THE DECISION TO USE OFF-SITE MANUFACTURING (OSM) SYSTEMS FOR HOUSE BUILDING PROJECTS IN THE UK

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November 2014
The University of Brighton
This work is dedicated to
my Father, in loving memory

“Construction is about people and how we live; our environment and how we build for our people. We will always need buildings and as our awareness of issues such as climate change increases, so does the appetite for a greener and more sustainable built environment.”

Michael Brown, CIOB Deputy Chief Executive
ABSTRACT

The decision to use Off-Site Manufacturing (OSM) as a construction strategy in the house building industry is often made using ‘gut-feel’ or poor information and at the wrong time and for the wrong reasons. Research has shown that the correct use of OSM in house building has the potential to address some of the key challenges facing the UK house building industry, such as the increase in supply of new homes, skills shortage gap, the need to reduce CO2 emissions and environmental impacts, reduce overall project duration, minimise overall project costs, and reduce defects in new housing. However, with poor decision making surrounding the use of OSM, this potential remains untapped.

At the strategic level, construction decisions that require executive data and the use of expert systems and decision support systems for evaluation are often unstructured or semi-structured. Such support systems are currently not available with respect to the use of OSM as a construction strategy. There is evidence to suggest that this results in poor understanding of the decision making process and the issues surrounding the process. This thesis therefore aims to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between OSM and Traditional On-Site (TOS) production as a construction strategy in house building projects in the UK.

The study was based on two main sources of data collection: firstly, an in-depth literature review of existing knowledge associated with the use of OSM and decision making process in the construction industry with particular reference to house building; and secondly, primary data collection using semi-structured interviews, questionnaires with key construction practitioners, and case based precedence review of numerous housing projects that have used both OSM and TOS in the UK. The findings from both sources were analysed and used to develop the DSM. The research initially established a robust set of sixteen key decision factors; then produced a Severity Indices Matrix (SIM); and finally developed a methodology for arriving at a decision outcome.

The DSM provides a reliable system that transforms an unstructured situation into a structured decision making process and improves the quality of information required to arrive at an outcome within its project environment. The research has identified the most suitable time in the project life cycle that the decision needs to be taken to achieve an optimum outcome. It has also established that the client, the architect and the main contractor must all be involved in the decision making process.
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KEY GLOSSARIES

BCIS – Building Construction Information Services
BoS – Buildoffsite
BRE – Building Research Establishment
BSI – British Standards Institution
BSRIA – Building Services Research and Information Association
BURA – British Urban Regeneration Association
CABE – Commission for Architecture and the Built Environment
CBPP – Construction Best Practice Programme
CIB – Construction Industry Board
CIH – Chartered Institute of Housing
CII – Chartered Insurance Institute
CIOB – Chartered Institute of Building
CIRIA – Construction Industry Research and Information Association
CITB – Construction Industry Training Board
CME – Construction Management and Economic
CML – Council of Mortgage Lenders
DBIS – Department for Business Innovation and Skills
DCLG – Department for Communities and Local Government
DEFR – Department for Environment, Transport and the Regions
DEFRA – Department for Environment, Food and Rural Affairs
DTI – Department of Trade and Industry
FMB – Federation of Master Builders
GDP – Gross Domestic Product
HBF – Home Builders Federation
HMSO – Here Majesty’s Stationery Office
LGA – Local Government Association
M4I – Movement for Innovation
MSC – Manufacturing Sustainable Communities
NAO – National Audit Office
NHBC – National Housing Building Council
NHPAU – National Housing and Planning Advice Unit
ODPM – Office of the Deputy Prime Minister
OGC – Office of Government Commerce
OSM – Off-Site Manufacturing
POST – Parliamentary Office of Science and Technology
prOSPa – Promoting Offsite Production application
R&D – Research and Development
RICS – Royal Institution Chartered Surveyors
TCPA – Town and Country Planning Association
TOS – Traditional On-Site
WRAP – Waste and Resources Action Programme
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Finally, I would like to send my deepest gratitude to my family for their support and patience much indebted. The special support and constant encouragement of my brother Hakim throughout my research is deeply appreciated.
AUTHOR’S DECLARATION

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any other university for a degree, and does not incorporate any material already submitted for a degree.

Signed …………………………………………………

Dated …………………………………………………
CHAPTER ONE: INTRODUCTION

1.0 Introduction

This chapter introduces the thesis and provides an overview of the research that has been undertaken. It starts with a discussion of the rationale for the research, the challenges facing the UK construction industry, and the shortcomings of the decision making process to use Off-Site Manufacturing (OSM) in house building. The chapter provides the evidence to support the need to undertake this research work; the research questions, aim and objectives, and establishes the scope of works. Finally, the chapter provides an outline of the research methodology and the layout of the thesis.

1.1 Rationale of the Research

The success of a construction project can be assessed according to the degree to which it meets the three key project management indicators of time, cost and quality, and the overall level of satisfaction of the client, the end user and the general public. However, delivering a construction project within budget, on time and to the required quality is historically poor within the industry in the UK (Bertelsen, 2003). This is usually associated with the current traditional methods and systems of construction used by the industry. The UK house building industry, in particular, has often been criticised for the poor build quality of its products and the inefficiency of its production processes (Roy et al., 2005). The construction industry has been significantly impacted by the Latham (1994) ‘Constructing the Team’, Egan (1998) ‘Rethinking Construction’ and Wolstenholme (2009) ‘Never Waste a Good Crisis’ reports, all of which have recommended the need to improve efficiency of the construction industry by learning from other industries such as the manufacturing industry. Despite Egan’s call for the construction industry to adopt supply chain management techniques to increase productivity (Egan, 2002), house building is still very much dependent on manual labour undertaking intensive activities carried out onsite (Martin, 2005). Consequently, construction is known as a low-innovation industry compared with other industries such as manufacturing (Ozorhon, et al., 2014). Research suggests that the construction industry should learn from the experience and process of manufacturing industries (Cox
and Piroozfor, 2011). The use of IT has significant impacts on productivity including design automation, numerical control machinery, production automation, instruments for quality control, and other advance technologies that are broadly available in manufacturing (Eastman and Sacks, 2008). OSM has the capability to produce high-volume and high-quality homes based on using the efficiencies of manufacturing principles (Menley et al., 2009; Mustafa et al., 2014). Blismas and Wakefield (2009) suggested that OSM is a promising solution to increase the supply of housing. One key feature in these reports has been the request to adopt ‘factory production’ style methods in construction, to improve efficiency through using manufacturing processes in construction.

There is a growing interest in new building methods with a greater degree of innovation, using a range of materials and processes in housing building (Roy et al., 2005). Furthermore, the government and industry have set new targets and strategies to transform the UK construction industry by 2025 in terms of achieving lower costs, faster delivery, lower emissions and an improvement in exports (HM Government, 2013). The house building sector has made some efforts to review its operations and seek ways of improving the delivery of new housing projects. Given the current global economic challenges facing the UK and its partners, Buildoffsite (2010) highlighted that the construction industry is under continuing pressure to raise productivity, reduce costs, improve quality, reduce health and safety risks and enhance sustainability. These requirements and targets have created a dilemma that the construction industry will not be able to resolve without a ‘step change’ in the delivery of house building projects. Thus, there is a need to create a better understanding of the potential of using OSM in the construction industry and identify what measures the industry needs to take in order to optimise the use of OSM in house building.

The Government’s drive for change and targets designed to improve the construction of new homes lends to the possible use for offsite technologies in construction. There are over 25 million dwellings in the UK accounting for 30% on the UK’s CO₂ emissions (DEFRA, 2008). The Climate Change Act 2008 commits the UK to reducing CO₂ emissions by 34% by 2020 and by 80% by 2050 compared to the 1990 level (HMG, 2008).
The UK generated 200 million tonnes of total waste in 2012, half of it generated by construction industry (DEFRA, 2014). The Government’s waste reduction target has been set to achieve at least 70% of construction and demolition waste reduction by 2020 (DEFRA, 2011). This can be achieved through waste prevention in the first place, subsequently through reuse and recycling of construction waste and, finally, safe disposal. Reducing energy use in the housing sector will be critical to the achievement of these targets, by moving to a more efficient and low carbon emissions homes. One factor that can have a significant impact on the energy use and carbon emissions attributable to new homes is the performance of building fabric (Johnston et al., 2010).

In addition, the construction industry has long been suffering from low productivity and rising costs among its sectors (Jonsson and Rudberg, 2014). In 2011, the Government Construction Strategy set out a new target of a 15-20% reduction in capital costs for Government projects by 2015 (Cabinet Office, 2012). The strategy set a target of £2bn of savings over 4 years, in terms of reducing the costs of construction to the Government, for the reform of the industry and fostering innovation and growth (HM Government, 2013). The UK Government Construction Strategy also announced that the Government required the use of Building Information Modelling (BIM) on all centrally procured Government projects by 2016 (Cabinet Office, 2011). The BIM can help to drive a step-change to increase productivity of the construction process, tangible quality improvements and associated reduction in costs (HM Government, 2012), and to achieving a 20% saving in procurement costs of Government projects (BCIS, 2013). Buildoffsite (2012) stated that the required level of quality and accuracy can be achieved through the use of off-site manufactured products and the role of BIM can encourage embedding increasingly complex off-site components and assemblies into the design and construction process.

1.1.1 Challenges Facing House Building

Given the current key challenges facing the UK construction industry, this section outlines key issues facing the house building sector to deal with rising housing demands, capacity of house builders, skills shortages, and decision making. These issues are discussed as follows:
Demand for Housing

There is concern over the number of houses being built annually in the UK. Currently, the UK Government is concerned that there have not been enough homes built to meet the needs of a growing and ageing population (Smith, 2013; DCLG, 2014). However, this issue of housing supply is not a new concern; the UK Government reports including the ODPM’s Sustainable Communities (2003) and Barker’s review of housing supply (2004) have repeatedly drawn attention to the shortfall in production of housing as compared with estimates of needs in the UK. The National Audit Office (2005) emphasised that the rate of new house building is still not enough to meet the UK demand by the ways the industry constructing homes. The office of the Deputy Prime Minister (ODPM, 2005) indicated that increasing housing and residential supply must now become a national priority.

The Department of Communities and Local Government (DCLG, 2007b) estimated the demand for new housing at 240,000 new homes annually until 2016. This figure has subsequently been revised by the National Housing and Planning Advice Unit (NHPAU, 2007) which estimates the demand to be about 270,000 new homes a year by 2016. Buildoffsite Group (2013) projected a new figure for the current housing demand, between 230,000 – 300,000 units per year. They also postulated a need for a further 230,000 – 330,000 units per year by 2020 based upon principal the projected growth in the UK. Another figure of housing demand was estimated by the Cambridge Centre for Housing and Planning Research at 243,000 new homes should be built a year in the UK up to 2031 (CIOB, 2014). Table 1-1 summarises the recent and the current housing demand that required to be built a year in order to address housing shortages in the UK.

