	1, 2, 5		O3, H3, P4, M4	4	4	4	4	5	4	4	5	3	3	4	4	4	5	2	3	4	4	3	A, H, L	F,I, J
R5	1	2	3	1	5	O2, H1, P3, M4	O3, H4, P3, M4	5	4	5	4	4	5	5	4	5	5	4	4	4	3	3	4	4	3	3	E2,F1, H3	C1, I3,J2
R6	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2, G1	I3,L1,M2
R7	1	2	1	5	1, 5, 7	O3, H2, P4, M1	O5, H3, P2, M4	1	4	4	5	3	3	3	3	3	4	2	3	4	4	2	2	2	4	2	A2,F1,I3	H1, J2, M3
R8	1	2	3	2	2, 3, 5	O1, H4, P3, M2	O5, H4, P4, M4	3	2	4	4	4	4	3	4	5	2	4	4	3	4	2	2	1	2	1	E1,G3,I2	C1, F3, H2
R9	1	4	2	1	5, 6	O4, H2, P1, M3	O3, H4, P5, M4	5	2	5	4	4	4	5	4	5	2	4	4	3	4	2	2	1	2	1	E1,G3,I2	C1, F3, H2
R10	1	2	1	2	1, 2, 3	O3, H2, P1, M4	O3, H4, P5, M5	5	5	4	4	3	2	4	4	4	2	2	4	4	4	4	4	4	2	3	B2,E1, G3	E2, K3, M1
R11	2	2		4	4	O1, H3, P2, M4	O3, H4, P5, M5	5	5	5	3	3	5	5	5	3	3	3	4	4	4	4	4	4	2	4	B2,E1, G3	E2, K1
R12	1	2	1	2	1, 5, 6	O3, H4, P1, M2	O5, H4, P4, M4	5	4	5	4	2	4	4	5	4	3	4	2	2	4	2	1	2	3	1	E1,F2,J3	C1, G2, K3
R1	1	2	1	2	1, 2,	O3, H4,	O3, H3,	4	4	5	3	2	4	5	4	4	2	4	3	4	4	3	4	3	3	2	E2,F	A2, C1,

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
3					5	P1, M2	P4, M5																				3, G1	E3
R14	1	2	2	3	1, 2, 6	O1, H2, P3, M4	O4, H4, P4, M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D2, G3	A1, E2, G3
R15	1	2	2	1	4, 5	O1, H4, P3, M2	O4, H3, P2, M4	5	4	4	5	3	3	3	3	3	5	1	4	3	5	1	2	2	3	2	F1,I2, N3	H2, J1, M3
R16	1	2	1	4	6	O, H, B	O4, H4, P5, M3	4	3	4	3	2	4	4	5	4	3	5	2	2	4	2	2	3	3	1	E1,F2, M3	A2,I3,J1
R17	2	3	3	4	5	P	O3, H3, P4, M5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	4	2	A	G
R18	1	2	2	1	1, 3, 5	O, P, M	O4, H2, P3, M5	5	5	3	4	2	4	4	2	5	2	5	4	4	3	4	2	4		5	E, G,I	A,H,K
R19	1			2	1	O, P	O4, H2, P5, M1	5	4	5	5	3	4	2	2	4	2	4	4	2	4	4	2	4	3	1	E, F, H	C
R20	1	2	2	1	1, 2, 4		O4, H4, P5, M5	4	2	4	4	3	4	4	5	5	3	4	4	4	5						E1,G2, H3	A2, C2, F1
R21	1	2	2	1	1, 5, 6	P	O4, H4, P4, M4	4	4	5	5	4	4	3	5	4	4	4	2	4	4	3	3	3	4	3	E, F, H	I,J, M
R22	1	2	3	2	5	O3, H2, P4, M1	O5, H3, P2, M4	4	4	4	4	4	3	5	5	5	5	2	4	4	4	4	2	2	3	3	D3,E1, H2	A1, C2, H3
R23	1	2	2	2	5	O1, H4, P3, M2	O5, H4, P4, M4	4	4	4	4	4	5	4	4	5	2	2	4	4	4	4	3	4	3	3	D1,E2, F3	A1, F2, J3
R24	1	2	3	2	5			4	4	5	4	4	3	5	3	3	4	2	4	4	4	4	2	3	3	3	E1,F3, H2	A1, C2, I3
R25	1	2	2	2	5	O1, H4, P3, M2	O4, H3, P2, M4	4	4	4	4	4	3	4	4	4	4	2	5	4	4	4	3	4	3	3	E1,F3, H2	C3, I1,J2