Table 1-1: summary of the recent and current demand of housing supply

<table>
<thead>
<tr>
<th>Government and Non-Government bodies</th>
<th>Demand</th>
<th>Until</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCLG, 2007</td>
<td>240,000</td>
<td>2016</td>
</tr>
<tr>
<td>NHPAU, 2007</td>
<td>270,000</td>
<td>2016</td>
</tr>
<tr>
<td>BoS Group, 2013</td>
<td>230,000 – 330,000</td>
<td>2020</td>
</tr>
<tr>
<td>CIOB, 2014</td>
<td>243,000</td>
<td>2031</td>
</tr>
</tbody>
</table>
There can be little doubt that most of the housing construction firms still face increasing pressure to expand their productivity to meet the current housing demand. Further, the Town and Country Planning Association (2009) reported that housing supply has fallen and the demand has increased to match annual population growth and to replace ageing housing stock in the UK. To quote the FTI Consulting (2012), for decades the supply of both private and public housing has fallen below the level needed to match increasing demand. However, the capacity of UK house builders is unlikely to be sufficient to deliver the current demand for new homes with the current traditional construction techniques (CIOB, 2012; HM Government, 2013). In this context, Pan et al., (2008a) claimed that increasing the demand of housing supply in the UK drives the industry to consider using more alternatives of building systems to deliver house building projects. The current capacity of UK’s house builders illustrates in the next sub-section.

**Capacity of House Builders**

In 2009/2010, according to the Department for Communities and Local Government, (DCLG, 2013), there were only 115,000 homes built; while the Chartered Institute of Housing, (2012) pointed out that there were 109,000 homes completed in 2010/2011. Buildoffsite, (2013) highlighted that there were 100,000 new homes built during 2011/2012, and about 125,000 new homes were completed in 2012/2013 stated by CIOB, (2014). Table 1-2 summarises the rate of housing supply achieved in the recent years.

**Table 1-2: summary of housing supply built in the recent years**

<table>
<thead>
<tr>
<th>Government and Non-Government bodies</th>
<th>Housing Units Completed</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCLG</td>
<td>115,000</td>
<td>2009/2010</td>
</tr>
<tr>
<td>CIOH</td>
<td>109,000</td>
<td>2010/2011</td>
</tr>
<tr>
<td>BOS Group</td>
<td>100,000</td>
<td>2011/2012</td>
</tr>
<tr>
<td>CIOB</td>
<td>125,000</td>
<td>2012/2013</td>
</tr>
</tbody>
</table>

The highest delivery rate of housing supply was in 2006/2007 that there were 175,560 new homes built (CIOH, 2012). Subsequently, there has been a decline in the housing supply. Miles and Whitehouse, (2013) claimed that house builders currently may be able to undertake a build rate of 130,000 – 150,000 new homes a year at the best.
The construction industry has been slow to adopt alternative construction techniques and traditional construction methods are unable neither to meet housing demand nor to build to a high standard end product (Pan et al., 2004b). Hence, there is a need to secure a step-change across the industry by encouraging the use of new methods of production in the construction of housing. In order to respond to the housing supply shortage, builders are looking for more efficient way of building homes by using new materials and utilising new methods of construction (Mostafa et al., 2014a).

The use of offsite manufacturing technologies has been claimed as key to address some challenges facing house building sector (Blismas and Wakefield, 2009), however, the acceptance of the offsite construction processes remains lower than anticipated in house building (Pan et al., 2012a).

Projected Skills Shortage

The projected skills shortage gap is not a new concern within the construction industry. The Office of the Deputy Prime Minister (ODG, 2006) pointed out that there are significant skills shortages in the construction industry for 2005 – 2015 to meet the construction demand in the UK. Danby and Painting (2006) stated that the effect of the skills shortage coupled with the short timescale demand of new house building is exacerbated by the use of traditional forms of construction. The ongoing skills crisis in the UK construction industry has constrained the productive capacity of the industry (Chan and Dainty, 2007). Further, the Chartered Institute of Building (2008) highlighted that there was an increase in the skills shortage in the construction industry that was predicted to worsen by 2012. Whilst these concerns have been in relation to TOS, skills shortages, then industry needs to consider how it will respond to a new skills set and demand from OSM.

According to Wilson (2013), house builders and the Construction Industry Training Board (CITB) should urgently respond to the UK skills shortages in housing to prevent UK firms looking overseas for workers to help them. In addition, the CIOB (2013) indicated that the construction industry is still suffering from skills shortages. Miles and Whitehouse, (2013) indicate that “house builders have concerns about the declining level of traditional skills within the workforce due to an ageing work force, cyclical demand causing loss of workers to other industries and limited supply of trainees”. In
2014, the Federation of Master Builders (FMB, 2014) recorded that most parts of the construction industry are still challenged by skills shortages, while CITB (2014) warned that the current shortages of skilled construction workers within the industry could have an adverse impact on the UK house building market in the months ahead. The skills shortage seems an ongoing concern over the last decade which presents a challenge for traditional forms of construction. There are efforts need to be made to mitigate an acute skills shortage crisis threaten the productive capacity of the construction industry across its sectors (Chan and Dainty, 2007).

These are the key challenges facing the house building industry along with other have been identified in previous researches. For instance, Goodier and Pan (2010) identified further challenges to include land supply and planning, climate change, slow take-up sustainability and zero carbon agenda. Pan and Goodier, (2012) stated that the UK house building industry is facing significant challenges to deliver new homes of quality, supply rate and cost-effectiveness with a risky and complicated market. However, Spratt (2013) suggested that the level of planning permissions for private and social developments is a key factor in increasing the number of housing starts in the UK. This issue is supported by the Mayor of London report (2012) regarding the ‘barriers to housing delivery’; with the claim that house builders and developers feel the planning system is slow to grant approval. In addition, the lack of permissioned land for house builders also has an influence on the delivery of new housing (HBF, 2014). In order to tackle the above challenges, there is need for the construction industry and its stakeholders to consider alternative ways of constructing new homes.

1.1.2 Off-Site Manufacturing (OSM) in the Context of House Building

The construction industry contributes about 7% of GDP (£110bn per annum), with the housing sector representing about 38% (£42 billion per annum) of the total contribution (Cabinet Office, 2011). Public and private housing together contributes a total value of £3,923 billion or 56% of the UK nation’s wealth (Pan and Thomas, 2013). Miles and Whitehouse (2013) highlighted that there are two critical aspects which drive the demand for housing: firstly, the UK population is expected to increase with changes taking place in family living styles and secondly, there is an increasing life expectancy. These critical aspects and the Governments drive for change (HM Government, 2013) highlights the importance of carrying out this research in order to understand how house
building in the UK needs to change to contribute to and achieve the economic, social and environmental goals set by rising demands.

The potential to exploit ‘factory production’ methods and benefit from the resulting efficiency gains is not a new concept (Abdullah and Egbu, 2011; Khalili and Chua, 2013; Larsson et al., 2014), indeed nor is its application in the construction industry (Nissen, 1972). The evolution of new materials, modernised machinery and industrialised techniques emphasise the potential for construction to use Off-Site Manufacturing. The use of factory or industrialised concepts in construction has long been considered an alternative way of building homes to tackle housing shortages (Nissen, 1972). Indeed, mechanised factory production processes were utilised in the construction of houses following the end of the First World War in the UK, in order to tackle major shortages in both a reduced skilled workforce and in raw building materials (Venables, et al., 2004). Houses destroyed during the war led to a great demand (Waskett, 2001) and emphasised the need to supplement traditional construction methods, thereby emulating manufacturing in other industries such as the aircraft and car industries (Taylor, 2009).

It seems that traditional approaches to house production cannot meet the increasing demand for homes in the UK. The lack of both capacity and labour has forced the industry to find more efficient ways to increase production by improving productivity (Nissen, 1972). Major ideas adopted from manufacturing and applied to the construction environment are: standardisation, mass-production and mass-customisation (Cox and Piroozfor, 2011). These ideas have helped manufacturing industries increase productivity, speed of delivery, improve quality and save cost through ‘economies of scale’ (Jonsson and Rudberg, 2014), by using an assembly line approach in a factory environment.

In recent years, the construction industry continues to see pressure to raise productivity and improve housing supply rate, reduce overall project costs, improve the quality of new homes, reduce health and safety risks, reduce environmental impacts and enhance sustainability (Buildoffsite, 2010 and 2012). Off-site construction has been reported as an effective alternative to traditional site-based construction, with wider realised benefits (Pan and Sidwell, 2011). By evolving from traditional site-based construction methods to a more dynamic combination of methods involved a greater use of offsite
production technologies and industrialised techniques in construction (Pan et al., 2012b).

The key feature of off-site production is based on the relocating of the most activities from on-site to an off-site factory controlled environment, providing a variety of benefits to the overall building process in comparison with the traditional site-based construction methods (Zhai, et al., 2014). While providing clear benefits, the industry focuses its attention on creating a more sustainable built environment by using more industrialised technologies and methods for construction that provide a rational alternative to existing traditional methods (Schmidt III, et al., 2014). Despite the acknowledged advantages, the acceptance of the offsite manufacturing processes in house building remains low (Pan and Sidwell, 2011; Zhai, et al., 2014; Rahman, 2014).

Although some construction companies may be keen to use offsite technologies and methods, they are concerned about the context in which it is employed. Smith (2010) outlined three criteria that have proven necessary for offsite technologies to thrive within other industries. These are:

- Environment, which refers to the market, industry, infrastructural, and cultural context.
- Organisation, which refers to linkage, communication, and responsibility given to members of a collaborative.
- Technology, which indicates to the availability and characteristics of technology (will be in use) itself.

Utilising offsite innovations and technologies in construction is challenging due to the fragmented and project-based of the industry (Ozorhon, et al., 2014). The use of off-site manufacturing could become a key innovation of house building projects, due to its potential for addressing the key challenges facing the house building industry in meeting the Government’s agenda (Mostafa et al., 2014a). However, the use of OSM is still limited and lower than anticipated in the UK house building (Taylor, 2009; Buildoffsite, 2012; Pan et al., 2012a; Zhai, et al., 2014).

The limitation of using OSM seems to be related to the decision making process. The Construction Industry Research and Information Association (CIRIA, 2000) highlighted that the use of offsite manufacturing technologies is poorly understood within the
industry. Whilst in 2002, Pasquire and Gibb, (2002) stated that making decisions to adopt offsite construction methods as still largely based on subjective evidence rather than accurate data, and that there was no formal measurement methodology available within the industry to guide the choice, current literature indicates that this is still the case in 2014. There also seem to be inadequacy decision making process for assessing the applicability of using offsite construction methods in house building (Pasquire et al., 2004). In addition, the factors that most influence the suitability of offsite production as a construction strategy are not formally defined (Pasquire et al., 2004). Thus, decisions regarding the use of offsite production are consequently unclear and the decision making process used to evaluate what extent a component or building system should be produced offsite is inadequate within the industry (Blismas et al., 2006).

Therefore, the decisions to use OSM were seemed to be made based on subjective evidences, mixture of gut feeling, and experience rather than reliable data of house building. This is necessity to study the existing knowledge associated with the use of Off-Site Manufacturing (OSM) in house building in order to find the problems and gaps that limited its use in house building.