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
R26	1	2	3	2	3,5,6		O3,H4,P4,M4	5	4	4	2	4	4	3	4	4	4	5	5	4	4	3	4	3	3	2		
R27	1	2	3	2	5	O4,H3,P2,M1	O3,H3,P4,M4	4	4	5	5	4	3	4	5	4	2	4	5	4	4	3	2	3	2	2	E1,H2,O3	C1,J3,M2
R28	3	2	1	5	1,3,5	M	O4,H4,P4,M4	4	4	4	4	4	4	4	4	3	4	3	3	3	3	4	4	3	4	3	E,G,M	C,H,J
R29		4	1	2			O3,H3,P4,M4	5	1	5	4	5	2	2	4	3	2	3	5	4	5	4	2	3	2	2	E3,H2,O1	C1,J2,M3
R30	2	2	3	1	2,4,6	P	O3,H3,P3,M3	4	2	4	3	5	3	3	3	3	3	3	4	4	5	3	3	3	3	3	E,H,I	A,K,L
R31	1	2	3	2	1,2,6	H	O3,H4,P4,M4	3	4	3	3	2	3	4	2	3	2	2	3	3	2	3	2	4	2	4	E2,F3,I1	
R32	2	2	2	4	1,2,5	M	O5,H4,P5,M5	5	4	4	5	4	5	3	4	5	3	5	4	5	2	4	3	4	3	2	E,G,J	A,C,E
R33	1	2	2	1	1,5,6	O	O4,H4,P4,M4	4	2	3	4	2	3	4		3	3	2	4	4	3	3	2	4	4	2	C,E,J	A,C,L
R34	1	2	3	1	6	H,M	O4,H4,P3,M3	5	4	4	4	4	3	3	4	2	3	3	4	5	4	3	2	4	4	4	E,G,H	A,C,K,M
R35	1	4	2	3	7	O,P	O4,H4,P4,M4	4	2	3	4	2	3	4	4	3	3	3	2	4	3	3	2	4	4	2	C,E,J	A,C,L
R36	1	4	1	1	6	O	O4,H4,P4,M4	4	1	5	5	1	4	3	3	4	3	4	4	4	5	4	1	4	4	1	E,G,H	C,I,K
R37	1	2	2	2	6	O,H,M	O4,H4,P4,M3	4	4	4	4	4	5	3	3	4	2	3	4	5	4	3	2	3	4	4	E,F,H	C,K,M
R3	1	4	1	2	1,4,	H2,P1,	O4,H5,	5	5	5	5	2	4	2	4	4	3	4	4	5	5	4	2	2	4	3	F1,G	C2,H1,