1.2 Existing knowledge Associated with the use of OSM in House Building

There is a need to identify what the industry requires in order to optimise the use of OSM in house building. This section briefly outlines the existing knowledge and gaps in relation to the use of Off-Site manufacturing (OSM) production in the construction with particular focus in the house building. The following pullet points are summarised from the literature review in the proceeding chapter (for details see section 1.1), chapter 2 (for details section 2.3 and 2.4), and chapter 3 (for details see section 3.2, 3.4 and 3.5):

- **Existing Knowledge of the Concept of OSM**

  There are concerns about the ability of using the Traditional On-Site (TOS) methods to address the current challenges facing the UK house building sector, neither to meet housing demand nor to achieve an end product at the required quality. This has driven the house building industry to seek alternative ways to deliver housing projects by adopting more innovations and offsite manufacturing techniques for house building. Off-Site Manufacturing (OSM) could be a key innovative factor of house building, due
to its capacity in meeting the growing housing demand and contribute to some of the key challenges facing the industry (Mostafa et al., 2014). The potential of using OSM systems in construction are commonly cited and well documented (Pan and Gibb, 2008; Johnsson and Meiling, 2009; Goodier and Pan, 2010). However, the use of OSM is still limited and lower than anticipated in the UK house building (Taylor, 2009; Buildoffsite, 2012; Pan et al., 2012a; Zhai, et al., 2014). This raises concerns and questions about the use of OSM as a construction method with particular reference to house building.

The advantages of using OSM are very plausible, the idealism behind its use is far from being practical and beneficial to the majority of contractors (Kamar et al., 2009). This is due to the lack of understanding how to compare offsite production appropriately with traditional construction methods (Pan et al., 2012b), as result, its uptake inhabited. The consequence of this is that the traditional onsite methods are still dominated the industry as preferred construction method (Rahman, 2014) that fail to contribute to the government and industry targets (Buildoffsite, 2012). With increasing pressure on construction practitioners to raise productivity and improve efficiency, the house building sector is also being challenged by recent economic recession (Ogden, 2010) and the government’s spending reductions (Pan and Goodier, 2012). This has become more challenging within housing sector and its stakeholders to use OSM in the construction, concerning about level of house building which is insufficient to meet the current demand. Thus, there seem to be a poor understanding of decision making process associated with its use in house building by many of those involved in the construction process. Therefore, this requires an optimum decision strategy which involves careful understanding of the potential of using OSM as alternative construction strategy in order to optimum its use OSM in house building.

- **Existing Knowledge of the Decision Making Strategy to use OSM**

The literature revealed that there is a lack of ability to evaluate and choose a strategy between the growing number of construction methods and manufacturing opportunities. This is as result of the lack of relevant guidelines which highlighted as a key barrier bias against the use of OSM (Blismas and Wakefield, 2009), and lack of confidence of the decision to its use in house building (Ogden, 2010). The use of OSM has been regarded as an effective means of improving construction quality and efficiency of the construction as alternative method to Traditional On-Site (TOS) based construction. In
order to select a construction strategy for project, a choice occurs need to be made in the first place between onsite and offsite production (Eastman and Sacks, 2008). It has been also indicated to consider OSM as construction strategy among RIBA Plan of Work stages at early project development (RIBA, 2013). Thus, the industry practitioners should conduct a systematic comparison between offsite and onsite construction methods based on best practice in house building (Zhai, *et al.*, 2014). The construction industry is a diverse and project-based industry. However, the literature revealed that the evaluation for using OSM is largely being ignored at the project level; thus it is necessary to bring the full benefit of OSM early in the project strategic level when evaluating alternatives construction methods. Therefore, there is a need for a new robust decision making mechanism that can be used in practice to guide the choice between OSM and TOS as a construction strategy at the project level.

- *Existing Knowledge of the Decision Support Systems to use OSM*

The practical implementations relate to highlighting the importance of OSM applications in house building is more about the need for improving the existing evaluation support tools (Atkin, 2014), or develop relevant quality assessment and support tools (Rahman, 2014). However, the existing DSSs have been criticized for their complexity or/and reliability in making decisions to OSM in construction. The lack of existing decision support and evaluation tools to use OSM also highlighted in house building that could help housing practitioners make decisions upon the most appropriate construction method, based on specific project criteria. Thus, due to the current industry scenario, experience of individual decision maker and heuristics seem to be the dominate approach in decision making among housing industry (Abdullah and Egbu, 2011). There is a demand within the industry for a systematic and affective evaluation tool for selection of sustainable and efficient technologies to use in house building (Pan *et al.*, 2012b). Whilst, there exists decision support systems within the UK construction industry, it seems to be none fully appreciated by practitioners that satisfied their need in structuring and making decisions between using OSM and TOS as a construction method for house building projects. Therefore, there is a need for a robust decision making tool or system to be designed based on the best practice to use OSM in the context of house building.
• **Existing Knowledge of the Decision Making Factors to use OSM**

The literature revealed that there is limited understanding of how best to integrate the use of OSM into house building process. This limitation is due to a lack of ability of decision makers to make decision based on a direct comparison between OSM with TOS methods, due to a lack of value-based decision criteria (Pan et al., 2012b). The decision criteria practice used to select the optimal construction method or building system are still primarily cost-based rather systematic value-based evaluation in the construction industry (Zhai, et al., 2014). This is due to a lack of rational, robust and balanced decision criteria to choose a construction strategy between alternative construction methods (Pan et al., 2012a). There also lacks a comprehensive established list of factors that influence the decision making process associated with comparison of the alternative construction methods. Thus, this led to lack of confidence of the existing decision support systems and their measurement methodology for evaluating the use of OSM as alternative construction method in house building. Consequently, there is no recognised objective method for the decision making process for using OSM in place of Traditional On-Site (TOS) construction methods for house building. Therefore, there is a need to establish a set of decision factors that have the most significant impacts on the decision whether to use OSM or TOS production in house building.

• **Existing Knowledge of the Decision Making Process to use OSM**

House building as any construction project which establishes and manages by a number of different parties and stakeholders brought together temporary for each project and take the necessary decisions to meet its objectives. However, decisions to use OSM are made based on subjective evidences and past experience lacking facts and figures to back the decision outcome rather than adequate data. Thus, decisions to use OSM are made with limited information lacking project characteristics and specific requirements in an unstructured situation. However, the literature also revealed that decisions to use OSM seem be made by the wrong persons and at the wrong timing of project development stages. The construction clients’ prefer to keep control of making decisions over the construction strategy of project directly based on individual experience and subjectivity determined values of past project rather than taking sufficient assessment of each project. It has not been established yet at which stage the key decision to choose the construction strategy be carried out, therefore, there is a need
for a better understanding of the decision making process to use OSM and identifying the key decision makers and their influences upon the final decision in house building.

Figure 1-1, suggests, at this early research stage, possible reasons why the house building industry is not using OSM as a construction strategy in its projects.

Figure 1-1: Possible reasons why the house building industry is not using OSM as a construction strategy in its projects.

This body of existing knowledge seems to suggest that there is poor understanding of the decision making process to use OSM in house building. Figure 1-2 illustrates where in the project’s life-cycle the proposed decision making ‘tool’ could be used to address emerging gaps in existing knowledge and problems associated with poor decision making.
Figure 1-2: Potential Period to Implement a Decision Making ‘tool’ for choosing between OSM vs. TOS
The Figure 1-2 maps both the stages within the RIBA Plan of Work 2013 and the phases of the Process Protocol Map (1998). The Process Protocol Mapping indicated that there are four phases involved in the development of any construction project throughout its life-cycle; namely: - Pre-project, Pre-construction, Construction and Post-construction. This research has focused on the pre-project phase where most of the key decisions need to be made before the project moves to the design stages. One of the major decisions that need to be made at the pre-project phase is to choose between a construction strategy of using Off-Site Manufacturing (OSM) or Traditional On-Site (TOS) production method. The current position and timing of decision making occurs in the stage two (Concept Design) according to the RIBA and in the phase three (Substantiate Feasibility Study & Outline Finance Authority) according to the Protocol Process Map.

The decision outcome on whether to use OSM or TOS is followed by another major decision, for example; if the construction strategy chose to use Traditional On-Site (TOS) methods, then the particular TOS building system needs to be established (i.e. concrete, masonry, timber frame) followed by the implementation strategy for this method. Conversely, if an OSM system was decided upon then there is equally the need to choose which OSM building system should be used for the project (e.g. volumetric, non-volumetric or modular building) followed by its implementation method. Whilst this research recognises that these two approaches are not exclusive and invariably co-exist in most, if not all, building projects; there seems to be factors the divide the determination on whether a project is best suited OSM or TOS manufacturing methods and systems. A number of studies have developed guidance and decision support tools to choose between different OSM systems, however, there seems to be a lacking is any specific decision system, particularly aimed at the house building sector comparing the use of OSM or TOS. Having not yet carried out the primary research activities, this work suggests that there is not yet an established guidance or decision support tool to help practitioners making such decisions.

1.3 Initial Investigatory Research Problems

The initial investigatory research problem is: Why is the uptake of Off-Site Manufacturing (OSM) as a construction strategy in house building limited?
If this research problem is supported by the literature review and critical appraisal stages then, it will be essential that the use of OSM in house building is viewed from a project-wide perspective and a suitable strategy is developed at project strategic-level. This requires preliminary knowledge of the industry perception and current practices relating to the use of off-site technologies in house building.

In an effort to understand current decision making processes used to consider OSM, further research problems present themselves and must be answered or developed into Research Questions:

- What are the industry drivers that could bring about greater uptake of OSM in house building?
- What are the key factors influencing the decision to choose OSM as a construction strategy for house building?
- What are the problems and issues associated with the current decision making process for using OSM in construction with particular reference to house building?

There is a recurring theme running throughout these research questions that there is misunderstanding among the industry’s practitioners concerning the significance of OSM and decision making process associated with its use in house building. The practical implications related to highlighting the importance of OSM applications in house building is more about the need for improving the existing evaluation support tools (Atkin, 2014), or developing relevant quality assessment and support tools (Rahman, 2014). In addition, there is a lack of existing decision support and evaluation tools that can assist practitioners in making decisions to use offsite production technologies in house building (Atkin, 2014). In order to enhance the uptake of OSM, Zhai, et al., (2014) emphasised that the industry should conduct a systematic comparison between offsite and onsite construction methods based on best practice in house building.

1.4  Aim and Objectives of the Research

This work will provide information to assist those build a better understanding of the decision making process to use OSM and to create an optimum decision strategy to assist practitioners in making decisions to enhance its use in house building. The aim of
this research work, therefore, has been to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between Off-Site Manufacturing (OSM) or Traditional On-Site (TOS) production as a construction strategy for housing projects in the UK.

The following objectives have been identified in order to achieve the research aim:

1. To investigate the issues, characteristics, terms and considerations of using Off-Site Manufacturing (OSM) systems in the construction industry.

2. To identify and review existing decision support systems used in the UK construction industry.

3. To identify the process, drivers, factors, problems, constraints and measures associated with current decision making methods and procedures used in the determination of using Off-Site Manufacturing (OSM) in the UK house building.

4. To establish the components and measure the impact of the key factors used at the evaluation stage for effective decision to use Off-Site Manufacturing (OSM) as a construction strategy for house building projects.

5. To measure the impacts of the key factors on decision to use Traditional On-Site (TOS) as a construction strategy for house building projects.

6. To develop and test the theoretical decision model for choosing between Off-Site Manufacturing (OSM) and Traditional On-Site (TOS) as a construction strategy for house building projects.

1.5 Scope of the Research

Creswell, (2009: 23) highlighted that the review of related existing knowledge to the research topic helps to determine insight into ways in which the research can limit the scope to a needed area of inquiry. An intensive literature search and review have been applied in order to identify boundaries of the research being studied:

1. The research focuses on decision making processes at a project’s strategic-level for determining an optimum decision strategy between the use of OSM and the use of
TOS for house building. It is assumed that the construction industry uses a hierarchy of strategic, tactical and operational levels of management.