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
8					5	M3	P5, M3																				2, M3	L3
R39	1	2	2	1	3, 5, 6	P, M	O4, H3, P4, M4	5	1	4	3	2	2	4	5	4	5	1	5	3	4	2	4	4	5	3	B, F, H	C,G ,J
R40	1	2	1	5	1, 4, 5	O	O4, H4, P4, M4	4	4	4	4	3	5	3	4	5	3	3	4	3	4	3	2	3	4	3	D1 ,E 2, G3	A1, C2, H3
R41	1	4	3	1	1, 5, 6	O	O4, H4, P4, M4	5	4	4	3	2	3	4	3	3	3	3	4	3	4	3	2	3	3	3	E, F,J	C,K ,M
R42	3	2	2	3		M		4	3	4	4	4	3	2	2			4	4	2	4						A, F,J	D,F ,H
R43	1	2	2	2	2	O2, H3, P4, M1	O4, H3, P3, M4	4	4	4	3	4	4	3	4	3	1	3	3	3	4	3	3	3	3	3		
R44	1	2	1	2	2, 5, 6	O, P		4		4	2	3	3	5	2	3	4	4	4	3	3	3	4	4	3	3	C, H, M	C,F ,K
R45	1	4	2	1	1, 5, 6		O4, H3, P5, M5	4	5	5	2	4	3	4	4	2	3	1	4	4	4	2	2	2	2	2	E, G, H	J,K, M
R46	1	2	3	1	6	O, M	O4, H4, P3, M4	4	2	4	4	3	4	3	4	3	2	4	4	4	4	4	3	2	3	5	A, E, K, M	C,K ,L
R47	1	2	3	2	1, 5, 6	O, P		5	4	3	4	4	3	4	5	3	2	5	3	5	5	3	3	5	4	4		
R48	1	1	2	2	2, 3, 5, 6	O, M	O4, H5, P4, M4	2	4	4	3	2	2	4	5	4	5	1	5	3	1	2	3	4	4	4	E, G,I	C,F ,I
R49	1	4	3	1	6			1	1	1	1	2	2	4	4	2	1	1	4	5	4					2	D, E, H	C,G ,K
R50	1	4	2	2	1, 2, 5	O	O4, H3, P4, M3	4	5	5	5	4	5	4	5	3	5	4	3	3	5	2	4	2	4	4	E, F, H	D,I, J
R51			3	1	5	O		4	4	4	4	3	3	5	5	4	4	4	4	4	4	3	4	3	5	4	E2 ,F 1,J 3	C3, H2, M1

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
R52	1	2	1	3	3, 4, 5	O		5	2	5	4	4	4	4	3	4	2	4	4	2	4	3	4	2	4	4	E, F, H	D,F ,K
R53	1	2	3	1	3	P		5	2	3	4	3	5	2	3	4	5	4	4	4	3	2	2	2	3	2	E, F,I	C,E ,J
R54	4	1	2	1	3, 6	O	O4, H3, P3, M3	4	4	3	3	4	4	4	4	3	3	4	4	3	2	4	3	3	4	3	D, G, K	C,H ,L
R55	4	1	1	1	3, 6	O	O5, H3, P3, M3	5	5	4	5	4	4	4	4	4	2	5	2	2	4	2	2	4	2	1	F3 ,G 1, H2	A,D ,H
R56	1	3	3	1	3, 6	O	O4, H3, P3, M3	4	4	3	4	4	4	4	4	3	2	3	2	1	2	4	2	4	2	2	F, G, H	A,D ,L
R57	1	2	2	1	3, 6	O	O5, H3, P3, M3	5	5	2	4	4	5	4	5	4	2	2	4	4	4	4	2	4	2	2	E2 ,G 1, H3	C3, K1, L2
R58	1	1	3	1	3, 6	O	O5, H3, P3, M3	5	4	2	4	4	4	3	4	4	2	5	3	5	4	5	4	4	3	4	F, G, H	A,C ,D
R59	3	2	2	4	3, 6	O	O4, H3, P3, M3	4	2	2	4	4	4	5	4	3	4	4	5	4	2	5	2	2	2	4	D, G, H	A,C ,I
R60	1	3	3	1	5			3	2	5		2		2	4	4	1	2	3	4	2	2	3	2	2	5	G, H, L	A,E ,J
R61	4	1	3	2	3	O	O4, H3, P3, M3	4	2	2	4	4	4	4	4	4	4	4	4	4	2	2	3	2	2	3	D2 ,E 3, G1	A,C ,D
R62	2	3	2	1	6	M	O4, H4, P4, M4	4	4	4	4	4	4	2	2	4	4	2	4	2	2	4	2	2	4	3	E, G, H	A,E ,L
R63	1	2	2	1	3, 6	O	O4, H3, P3, M3	4	2	4	4	2	1	4	4	4	2	4	4	1	1	1	2	4	4	2	D, E, G	A,C ,H
R64	1	2	2	2	3	O		5	4	5	3	2	4	3	4	4	5	5	3	3	3	2	3	3	3	3	E, G, H	
R6	1	2	2	1	1, 5,	O	O4, H4,	5	5	5	5	4	4	4	4	4	2	2	4	4	4	4	2	2	2	2	B2 ,E	C2, H1,