2. Details and characteristics of traditional forms of construction is out of the scope of the research, assuming that they are well documented and well known among the industry practitioners.

3. The investigation limited to the house building sector in the UK construction industry. This means that the outcomes of the study may not be necessarily applicable in other countries or even in other sectors within the UK construction industry.

It is necessary to establish what is meant by ‘a project’s strategic-level’ and so the following definitions and context has been provided to clarify:

**Project Strategy:** The concept of a project strategy refers to the strategy of a single project which mainly considers the goals and plans at a strategy level (Artto *et al.*, 2008). They also set a generic definition of project strategy as a ‘direction’ in a project that contributes to success of the project in its environment. It refers to the assumption that how the project is able to achieve its goals within its boundaries. Thus, project strategy is influenced by how autonomous a position the project takes towards its organisation. Projects are recognised by organisations as the means by which a significant proportion of their activities (Maylor, 2003: 54). This means that it is important to move to a more concentrated at projects.

**Levels of Project Management:** Cleland and King illustrated the three managerial levels of project management (1988: 24) as institutional, strategic and tactical levels as shown in Figure (1-3), which have important managerial relation to each other and each has an essential role to play in the management of every project.
The institutional level (I) is the top/senior management level and concentrates upon the enterprise and issues outside the project environment such as; finance, government and industry targets, planning and regulatory agencies, and economic and environmental benchmarks. This top management level and work is of a ‘strategic’ nature and will laying the axes upon which the detailed ‘tactical’ work and the third ‘production’ phase will rest (Cleland and King, 1988: 22). The strategic level (II) is the middle management and coordinates project’s technical core and buffers from outside world and guidance in how to avoid external pitfalls. While, the tactical level (III) is the technical management which provides the technical input together of project.

The project strategy is the basis for many planning decisions (Kerzner, 2001: 26). Thus, it means understanding the significance of planning and making decisions, Harris (1998) has classified decision levels to three zones of project management:

- **Strategic level**: Strategic decisions are the highest level where a decision concerns general directions, long term goals, philosophies and values.
- **Tactical level**: Tactical decisions support strategic decisions where tend to be medium range and with moderate consequences.
- **Operational level**: The decisions at this level are used to support tactical decisions. These include such resources and management decisions.
Decision making takes place at each level of management and each level has substantially different information requirements (Lucey, 1997: 86). At the strategic level, decision making is much more dependent on human factors and judgement of evaluating the outside world issues and factors related to project environment. The strategic decisions had to be made concerning the technical issues in which are supported by operational decisions (Kerzner, 2001: 27) for the best delivery of construction project and achieving its goals.

1.6 Outline of Research Methodology

It is essential to understand the nature of research and the terminology of its operation and design process (Ashton, 2003). In order to address the research questions, aim and objectives, the design of this research involves the use of both qualitative and quantitative approaches to data collection and analysis. Firstly, an intensive literature review was undertaken in order to understand the existing knowledge and the research context regarding the decision to use OSM in house building. Secondly, different research methods were used for primary data collection in respect to the decision to use OSM or TOS as a construction strategy with particular reference to house building (interviews and questionnaires and case based precedence projects review). The validation of the findings and testing of the Decision Support Model (DSM) mainly used the methods of interviews and case studies at different stages throughout the research. Details of the specific research methods adopted at each of the stages of the research process are provided in chapter four.

The following section outlines the research methods used to achieve each of the research objectives:

**Objective One:** A literature review has been carried out in order to achieve the research objective one. It involves a search for literature across many disciplines and sources related to the use of off-site technologies in construction. The literature review was conducted in order to provide documentary evidence of key issues related to the use of OSM in the construction industry. It focused on the characteristics of using OSM systems in construction, followed by in-depth-review of definitions for the term of OSM, classifications, advantages, disadvantages, and applications of OSM systems in the construction industry particularly in house building.
**Objective Two:** In order to achieve the second research objective, a literature search was undertaken to investigate the current state-of-art of decision support systems used in the UK construction industry. The literature review revealed the existing decision support systems and techniques used by the construction practitioners to assist them in making decisions to use OSM with a particular reference to house building. It was followed by an in-depth review of the various decision techniques and their usability and popularity among housing practitioners. This provided an identification of the levels of sophistication and limitations of the existing decision support systems and techniques used to evaluate decisions to use OSM in construction with a particular reference to house building.

**Objective Three:** A combination of a literature review and semi-structured interviews were conducted in order to achieve objective no. 3. The literature review was carried out in order to reveal the key drivers and constraints and decision making processes for using OSM as a strategy in the construction with particular reference to house building. This was enriched by using semi-structured interviews conducted with a selection of top UK’s house builders including: clients, developers, consultants, project managers, architects and contractors to investigate the perspectives and current practices of house builders on the use of OSM based on their experiences. The semi-structured interview survey investigated the key factors including the processes, drivers, constraints, and problems associated with decision making that the industry’s practitioners experienced from using OSM in house building.

**Objective Four:** a postal questionnaire survey was carried out, sent to key stakeholders within the UK’s house building sector including: clients, project managers, architects, consultants and contractors. The questionnaire survey was used to investigate how decisions were currently made among house builders and what were the key issues and factors that significantly influence the decision to use OSM systems. It was also used to identify who has the most influence on decisions among the project team and to inform at which stage the decision should be made.

**Objective Five:** a second questionnaire surveys designed to specifically focusing on On-Site decision making factors was also sent out to a selection of senior managerial level participants of the top UK house builders. The second questionnaire surveys was conducted in order to obtain a full range of house builders’ opinions and views currently
experienced and the impacts of the key factors on their decisions to use TOS as a construction strategy in their projects. The key lessons learned from implementing the strategy were also obtained. The results conducted from both questionnaire surveys provided the key factors and criteria used for the decision to use TOS as a construction strategy in house building.

In order to triangulate information received from objective three, four and five, the semi-structured interviews and postal questionnaires; 15 projects were selected from both TOS and OSM developments to review ‘current’ decisions and historic actions taken using case-based precedence review.

**Objective Six:** In order to achieve this final objective, the combined key findings obtained from literature review, primary data and analysis were used to initially develop a conceptual model. The model is made up of four major decision processes with regard to decision making process used within the construction industry with particular reference to house building. In order to test and apply this model in practice, it has then transformed further into a methodological model which formed the main phases of the DSM, ultimately, achieving the overall research aim.
### Overview of the Research Steps

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<td>Literature Review</td>
<td>Chapter 1: Introduction</td>
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<td><strong>Objective 2</strong>: To identify and review existing decision making systems used for OSM in the UK construction industry.</td>
<td>Literature Review</td>
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<td><strong>Objective 3</strong>: To identify the process, drivers, factors, problems and constraints associated with DM used in the determination of using OSM in the UK house building.</td>
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<td>Interviews Survey (30), OSM Questionnaire Surveys: - House builders (30) - Case projects (15)</td>
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</tr>
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<td><strong>Objective 5</strong>: To measure the impact of the key factors on decision to use TOS as a construction strategy for housing at evaluation stage.</td>
<td>TOS Questionnaire Surveys: - House builders (30) - Case projects (15)</td>
<td>Chapter 5: Factors Associated with Decision Making Process for Using OSM as a construction strategy in House Building</td>
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**Figure 1-4: Research Process Flowchart**
Figure 1-4 illustrates the relationships between the research objectives, research methods and layout of chapters of the thesis towards achieving the aim of the research. The next section outlines the layout of the chapters of the thesis in more detail.

1.7 Layout of the Thesis

The thesis is laid out in eight chapters which include the introductory and conclusions chapters. The content of the thesis chapters is structured as follows:

The current chapter introduces the research undertaken and reveals the rational, challenges and problem to be solved by the study. It sets out the aim of the research and objectives that are required to achieving the aim. The chapter also outlines the gap of knowledge, the scope of work and general layout of the thesis.

Chapter two presents the first part of the literature review concerning the use of OSM in the construction industry in general terms. It aims to identify the current problems facing the construction practitioners in relation to the use OSM in house building. Firstly, the chapter focuses on definition, terms, classifications and characteristics of OSM in construction, also, gives a historic background, development and applications of off-site technologies in other industries and countries. Secondly, the chapter also provides an overview of the current state of using OSM, with special focus on the use/capacity, drivers and constraints to the use of OSM in house building. One of major issues found is that there is misunderstanding of the decision making process to use OSM in house building by many involved in the construction process.

Chapter three present the second part of the literature review with aim to identify the shortcomings of the current decision making process to use OSM as a strategy in house building. Initially, the chapter provides an overview of decision and decision making process based on existing knowledge, including definitions, types and categories of decisions used in the construction. Secondly, it provides an overview of how decision is currently being made for choosing OSM in construction and the criteria used in taking such decisions. Thirdly, it investigates the adequacy of the existing decision support systems and techniques used for choosing OSM as a construction strategy in the construction industry with particular reference to house building.

Chapter four details the research methodology and the research methods used for collection and analysis of the data. The research methodology describes the data
collection, the ontology and epistemology and the ethical considerations of the research work.

**Chapter five** presents the collection and analysis of data conducted from construction practitioners on the use of OSM in housing projects, using interviews and questionnaires both house builders and case based precedence projects review surveys. This mixed research methods provides a range of views and opinions on the use of OSM and explores how decisions to use OSM were currently being made in the house building. The chapter also provides the key findings and establishes a robust set of 16 themes or key decision factors that have the most significant influence on decision to the use of OSM as a construction strategy in house building.

**Chapter six** discusses the collection and analysis of data conducted from the construction practitioners on the use of TOS in housing projects, using questionnaires both house builders and case based precedence projects review surveys. Firstly, the chapter provides a wider view of house builders and how decision to use TOS is being made within the house building sector. Secondly, it represents the impacts of the established robust of the 16 key decision factors on decision to use TOS as a strategy in house building. Thirdly, the chapter gives a comparison of the key findings from both OSM and TOS investigations, and established the impact of the 16 key decision factors on decision to use OSM and TOS which presents in Severity Index Matrix (SIM), using the significance and importance index values of these factors. SIM is the key component of the DSM.

**Chapter seven** firstly illustrates the development process of Decision Support Model (DSM). Secondly, it discusses the validation and the testing process of the DSM in the field by four housing case studies at their pre-construction stages. Finally, it discusses the DSM in relation to the features and limitation of its use which draws from house builders’ feedback and validation outcomes.

**Chapter eight** presents the conclusions derived from the study. It also highlights the contributions and implementation of the DSM. The chapter also points out the limitations of the study and proposes recommendations for further research.
1.8 Summary

This chapter gives an overview of the research context, problem, and work plan. It sets the tone about the emphasis and relevance of the use of Off-Site Manufacturing (OSM) in construction industry, with particular reference to house building. However, the current use of OSM systems remains much lower than hoped for in house building, due to the lack of understanding about how to adopt its use and decision making process appropriately by a majority of those who are involved in the construction process. There are also insufficient decision support systems and guidance currently in use within the industry to support decisions to use OSM as a construction method for house building. Thus, there are many clients, developers and contractors reluctant to use OSM production in their projects and, as a result, its use remains low in the house building industry.

Against the current demand of about 240,000 units per year in the UK, the average housing supply was approximately 110,000 units per year. The demand was also forecasted to increase to an average of 300,000-330,000 homes per year by 2020. One of the reasons for this shortfall is the limitation of current use of traditional construction methods dominating the housing industry (Rahman, 2014). The Government and industry are keen to address the shortage of housing supply by encouraging the use of off-site production techniques in construction for faster delivery of house building projects.

The rationale for the research stemmed from the initial research question and the research issues and suggested gaps in current knowledge of using OSM as a strategy in house building. The chapter has established the aim of the research and its objectives. It has also provided an outline research methodology with statements of how each research objective has been achieved throughout the research process. Further, the scope of this research has been defined and outlined the chapters of the thesis. The term ‘OSM’ and the concept of its use in house building will be addressed in the following chapter.
CHAPTER TWO: LITERATURE REVIEW: OFF-SITE MANUFACTURING (OSM) IN HOUSE BUILDING

The aim of this research has been to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between using OSM and TOS Production as a construction strategy for housing projects in the UK.
2.0 Introduction

This chapter addresses the concept of using offsite technologies in the UK construction industry and draws a wider picture of its use in house building, with the aim of identifying the problems, issues and consequently identify the gaps in our knowledge currently facing house builders. It starts with definitions of the term ‘offsite’ currently used in the UK’s construction industry, that leads to a practical definition of the term Off-Site Manufacturing (OSM) in the context of house building. Offsite technologies have been classified into categories, types, systems and methods in relation to their use in construction. A comparison and contrast of the characteristics of offsite construction against that of traditional onsite construction is also made. The chapter reviews the current state of OSM in the house building industry, as well as the drivers of the use of OSM in house building.

2.1 Off-Site Manufacturing (OSM) in the Construction Industry

There exists a significant amount of published literature about offsite technologies and their use in the UK construction industry. In the UK, offsite construction has been promoted as an innovation attempt to improve the efficiency of construction (Pan and Sidwell, 2011). Rogers (2003:12) defined innovation as “an idea, practice, or object that is perceived as new by an individual or other unit of adoption”. The concept of innovation in construction can be referred to as the creation of new ideas in design, production and implementation processes, where attention focuses on technical solutions, planning and implementation (Larsson et al., 2014). Ross et al, (2007) highlighted that the key innovation in house building has been an attempt to speed up the construction process, reduce workload and labours’ activities onsite, and improve the quality of new houses.

2.1.1 Terms and Definitions used to describe OSM

There are a wide range of definitions, terms and classifications used to describe innovation and offsite technologies in construction. The term offsite is a generic term describing a range of construction techniques that are different from traditional onsite forms of construction (Ross, 2002). Non-traditional methods are onsite forms of construction which involved two production sites: offsite factory and then onsite.
construction (Mostafa et al., 2014a). Traditional construction is a term often used in the construction industry to define the onsite construction processes (McCarney and Gibb, 2012). The traditional onsite processes are largely site-based construction methods based on labourers’ activities, materials and other resources onsite, producing building elements in situ (Zhai, et al., 2014). An initial simplistic definition for offsite construction methods is described by Anthony (1945: 42) as an aim to construct as much of a building as possible under cover and out of the rain. This definition begins to identify some of the accepted benefits of manufacturing, related to working at a location and in an environment that is best suited to safe, efficient and productive construction.

Currently, there are different terms commonly used to describe offsite technologies in construction which vary from country to country. These terms include: Modern Methods for Construction (MMC), Off-Site Construction (OSC), Off-Site Production (OSP), Off-Site Manufacture (OSM), Industrialised Building System (IBS), Off-Site Prefabricated housing, Industrialised Building (IB), Modular Building (MB). These terms are widely used by the practitioners, researchers, government and industry institutions to represent a number of offsite technologies and methods in construction. The terms may be also used to cover the concept of industrialisation which often refers to innovation in construction (Kamar et al., 2011). However, some researchers argue that industrialisation and innovation are two similar concepts, both of which can be interpret as products and processes of adoption (Kamar et al., 2011). This refers to mechanisation, standardisation and prefabrication and preassembly techniques involved in production lines.

**Modern Methods of Construction (MMC)**

The Office of the Deputy Prime Minister (ODPM, 2005) defines the term MMC as a process to produce more, better quality homes in less time, with the aim of improving business efficiency, customer satisfaction, environmental performance, sustainability and the predictability of delivery times. Further, the British Urban Regeneration Association (BURA) defines the term MMC as those construction methods which provide an efficient product management process to provide more products of better quality in less time (Burwood and Jess, 2005).
**Industrialised Building System (IBS)**

The term IBS is a construction system based on the principle that as much of the works as possible are transferred from the site to the factory, leaving only a simple assembly operation to be carried out onsite (CIRIA, 1996). Kamar *et al.*, (2009) stated that IBS has been identified as a promising system to improve overall construction performance in terms of quality, cost effectiveness, safety and health, waste reduction and productivity. IBS was also described as a set of interrelated elements and components that act together to enable the designated performance of building to be achieved (Abdullah *et al.*, 2010).

**Modular Building (MB)**

Modular Building (MB) is a term used to describe the use of a number of prefabricated and standardised building elements that can be used to form modular units or buildings (Nissen, 1972). These elements must be joined together in a pre-ordained sequence or arrangement (Tatum *et al.*, 1986), thereby enclosing the usable space to shape a modular building (Burwood and Jess, 2005), with most of the work competed at the factory and then delivered to the site for final assembly. Modular buildings consist of multiple modules or sections (Tatum *et al.*, 1986), and refer to construction using standardised units or standardised dimensions (Waskett, 2001). Complete or near-complete modules have become regarded as a perfectly acceptable solution for certain types of commercial and industrial buildings and, in some countries, for house building too (Atkin, 2014).

**Off-Site Manufacturing (OSM)**

Off-Site Manufacturing (OSM) refers to the prefabrication of components in an offsite factory environment as well as the subsequent fabrication activities on a building site (Goulding *et al.*, 2012). A similar definition was provided by Mtech Group, (2006), with the term of OSM understood as the part of the construction process that is carried out away from the building site and which would normally be carried out on site. The Construction Best Practice (2003) adds that OSM involves the manufacture and assembly of buildings or parts of buildings ahead of the time that they would traditionally be constructed onsite. Burwood and Jess (2005) claimed that OSM in its broadest sense encompasses many modern construction techniques and methods which
form substantial parts of a building, which are prefabricated and preassembled to the point of production then transported to site and installed in their final place with only the minimum of onsite work needed. Increasing production without a corresponding increase in the demand for site labour is, effectively, to move to offsite manufacturing (Venables, et al., 2004). OSM is seen as a key vision for improving the construction industry through its capability to produce high-volume and high-quality homes based on the efficiencies of manufacturing principles (Menley et al., 2009; Mostafa et al., 2014a), also leading to a reduction in house prices (Mostafa et al., 2014b).

**Other terms: Pre-fabrication, Pre-assembly and Standardisation**

There are other terms used to describe ‘offsite’ technologies and innovations in construction including, Pre-fabrication, Pre-assembly, and Standardisation. Waskett, (2001) pointed out that the use of offsite construction methods such as modular building systems do not have to be built using prefabrication, although this is usually the case. Pre-fabrication is often associated with the terms ‘offsite’ and ‘assembly’ or just ‘fabrication’ which means to fabricate the parts of building at a factory (Smith, 2010: xi), uniting standardised parts (Gibb, 1999: 2), on the basis of common system dimensions and consistent degrees of accuracy (Nissen, 1972). While White (1965: 2) described prefabrication as “any integrated system of construction of which the parts had been prepared away from the site, or even partly so prepared; … to over-simplify, and to look a bit into the future, if you shove and snap a product into place in the field, that is prefabrication”.

However, Pre-assembly is defined as a process by which various materials, components, and/or equipment are joined together at a remote location for subsequent installation (Tatum et al., 1986), into sub-assemblies either offsite in a factory or onsite in a dedicated facility prior to final installation in place (Winch, 2002: 304). “One way of improving process capability in construction is to use either standardisation, pre-assembly or a combination of the two” (Winch, 2002: 304). The key benefit of the use of standard elements, components or modules, is that the development and production overhead costs are shared across a number of construction projects. Standardisation thus has the potential to produce a significant contribution towards a reduction in real construction costs (Graing, 2000). This is because of lower activities and lower dependency on skilled workers and lower resources required on building sites (Khalili
and Chua, 2013). Others argue that the benefits from advances in manufacturing industries can only be realised in construction where standardisation is accepted through preassembly (Gibb, 2000; CIB, 2010). These benefits include predictability, reliability, efficiencies in system processes, speeded up construction processes and reduced construction waste (CIB, 1998), which are the most realised benefits (Robinson et al, 2012).

These offsite terms have been classified by Pan (2006) to provide an approach to distinguish between the different terms of offsite technologies used in the construction. This generates four categorisation families/terminologies of the terms: Offsite, Pre, Modern and Building. Table 2-1 shows the categories of offsite terminologies based on the current terms found in the existing literature which are widely in use in the construction industry nationally and globally.

Table 2-1: Categorisation of offsite terminologies

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Term</th>
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<tbody>
<tr>
<td>Offsite</td>
<td>Offsite Production (OSP)</td>
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<td></td>
<td>Offsite Construction (OSC)</td>
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<td></td>
<td>Offsite Fabrication (OSF)</td>
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<td></td>
<td>Offsite Manufacturing (OSM)</td>
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<td></td>
<td>Offsite manufactured housing</td>
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<td>Pre</td>
<td>Prefab</td>
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<td></td>
<td>Pre-fabrication</td>
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<td></td>
<td>Pre-assembly</td>
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<td></td>
<td>Pre-fabricated residential housing</td>
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<td></td>
<td>Pre-fabricated housing</td>
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<td></td>
<td>Pre-work and manufactured houses</td>
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<tr>
<td>Modern</td>
<td>Modern Methods of Construction (MMC)</td>
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<td>Modern Methods of House Construction</td>
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<td></td>
<td>Modern Methods of House Building</td>
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<td>Building</td>
<td>System Building</td>
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<td>Modular Building</td>
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<td>Industrialised Building</td>
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<td>Non-Traditional Building</td>
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However, Kamar et al., (2011) stated that there has been no one commonly agreed definition of the term ‘offsite’ production in construction, which varies from country to country. Thus, a workable definition for the term ‘OSM’ may be necessary in order to clarify the term in the context of this research work.
The Preferred Definition of OSM in this Research

For the purpose of this research, the term OSM is understood as a construction strategy aimed at producing more in less time, better quality and less environmental impact homes by using off-site manufacturing processes that take place under a factory controlled environment. It transforms the traditional construction site into an assembly workshop of prefabricated elements and/or components. It also engages standardisation and mass-customisation, the use of technology, the use of labour more efficiently and provides an efficient integrated product management process of both offsite and onsite.

2.1.2 Categories of Off-Site Manufacturing (OSM)

The construction industry classifies OSM technologies based on the degree of innovation in construction materials, processes, products and systems. OSM technologies have gone through a many transitions in their manufacturing processes from prefabrication and preassembly of the components to modular buildings. The use of OSM technologies are involved two production sites: offsite factory and onsite construction (Mostafa et al., 2014a). In this sense, Burwood and Jess (2005) stated that offsite manufacturing techniques in construction fall into two types of categories: those aspects that are carried out ‘offsite manufacture’ and ‘onsite manufacture’.