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
5					6		P4, M4																				1, H3	M3
R66	4	2	2	2	1, 2, 5	O1, H3, P4, M2	O3, H3, P4, M4	3	3	4	3	4	4	3	3	4	4	3	4	4	4	3	2	3	3	2	E1,H3, K2	A1, E2, J3
R67	2		2	2	1, 2, 5	O1, H3, P4, M2	O3, H3, P4, M4	4	4	3	3	4	3	2	3	3	4	4	4	4	4	3	2	3	2	2	E1,F2,I3	A1, F2, J3
R68		2	2		1, 3, 4	O2, H3, P4, M1	O4, H3, P5, M4	5	4	4	3	4	2	2	4	3	4	4	4	3	4	2	2	3	2	2	E1,H2,I3	A1, C2, M3
R69	1	4	2	2	1,2,3,4, 5	O, P		4	2	5	3	2	4	4	4	4	3	4	4	5	5	2	2	2	3	1	E2,G1, H3	C2, H1, K3
R70	1		1	5	2, 5	M	O3, H3, P3, M4	4	1	3	2	5	3	4	2	2	4	2	4	4	4	5	3	4	5	2	A1,B2, E3	A1, C2, H3
R71	1	2	2	3	3, 5	O3, H1, P2, M4	O3, H4, P3, M3	4	3	3	4		4	3	4	3	3	4	4	4	4	4	3	3	3	4		
R72	1	2	2	1	5	O	O5, H3, P4, M2	5	5	5	5	5	5	5	5	5	2	5	5	5	5	2	4	2	4	4	A3,E1, H2	F3, J1, M2
R73			1	5	1, 2, 5	P		5	5	5	5	5	4	3	4	5	4	3	4	3	4	2	4	2	4	4	A3,E1, H2	F3, J1, M2
R74		4	2	1		O		5	3	5	4	5	5	3	4	5	4	3	4	5	4	5	2	2	2	3	B3,E2, M1	F3, K1, M2
R75	1	2	2	1	2, 5, 6	O1, H2, P4, M3	O3, H3, P3, M3	4	4	4	4	4	4	4	4	4	5	2	4	3	4	3	3	3	3	3	A3,D1, F2	C2, I1, M3
R76		1		1		O, P	O3, H3, P3, M3	5	5	5	4	3	5	2	2	5	5	1	4	2	4	2	2	3	3	1	E, F	C
R77	1	2	2	4	1, 5, 6	P	O3, H4, P4, M3	2	4	5	4	2	5	2	3	5	3	3	4	2	2	4	2	2	4	2	B, G, K	E,H,L

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
R78	1	2	3	5	1, 5, 6	O4, H2, P1, M3	O1, H4, P5, M5	5	5	5	5	4	5	4	4	4	3	2	5	4	4	3	4	2	4	2		A3, C1, K2
R79	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	3	4	2	B3,E2,G1	I3,L1,M2
R80	2	4	2	1	1, 2, 5	O2, H3, P4, M1	O3, H4, P4, M4	3	3	5	5	5	5	4	5	5	3	4	3	4	4	3	4	3	4	4	D3,H2,L1	A3, G1, I2
R81	1	2	2	1	1, 2, 6	O4, H1, P3, M2	O3, H4, P5, M3	4	5	5	4	2	5	4	4	3	2	4	3	4	5	3	4	3	4	3	A3,H1,L2	A1, H3, I2
R82	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2,G1	I3,L1,M2
R83	1	2	2	3	1, 2, 6	O1, H2, P3, M4	O4, H4, P4, M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D2,G3	A1, E2, G3
R84	1	2	2	1	4, 5	O1, H4, P3, M2	O4, H3, P2, M4	5	4	4	5	3	3	3	3	3	5	1	4	3	5	1	2	2	3	2	F1,I2,N3	H2, J1, M3
R85	1	2	2	3	1, 2, 6	O1, H2, P3, M4	O4, H4, P4, M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D2,G3	A1, E2, G3
R86	1	2	3	2	2, 3, 5	O1, H4, P3, M2	O5, H4, P4, M4	3	2	4	4	4	4	3	4	5	2	4	4	3	4	2	2	1	2	1	E1,G3,I2	C1, F3, H2
R87	1	2	2	1	4, 5	O1, H4, P3, M2	O4, H3, P2, M4	5	4	4	5	3	3	3	3	3	5	1	4	3	5	1	2	2	3	2	F1,I2,N3	H2, J1, M3
R88	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2,G1	I3,L1,M2
R89	1	2	3	2	2, 3, 5	O1, H4, P3, M2	O5, H4, P4, M4	3	2	4	4	4	4	3	4	5	2	4	4	3	4	2	2	1	2	1	E1,G3,I2	C1, F3, H2
R9	1	2	2	3	1, 2,	O1, H2,	O4, H4,	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D	A1, E2,