OSM is a collective term used to describe different construction methods that can apply to many different individual building products, systems and processes. In relation to the degree of offsite work, it mainly involves the processes which lead to the production of the system and its construction application (Kamer et al., 2011). Various authors (Gibb and Penlebury, 2006; Goodier and Gibb, 2008; Jaonsson and Rudberg, 2014; Mostafa et al., 2014a) have classified OSM into the following categories:

- **Component manufacture and sub-assembly** – this category is predominantly the traditional approach in construction. It falls short of being classified as systemic OSM but utilises factory manufactured innovative sub-assemblies or components. The sub-assemblies and components are always produced offsite and are never considered for onsite construction. This category refers to relatively small items such as light fittings, windows, and door furniture and trusses.

- **Non-Volumetric** – this category refers to ‘two-dimensional’ elements/panels that are pre-assembled units which do not enclose usable space in buildings. Typical
examples would be parts of the structural frame, internal partition panel systems, cladding panels, parts of building services, distribution ductwork or pipe-work and so forth.

- **Volumetric** – this category involves three dimensional modules and usually refers to pods that are pre-assembled (Ross *et al.*, 2006). These units enclose usable space and are typically fully factory finished internally but do not form the building’s structure with an independent structure frame. OSM volumetric is particularly suited to highly serviced areas such as bathroom and kitchen pods, plant rooms, building services risers, and lifts (Housing Forum, 2002). In house building, these units are usually installed in a new or existing building structure, or stacked onto prepared foundations to form the dwellings.

- **Modular Building** – Included in this concept are pre-assembled volumetric units which form the actual structure and fabric of a building. Modular building is produced offsite in a factory and the only work performed onsite is the assembly of the modules and finishing operations. Modules can also be fully fitted out before being transported to the final destination.

- **Non-OSM construction methods** – this category is intended to encompass schemes utilising innovate building techniques and structural systems that cannot be placed in the category of offsite manufacture (Taylor *et al.*, 2004). It has been defined as innovative construction methods which used onsite techniques and the use of conventional components in an innovative way (Ross, *et al.*, 2006). The main characteristic of this category is innovation through the use of a method of construction familiar in other sectors but new to house building, or through traditional components being combined in innovative ways (Burwood and Jess, 2005). Typical examples of this category are Tunnel Form or Thin Joint Masonry/Blocks (Gibb and Pendalebury, 2006).

### 2.1.3 Systems of Off-Site Manufacturing (OSM)

OSM has a various different classifications which are based on systems reflected in the existing literature. Generally, the OSM systems have been classified as panellised, hybrid, modular systems which are widely adopted by researchers.
• **Panellised System** – this system is the construction of the structural frame for the building using flat panel units built in a factory and transported to site for assembly into a three-dimensional structure or to fit within an existing structure (NAO, 2005). Panellised systems can include wall, floor and roof panels to create the complete structural shell; they can either be open panels or closed panels. The most common approach is open panels (Fawcett *et al.*, 2005), which are typically delivered to the site purely as a structural element with services, insulation, cladding and internal finishes installed in situ (House Forum, 2004). However, closed panels systems typically involve more factory based manufacturing such as lining materials and insulation; also services, windows, doors, internal finishes and external cladding may be incorporated (House Forum, 2004).

• **Hybrid System** – This system involves volumetric units integrated with panellised systems. Hybrid construction is also referred to as semi-volumetric construction; typically used for high value serviced areas such as kitchens or bathrooms constructed as volumetric units with the rest of the dwelling constructed with panels, or some form of framing system (NAO, 2005). The hybrid systems are sometimes used to increase flexibility in complex development sites and those requiring additional communal areas; this system can also be used to reduce uniformity in design (House Forum, 2004).

• **Modular system** – There are four kinds of modules: (i) Individual components: this includes small components, such as doors and windows; (ii) Individual components assembled onsite as part of a system, these elements are essentially two-dimensional such as walls and flooring panels; (iii) Early ‘volumetric’ or ‘box’ units: these are in the form of concrete box units, which when assembled together formed the building and only required the addition of services and general fitting out; (iv) Fully-finished modules system, these are the modules which representing the concept of volumetric units to produce a fully-finished, ready-to-use building element.

Whilst there are different classifications of OSM used in the construction literature, the purpose here is to develop a matrix for classifying offsite products with various degrees of manufacturing techniques on both production sites: offsite and onsite as shown in Figure 2-1.
### Classifications of OSM

<table>
<thead>
<tr>
<th>Terms</th>
<th>Off-Site Fabrication/Pre-fabrication (OSF)</th>
<th>Off-Site Production (OSP)</th>
<th>Modern Methods of Construction (MMC)</th>
<th>Off-Site Manufacturing (OSM)</th>
<th>Modular Building (MB)</th>
<th>Industrialised Building System (IBS)</th>
<th>Pre-assembly</th>
<th>Standardisation</th>
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<tr>
<td>Types</td>
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<tr>
<td>Categories/Systems</td>
<td>Volumetric OSM</td>
<td>Non-Volumetric OSM</td>
<td>Modular Building</td>
<td>Component Subassembly</td>
<td>None–Off-Site Manufacture</td>
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<td></td>
<td>Modular Components</td>
<td>Frame systems</td>
<td>Pods</td>
<td>Subassemblies e.g. Precast foundations</td>
<td>Fixtures &amp; Fittings</td>
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<td></td>
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<tr>
<td></td>
<td>3D Units</td>
<td>Panel Systems</td>
<td>Complete Buildings</td>
<td>Tunnel Form</td>
<td>Flat Slabs</td>
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<tr>
<td></td>
<td>Hybrid System</td>
<td>Cladding systems</td>
<td>Fixtures &amp; Fittings</td>
<td>Thin Joint Masonry</td>
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**Figure 2-1: Classifications of Off-Site Manufacturing (OSM)**
The figure illustrates the commonly used terms for the various OSM to aid understanding of how these technologies are used in house building. It is assumed that there are three levels of classification of OSM applications: terms, types, categories/systems.

### 2.2 Development of Off-Site Manufacturing (OSM) in House Building

This section focuses on the development of the concept of OSM process in the construction industry with particular reference to house building.

#### 2.2.1 Historical Background

For centuries homes have traditionally been built piece by piece, dealing with unreliable weather, inconsistent labour quality, and materials occupying space on building sites and usually stored outdoors, and other obstacles (Kaufmann and Remick, 2009). The house building process entails the complex arrangement and scheduling of the thousands of products and materials and numerous labour resources required to build a home (Martin, 2005). Using traditional construction methods, this process may take several months, even for simple dwellings, and can include unexpected delays and cost consequences (Martin, 2005).

In the nineteenth century new construction materials and methods were employed in house building based on factory production. Davies (2005) stated that factory produced homes have a long history with houses-on-wheels stretching back to the Gypsy caravan in Europe and the covered wagon in America. Davies (2005) also links offsite factory production with the prefabrication of twentieth-century architectural production that architects from Le Corbusier to Walter Gropius and Frank Lloyd Wright to the modern proponents of high tech have offered for prefabricated housing. It was very much part of the Bauhaus movement; architect Walter Gropius articulated the point in 1910 that “the idea of industrialisation can be translated into reality by repeating individual parts. This makes mass-production possible and promotes low cost and high ‘rentability’. Only by mass-producing can really good products be provided. With the present method of building, it is a matter of luck whether one finds efficient and reliable craftsmen. “Mass-production has a factory-guarantee identity for its products” according to Vale, (1995:
82). Offsite manufacture therefore was seen as the way to build large numbers of homes in a fast and effective way of construction.

In the twenty century at the end of World War One, the construction industry in the UK was affected by major shortages of labour and building materials (both having been diverted into the war effort (Taylor, 2009) which resulted in a shortage of housing supply. Following the Second World War, the shortage of housing doubled due to destruction by bombing and the lower priority given to new building works during the hostilities (Venables, et al., 2004). This shortage led to a search for new materials and ways of construction that could tackle the problem (Housing Forum, 2002). It required moving from using traditional materials and methods of construction to the use of offsite manufacturing and production process of new homes in a factory environment.

The use of offsite manufacturing systems was employed in various ways after the war. Its early use was mainly for temporary buildings such as army accommodation and stores (Venables, et al., 2004). However, in the 1950s, according to CIRIA, (1996), there existed three key assumptions underlying the use of offsite construction in housing: need; standardisation; and workload continuity.

Throughout the 1950s and early 1960s a particular combination of social, political, and economic factors emerged in the UK building industry to give renewed impetus to manufactured housing (Homing Forum, 2002). In the 1970s, attempts have been made to increase the variety of housing types and styles produced from factory components, with the aim of exploiting economies of scope whereby producers can customise housing to meet individual requirements using more flexible production techniques (CIRIA, 1996). Traditional construction techniques dominated the market but were slow, and there were shortages of skilled manpower (Housing Forum, 2002). Adams, et al., (1998) pointed out that in the mid-90s, the aim was to develop offsite construction techniques to produce high-quality, long-lasting houses whilst reducing costs. In addition, Bottom, et al., (1996) stated that the consequences of energy price rises triggered research on energy saving technologies in housing, which led to further attempts to develop low-energy housing systems using offsite techniques.

In the UK, however, some first generation offsite manufactured homes (post-war-homes) were perceived as being of lower quality than traditionally built homes. However, recently the image of using offsite technology has changed very significantly
(Venables et al., 2004), as a means of improving quality, reducing time spent on site, improving onsite safety and overall cost reduction (Gibb, 1999: 32). There is significant changes in the culture and structure of UK construction industry towards the use of modern construction techniques (Parry et al., 2003), with considerable attention focussed on productivity and building performance (Pan et al., 2007). These include changes in working conditions, skills and training, approaches to design, use of modern technologies and methods, and supply chain (Egan, 1998), through to the investment towards mass production and customisation in the manufacturing process.

2.2.2 Mass-Production

Since the First World War, the historical evolution of the ethos of mass production through the manufacturing process has been seen when the necessity for the provision of new housing could not be handled by the trades system and traditional construction methods (Vale, 1995: 30). The idea of mass-produced houses had been developed so that the technologies existed to allow homes to be produced in factories, just as cars are produced. It would allow productivity within the housing industry to increase, as had happened in the car industry. As Le Cordusier (1927), an early advocate for mass produced housing, stated that “if the problem of the dwelling or the flat were studied in the same way that a chassis is, a speedy transformation and improvement would be seen in our houses. If houses were constructed by industrial mass-production, like chassis, unexpected but sane and defensible forms would soon appear, and a new aesthetic would be formulated with astonishing precision” (Vale, 1995:77). The main need was initially perceived to be simply to find an alternative to bricklaying (Waskett, 2001).

Davies (2005: 18) claimed that Le Cordusier was the most important European architect of the twentieth century. His statement indicates that the idea of houses from the factory has been linked to the mass-production of cars. It was through the work of Henry Ford that mass production could be used to manufacture high-quality objects such as cars (Arieff and Burkhart, 2002: 13). The car developed from the early craft-based product into the mass-produced item from the factory. Furthermore, the development of the automobile in manufacturing showed how the car had been transferred from a hand-made to a streamlined factory made product. One aspect of this rationalisation was the standardisation of components as a philosophical and artistic as much as a practical concept (Davies, 2005: 33). This approach embraces the possibility that if houses are to
be as streamlined as cars then this will result in similar benefits achieved in manufacturing industry.