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
0					6	P3, M4	P4, M4																				2, G3	G3
R91	1	2	2	1	4, 5	O1, H4, P3, M2	O4, H3, P2, M4	5	4	4	5	3	3	3	3	3	5	1	4	3	5	1	2	2	3	2	F1 ,I2, N3	H2, J1, M3
R92	1	2	2	1	4, 5	O1, H4, P3, M2	O4, H3, P2, M4	5	4	4	5	3	3	3	3	3	5	1	4	3	5	1	2	2	3	2	F1 ,I2, N3	H2, J1, M3
R93	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3 ,E 2, G1	I3,L 1,M 2
R94	1	2	2	1	4, 5	O1, H4, P3, M2	O4, H3, P2, M4	5	4	4	5	3	3	3	3	3	5	1	4	3	5	1	2	2	3	2	F1 ,I2, N3	H2, J1, M3
R95	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3 ,E 2, G1	I3,L 1,M 2
R96	1	2	3	2	2, 3, 5	O1, H4, P3, M2	O5, H4, P4, M4	3	2	4	4	4	4	3	4	5	2	4	4	3	4	2	2	1	2	1	E1 ,G 3,I 2	C1, F3, H2
R97	1	2	2	3	1, 2, 6	O1, H2, P3, M4	O4, H4, P4, M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1 ,D 2, G3	A1, E2, G3
R98	1	2	2	2	5			4	4	4	4	4	5	4	4	5	2	2	4	4	4	4	3	4	3	3	D1 ,E 2, F3	A1, F2, J3
R99	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3 ,E 2, G1	I3,L 1,M 2
R100	1	2	1	5	1, 5, 7	O3, H2, P4, M1	O5, H3, P2, M4	1	4	4	5	3	3	3	3	3	4	2	3	4	4	2	2	2	4	2	A2 ,F 1,I 3	H1, J2, M3
R101	1	2	2	1	4, 5	O1, H4, P3, M2	O4, H3, P2, M4	5	4	4	5	3	3	3	3	3	5	1	4	3	5	1	2	2	3	2	F1 ,I2, N3	H2, J1, M3
R102	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3 ,E 2, G1	I3,L 1,M 2

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
R103	1	2	1	5	1,5,7	O3,H2,P4,M1	O5,H3,P2,M4	1	4	4	5	3	3	3	3	3	4	2	3	4	4	2	2	2	4	2	A2,F1,I3	H1,J2,M3
R104	1	2	1	4	6	O,H,B	O4,H4,P5,M3	4	3	4	3	2	4	4	5	4	3	5	2	2	4	2	2	3	3	1	E1,F2,M3	A2,I3,J1
R105	1	2	2	3	1,2,6	O1,H2,P3,M4	O4,H4,P4,M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D2,G3	A1,E2,G3
R106	1	2	1	4	6	O,H,B	O4,H4,P5,M3	4	3	4	3	2	4	4	5	4	3	5	2	2	4	2	2	3	3	1	E1,F2,M3	A2,I3,J1
R107	1	2	2	3	1,2,6	O1,H2,P3,M4	O4,H4,P4,M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D2,G3	A1,E2,G3
R108	3	3	2	1	1	O1,H4,P3,M2	O5,H3,P5,M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2,G1	I3,L1,M2
R109	1	2	2	2	5			4	4	4	4	4	5	4	4	5	2	2	4	4	4	4	3	4	3	3	D1,E2,F3	A1,F2,J3
R110	1	2	2	3	1,2,6	O1,H2,P3,M4	O4,H4,P4,M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D2,G3	A1,E2,G3
R111	1	2	1	4	6	O,H,B	O4,H4,P5,M3	4	3	4	3	2	4	4	5	4	3	5	2	2	4	2	2	3	3	1	E1,F2,M3	A2,I3,J1
R112	3	3	2	1	1	O1,H4,P3,M2	O5,H3,P5,M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2,G1	I3,L1,M2
R113	1	2	1	4	6	O,H,B	O4,H4,P5,M3	4	3	4	3	2	4	4	5	4	3	5	2	2	4	2	2	3	3	1	E1,F2,M3	A2,I3,J1
R114	1	2	2	3	1,2,6	O1,H2,P3,M4	O4,H4,P4,M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D2,G3	A1,E2,G3
R1	1	2	2	2	5			4	4	4	4	4	5	4	4	5	2	2	4	4	4	4	3	4	3	3	D1,E	A1,F2,

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
15																											2, F3	J3
R116	1	2	1	5	1, 5, 7	O3, H2, P4, M1	O5, H3, P2, M4	1	4	4	5	3	3	3	3	3	4	2	3	4	4	2	2	2	4	2	A2,F1,I3	H1, J2, M3
R117	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2, G1	I3,L1,M2
R118	1	2	2	1	4, 5	O1, H4, P3, M2	O4, H3, P2, M4	5	4	4	5	3	3	3	3	3	5	1	4	3	5	1	2	2	3	2	F1,I2, N3	H2, J1, M3
R119	1	2	2	3	1, 2, 6	O1, H2, P3, M4	O4, H4, P4, M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D2, G3	A1, E2, G3
R120	1	2	1	5	1, 5, 7	O3, H2, P4, M1	O5, H3, P2, M4	1	4	4	5	3	3	3	3	3	4	2	3	4	4	2	2	2	4	2	A2,F1,I3	H1, J2, M3
R121	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2, G1	I3,L1,M2
R122	1	2	1	5	1, 5, 7	O3, H2, P4, M1	O5, H3, P2, M4	1	4	4	5	3	3	3	3	3	4	2	3	4	4	2	2	2	4	2	A2,F1,I3	H1, J2, M3
R123	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2, G1	I3,L1,M2
R124	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2, G1	I3,L1,M2
R125	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2, G1	I3,L1,M2
R126	1	2	2	3	1, 2, 6	O1, H2, P3, M4	O4, H4, P4, M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D2, G3	A1, E2, G3
R127	1	2	2	3	1, 2, 6	O1, H2, P3, M4	O4, H4, P4, M4	3	4	3	4	4	3	4	3	3	3	3	4	3	3	2	3	3	2	3	A1,D2, G3	A1, E2, G3

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q24	Q25	Q26	Q27	Q28	Q29	Q30
R128	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2, G1	I3,L1,M2
R129	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2, G1	I3,L1,M2
R130	1	2	1	5	1, 5, 7	O3, H2, P4, M1	O5, H3, P2, M4	1	4	4	5	3	3	3	3	3	4	2	3	4	4	2	2	2	4	2	A2,F1,I3	H1, J2, M3
R131	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2, G1	I3,L1,M2
R132		2	2		1, 3, 4	O2, H3, P4, M1	O4, H3, P5, M4	5	4	4	3	4	2	2	4	3	4	4	4	3	4	2	2	3	2	2	E1,H2,I3	A1, C2, M3
R133	4	1	3	2	3	O	O4, H3, P3, M3	4	2	2	4	4	4	4	4	4	4	4	4	4	2	2	3	2	2	3	D2,E3, G1	A,C,D
R134	3	3	2	1	1	O1, H4, P3, M2	O5, H3, P5, M3	4	4	5	5	4	4	4	4	5	5	5	3	4	5	4	4	2	4	2	B3,E2, G1	I3,L1,M2
R135	1	4	3	1	6			1	1	1	1	2	2	4	4	2	1	1	4	5	4					2	D, E, H	C,G,K
R136	1	2	2	1	3, 5, 6	P, M	O4, H3, P4, M4	5	1	4	3	2	2	4	5	4	5	1	5	3	4	2	4	4	5	3	B, F, H	C,G,J

Missing data