Arieff and Burkhart, (2002: 13) stated that factory production yields lower prices and better quality; and the hope was that the application of factory production techniques to housing would similarly improve its quality, affordability and accessibility. These aspects were implemented on the scale of a housing estate in 1925 to improve traditional methods in terms of construction time (Vale, 1995: 61). In the UK, the government were the first clients to stimulate the market for prefabricated housing soon after the war, bringing it out of the experimental stage and into the stage of actual mass-produced homes (Vale, 1995).

2.2.3 Mass-customisation

The house building industry itself is a producer rather than a consumer (Leishman, et al., 2004). Thus, new housing would be designed and constructed with householders’ preferences in mind in order to satisfy their needs. Mass-customisation is defined as a strategy that creates value by some form of company-customer interaction at the fabrication/assembly stage of the operations level, with a monetary price similar to that of mass-produced products (Kaplan, et al., 2007). Thus, mass-customisation aimed to increase the opportunity to deliver greater value to its customers across the industry (Davison et al., 2006). Meanwhile, Winch (2002) specified that mass-customisation is the combination of the two (standardisation and pre-assembly), where standardised modular kits are configured to meet particular project needs and pre-assembled for installation on site. However, this belies the true advances in manufacturing where mass-customisation has taken over from mass-production (Vale, 1995). With highly computerised technologies involved in the design, digitally controlled manufacturing fabrication machinery and automobile manufacture using robotic assembly lines in construction, there was no longer the necessity for identical standardisation components; accordingly, mass-customisation stepped in production processes. Mass-customisation requires flexible production lines to produce a range of alternative assemblies to produce a variety of end-products which meet individual customer requirements and maximises choice (Gibb, 1999: 3).

Franke and Piller (2003) stated that adopting mass-customised products in construction is influenced by two factors: the value of the customisation and possible rewards from
the design process. Davison et al., (2006) pointed out that in order to satisfy the client’s needs, mass customisation meets this challenge by offering individually customised products and services with mass production efficiency. The use of mass production and mass customisation in construction, therefore, is a key to the use of offsite manufacturing in housing in order to address some of the challenges facing the UK house building industry and its clients. For example, it can improve supply rate of new homes in less time, quality and low energy homes, and customer’s satisfaction with cost efficiency. The overall benefit to the house building sector is to produce attractive, customised and affordable homes to achieve the government and industry’s targets.

2.2.4 Practices in other Countries

The trend to move construction activities to a factory-based manufacturing process is well established in many other countries in contrast to the UK. Offsite manufacturing has been largely adopted in some places, such as Northern Continental Europe and North America (Venables et al, 2004). In Germany, it is commonly understood within the industry that one means of increasing productivity without a corresponding increase in the demand for site labour is to utilise OSM in house building (Venables et al, 2004). However, as happened in the UK, some first generation OSM homes in Germany were perceived as being of lower quality than traditionally built homes. This perception after some 50 years of development and experience by manufacturers seems to have been more than overcome and the image of OSM has changed very significantly (Venables et al., 2004). Thus, the German construction industry has regained its position through the development of quality standards and certification schemes and consistent promotion of the merits of OSM.

Annual production of new homes in Germany is larger than in the UK, at 285,000 units pa (Venables et al, 2004), compared with the UK current supply rate at around 100,000 pa (Buildoffsite, 2013). OSM is seen as the major construction contributor to the improvement of housing supply in Germany.

Like in many countries, the Swedish construction industry has been linked with inefficiency and not meeting client needs (Larsson and Simonsson, 2012), low productivity and raising production costs (Jonsson and Rudberg, 2014). Thus, utilising offsite manufacturing and industrialised processes in house building has been a response to the increasing demand for more efficient and competitive ways of construction.
Attempts at developing new materials, process and revisiting old methods have transferred the Swedish construction industry from object-oriented, onsite into process-oriented offsite with increased control of the value chain (Soderholm and Jonsson, 2014). This resulted in a continuous productivity improvement, leading to time and cost reduction (Larsson and Simonsson, 2012). The use also of high levels of repletion increases the opportunities to control work processes in house building, leading to lower production costs and quality improvement (Meiling et al., 2014). The Swedish and Japanese housing industries show significant similarities to manufacturing processes (Gann, 1996; Larsson et al., 2014). Most importantly, focus is given to maximising the efficiency of the production of the entire process rather than individual projects. In addition, the use of advance manufacturing processes in Sweden has been developed largely in the field of housing interiors and furniture, which a number of companies have established. For example, IKEA is a multinational group of companies; their design, production and sell strategy is based on the idea of ‘ready-to-assemble furniture’, ideally prefabrication offsite in a factory and the furniture assembly onsite in homes, offices or other facilities. IKEA is become the world’s largest furniture provider.

In Japan, the use of industrialised housing attempts to address problems at the time with shortages of carpenters, low-quality of post-war housing, earthquake protection, fire protection and manufacturers’ efforts to improve products (Palmer et al., 1998). Japanese housing producers have learnt from other manufacturing processes, particularly in the delivery of wider ranges of customer choice (Gann, 1996). The housing market utilises advanced offsite manufacturing methods adapted from automotive manufacturing processes (Davison et al., 2006), particular in the car industry (Gibb, 1999: 46). The aim was to develop manufacturing techniques to produce long-lasting houses whilst reducing the costs of these homes. Gann, (1996) stated that manufacturing principles derived from the car industry have been successfully used to produce high-quality, customized and affordable homes. Toyota, as an example, does not just produce motor vehicles, but recently produced several thousand factory made houses in a year, based on its understanding of car mass-production (Toyota, 2006). Housing firms are therefore able to achieve economies of scale through the production of large volumes of standardised components to meet the needs of a differentiated housing market (Adams, et al., 1998), with Japan currently building about 40% of its new homes using offsite production techniques (Rahman, 2014).
In comparison, other countries such as the USA and Australia have also realised the benefits of utilising OSM systems, although they are not yet using them on the scale of Japan. In Australia, the use of OSM systems has been increased throughout the post war period in order to provide affordable homes (Mostafa et al., 2014b). The construction industry in Australia has been characterised as adversarial and inefficient and in need of structural and cultural reform of its management and operation processes (Cole, 2003). OSM has a major role to play to contribute to these challenges in house building sector (Blismas and Wakefield, 2007). The Australian house building sector contributes significantly to the national economy with the overall production value approximately AUD 47 billion 2010-2011 (Mostafa et al., 2014a), representing about 7.5% of GDP (Khalfan and Maqsood, 2014). Thus, OSM has been recognised as a key vehicle for driving improvement within the construction industry across its sectors, although the uptake has been limited (Blismas, 2005).

In the USA, the house building industry has used OSM system as a response to the encouragement of the Department of Housing and Urban Development (DHUD). The DHUD confirmed that there are numerous opportunities of using OSM systems in house building as a means of achieving better quality, faster delivery and lower cost homes (PATH, 2002). Currently in the U.S. the OSM sector represents about 20% of the new home starts (Rahman, 2014). Likewise, the Hong Kong construction industry has adopted offsite manufacturing methods for the construction of housing (Jaillon and Poon, 2009). The major reason for the adoption OSM systems was a substantial increase in housing demand in a very short period of time (Jaillon and Poon, 2008). This change occurred after the construction industry review committee (CIRC) and the Hong Kong Buildings Department recommended a wider use of offsite technologies (Jaillon and Poon, 2009). It was largely to improve the housing supply rate, quality control and reduce construction waste and pollution from construction activates.

Therefore, the overall reasons driving the construction industries in these countries to use OSM systems in house building are little different from the situation in the UK. Although, the features of OSM housing may be different from country to country, reflecting local traditions and preferences, the process is largely the same. The gains that have been achieved in some countries through increasing the use of offsite technologies in house building suggest that the same effect might be achieved in the UK.
2.3 Opportunities for Using OSM in House Building

Moving to offsite production, the housing industry can benefit by learning from the advanced manufacturing techniques and processes used in other industries (Gann, 1996). Miles and Whitehouse (2013) stated that OSM products in a factory ensures the consistent delivery of a number of performance characteristics of offsite housing supply: predictable supply, predictable performance, low waste, fast construction programme, improved health and safety and better working conditions, new technical skills and multi-skills, and good sustainability. Predictability and reliability are highlighted as the two major characteristics of offsite production, where advanced productivity techniques can be employed and project outcomes will be more secure.

OSM has the capability of making a difference within the UK construction industry in terms of economic, social and environmental opportunities (Waskett, 2001; Jaillon and Poon, 2008). It has been identified as an effective method to deliver efficient and sustainable construction substantially when compared with traditional onsite production (Zhai, et al., 2014). The uptake of OSM is partly influenced by the perceptions of the industry practitioners with regard to its advantages and disadvantages (Venables et al., 2004). The following subsections will consider these OSM opportunities in more detail.

2.3.1 Major Sustainability Aspects

- Environmental Opportunities

The use of offsite manufacturing techniques can contribute to both materials conservation and waste reduction, with waste generated offsite easier to reuse and to recycle (Jaillon and Poon, 2008). Further, it allows time spent working onsite to be reduced; this means that the impact of construction sites on the local environment is reduced (Waskett, 2001). With regard to air pollution, Jaillon and Poon (2008), stated that pollution which occurs during the manufacturing process is easier to control in a factory environment than pollution that is generated onsite, while there is also reduced transport pollution from factory to site and reduced pollution due to plant at the site (Housing Forum, 2002). OSM has also the potential to reduce energy in use through improved thermal performance and better design of systems (Housing Forum, 2002). By better design of OSM, it can reduce the wastage of materials by nearly 50% (WRAP, 2010), by reducing onsite waste by up to 90%, particularly with the use of volumetric
offsite systems when compared to traditional construction (WRAP, 2009). Indeed, OSM can limit waste to less than 1.8% of the total weight of materials, with less than 0.6% of waste materials sent to landfill (WRAP, 2010).

- **Social Opportunities**

  The major benefits offsite manufacturing techniques offer to social aspects compared with onsite construction methods are improved site safety, working conditions, worker’s safety and reduced accidents and ill health (Jalillon and Poon, 2008), because most of the work activities take place under controlled factory environment (Gibb, 1999: 44). Using OSM in house building can offer potential improvement of working conditions, while factory-based jobs offer greater long-term security for individual workers, better staff training (Ross, 2002), improved quality of manufacture and technical performance leading to better quality indoor and outdoor environments (Housing Forum, 2002). OSM also offers better quality which can lead to reduced maintenance costs and household energy bills, while better design can lead to flexibility for future changes and customers’ satisfaction (Gibb and Pendlebury, 2006). Faster construction can also improve housing completion rates and satisfy higher levels of demand (Burwood and Jess, 2005).

- **Economic Opportunities**

  The use of offsite technologies in house building improves quality and offers more rigorous quality control, reduced defects and improves the durability of components; while onsite output quality is very much depended on the workmanship of construction labours and the supervision team (Jalillon and Poon, 2008). Adopting OSM has the potential to reduce onsite construction time, improve quality, reduce construction defects, and minimising overall life cycle costs (Goodier and Gibb, 2007). In addition, house builders can also benefit from adopting OSM through early project occupation due to short construction programme, reduced life-cycle costs of ownership due to greater technical reliability and reduced energy-in-use, and improved margins due to more efficient site processes (Housing forum, 2002). Ozorhon, (2013) stated that the use of offsite technologies in construction has been recognised as one of the key factors contributing to national economic growth and recently has been part of the ‘knowledge-based economy’.
A considerable amount of literature has been published on the advantages and disadvantages of using OSM systems in construction. The studies have suggested that the use of OSM systems in house building is influenced by the perceptions of clients, developers, designers and contractors. They are themselves influenced by their business needs and delivery processes as well as market demand and end users’ perception for the system. This is summarised in Table 2-2.

Table 2-2: Advantages and Disadvantages of Using OSM in house building

<table>
<thead>
<tr>
<th>Key Issues</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Environmental | ▪ Improve environmental impact by using sustainable materials.  
▪ Improve environmental performance in-use of environmental control systems (e.g. related energy from manufacture, construction, use, and eventually disassemble), lead to reduction in carbon emissions.  
▪ Reduce traffic movement to/from site cause less neighbourhood pollution and congestion.  
▪ Less site accommodation requires less heating/lighting during construction.  
▪ Improved performance –  
▪ Improve sustainability due to less materials wastage during construction.  
▪ Reduce the amount of waste to be dumped/landfill.  
▪ Increased recycle and reuse of the units and modules.  
▪ Reduced pollution due to limited plant at site. | ▪ Generally increase CO₂ emissions if production plants not in economic distance.  
▪ Difficult long-distance transport for large, heavy loads.  
▪ Use of heavy machinery onsite for installation of units may lead to increase energy consumes and surrounding impacts.  
▪ Difficult to control manoeuvre of big components and units with strict site location.  
▪ Insufficient industry investment in R&D. |
<table>
<thead>
<tr>
<th>Social</th>
<th>Economic</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Improved management and coordination of people onsite.</td>
<td>▪ Limited capacity of suppliers and OSM’ plants to enhance OSM efficiency.</td>
</tr>
<tr>
<td>▪ Higher quality, factory-based jobs with greater long-term security for the individual worker.</td>
<td>▪ Difficult and expensive long-distance transport for large, heavy loads.</td>
</tr>
<tr>
<td>▪ Reduced accidents onsite.</td>
<td>▪ Too rigid design and specification.</td>
</tr>
<tr>
<td>▪ More secure jobs in factors.</td>
<td>▪ Interface problems on site due to low tolerances if did not manage and coordinate well.</td>
</tr>
<tr>
<td>▪ Better working conditions in factors.</td>
<td>▪ Future maintenance can be potential problem for manufactured housing.</td>
</tr>
<tr>
<td>▪ Reduced traffic movement to/from site leads to improved neighbourhood road safety.</td>
<td>▪ Lack of understanding of OSM local authorities.</td>
</tr>
<tr>
<td>▪ Provided fewer trades and interfaces onsite in the same time.</td>
<td>▪ Possible increased consequences of incidents.</td>
</tr>
<tr>
<td>▪ Provided wider range of design (customer choice).</td>
<td>▪ Regulations are too old and lack of codes and standards to cover lenders requirements &amp; warranties.</td>
</tr>
<tr>
<td>▪ Improved indoor environment issues (lighting, size, heights, ventilation, etc.).</td>
<td>▪ It appears expensive when compared to traditional methods (unaffordable)</td>
</tr>
<tr>
<td>▪ Easily offer adaptability for future changes and customer’s needs.</td>
<td>▪ Lack of training for installation and maintenance issues (secure jobs).</td>
</tr>
<tr>
<td>▪ Better factory control of dangerous substance.</td>
<td>▪ Leak media attention (to increase perception).</td>
</tr>
<tr>
<td>▪ Faster construction programme can lead to improved financial performance.</td>
<td>▪ Interface problems on site due to low tolerances if did not manage and coordinate well.</td>
</tr>
<tr>
<td>▪ Increased predictability of project outcome.</td>
<td>▪ Too rigid design and specification.</td>
</tr>
<tr>
<td>▪ Improve life span and durability of products.</td>
<td>▪ Future maintenance can be potential problem for manufactured housing.</td>
</tr>
<tr>
<td>▪ Increased productivity of project scale.</td>
<td>▪ Limited capacity of suppliers and OSM’ plants to enhance OSM efficiency.</td>
</tr>
<tr>
<td>▪ Reduce costs when resources are in short supply, or in remote areas.</td>
<td>▪ Difficult and expensive long-distance transport for large, heavy loads.</td>
</tr>
<tr>
<td>▪ Reduce costs when resources are in short supply, or in remote areas.</td>
<td>▪ Too rigid design and specification.</td>
</tr>
<tr>
<td>▪ Alleviate skills shortages in certain centres.</td>
<td>▪ Interface problems on site due to low tolerances if did not manage and coordinate well.</td>
</tr>
<tr>
<td>▪ Function for working space, effectively increases the site area.</td>
<td>▪ Future maintenance can be potential problem for manufactured housing.</td>
</tr>
<tr>
<td>▪ Higher finished quality products (less re-work and snagging).</td>
<td>▪ Improved environmental impacts – energy efficiency-in-use (better systems installation).</td>
</tr>
<tr>
<td>▪ Improved environmental impacts – energy efficiency-in-use (better systems installation).</td>
<td>▪ Easily offer adaptability for future changes.</td>
</tr>
<tr>
<td>▪ Easily offer adaptability for future changes.</td>
<td>▪ Reduced maintenance costs (design for manufacture/assembly also facilitated).</td>
</tr>
<tr>
<td>▪ Improved organisation of onsite operations (less operation costs).</td>
<td>▪ Improved organisation of onsite operations (less operation costs).</td>
</tr>
</tbody>
</table>
2.3.2 Project Management – Time Cost Quality Triangle

The benefits of using offsite production technologies have been widely studied. These include: reduced and/or more predictable production time, improved quality of the end product or facility, and lower and/or more predictable cost rather than initial cost savings (Jonsson and Rudberg, 2014; Larsson et al., 2014). In addition to these benefits, OSM can lead to a reduction in defects, improvement in health and safety, fewer environmental impacts, and lower whole-life-costs, leading to a consequent increase in predictability, productivity, performance, and profitability (Pan and Sidwell, 2011; Pan et al., 2012a). The potential value that can be realised increases when OSM components or modules with a degree of standardisation can be produced instead of individual building elements (Khalili and Chua, 2013). Consequently, the number of building components is reduced with lower installation activities onsite. Thus, project time can be reduced, quality improved and costs may decrease because of lower activities and lower dependency on skilled workers and lower resources required on building site. This is shown in Table 2-3.

Table 2-3: Advantages and Disadvantages comparing time, cost and quality of Using OSM in house building

<table>
<thead>
<tr>
<th>Key Issues</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time</strong></td>
<td>- Reduce onsite construction duration&lt;br&gt;- Short overall project timescale&lt;br&gt;- Fast-track of construction process due to transfer most of work to factory control environment.&lt;br&gt;- Certainly of project completion date.&lt;br&gt;- Reducing time spent on non-construction and manufacturing processes.&lt;br&gt;- Ensuring project completion date is certain.&lt;br&gt;- Rapid construction programme.&lt;br&gt;- Speed of installation onsite.&lt;br&gt;- Early clients and end users occupations.</td>
<td>- Early design freeze means late changes not easy to accommodate within timescale&lt;br&gt;- Lengthened lead times.</td>
</tr>
</tbody>
</table>
### Quality
- Increasing predictability of project quality.
- Achieving higher finished products.
- Better working conditions and control environment in factory.
- Quality control production processes.
- Using wide range of new technologies and simplify processes lead to reduce defects.
- High trained and stable workforce in factory.
- Products inspected and tested in factory before delivered to installation work on build site.
- Achieving high quality finishes and tolerances of components and facility.
- High levels of consistency.

### Cost
- Ensuring project costs certainty.
- Faster construction programme lead to reduce overall project costs.
- Minimising construction costs.
- Less operation costs on site.
- Less storage on building site lead to lower handling of materials costs.
- Lower labour involved in onsite activities lead to cost savings.
- Quick client return on investment.
- Low household's billing.
- Minimising overall life cycle costs.

### Building Regulations and standards
- Building Regulations and standards are too old to cover all the aspects of OSM to all expectations of clients’ requirements and end-users’ wants.
- Need to specifically design products and building components.

| Building Regulations and standards are too old to cover all the aspects of OSM to all expectations of clients’ requirements and end-users’ wants. |
| Need to specifically design products and building components. |

### Limited or expensive available skilled onsite labour.
- Higher initial cost.
- Higher capital cost.
- Seen as expensive construction when compared with traditional forms of construction.

#### 2.3.3 The Variation of Project based-OSM

Construction is a diverse and project-based industry (Ozorhon et al., 2014). It is essential to understand the role of the key parties involved in the construction processes and their influence on decisions to adopt OSM systems individually and collectively (Ozorhon et al., 2010). There are various types of construction projects and each single project has unique characteristics, stakeholders, priorities, goals aspirations. Gibb, (1999) identified the key characteristics of project based OSM systems that can be expected to vary depending upon various client, project, site and labour considerations shown in Table 2-4.
In addition, there are major benefits that can be realised of implementing OSM systems in construction due to client, contractor, consultant and architect (Wilson et al., 1999). The realised benefits of their work were summarised under various key project players as shown in Table 2-5.
Table 2-5: Variation of Key Project Players to OSM in house building

<table>
<thead>
<tr>
<th>Client</th>
<th>Contractor</th>
<th>Architect &amp; Consultant</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Shorter construction programme</td>
<td>▪ Work performed offsite under controlled conditions</td>
<td>▪ Specialist design input</td>
</tr>
<tr>
<td>▪ Faster return on investment</td>
<td>▪ Reduction in onsite preliminaries</td>
<td>▪ Single point responsibility</td>
</tr>
<tr>
<td>▪ Improved quality and reduce defects</td>
<td>▪ Reduced onsite management costs</td>
<td>▪ Improved customer satisfaction</td>
</tr>
<tr>
<td>▪ Value added and business continuity</td>
<td>▪ Reduced deliveries and carnage time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Safer working conditions for onsite operatives</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Reduction in risk through labour shortages, project overruns and penalty clauses</td>
<td></td>
</tr>
</tbody>
</table>

These various benefits can be recognised from transferring the onsite activities and practices to offsite production in a factory controlled environment.

2.4 Current State of OSM in House Building

2.4.1 The Concept of Using OSM in House Building

Since Egan (1998) provided impetus for the UK construction industry to consider the way in which it operated and how it improved its management processes, many government and industry initiatives and researchers have investigated its activity from different perspectives (Gibb, 2001, House Forum, 2002; Baker, 2004, ANO, 2005). The construction industry also has come under continual pressure after been criticised for delivering construction projects which reflect poorly on the key stakeholder’s priorities for house building (ANO, 2007). In addition, house building has taken a severe knock as a result of the economic crisis and concerns about the level of house building, which is insufficient to meet rising demand in recent years (CLG, 2010). Ogden (2010) also states that the key to survival involves recognition by management that the only rational strategy is the adoption of new practices and innovative (often offsite) technologies.

The central message is that there needs to be a shift to the use of offsite technologies and modern methods in the construction. The key themes of its use are sustainability, efficiency and improvement that the government and industry wish to promote in the construction industry (Atkin, 2014). However, majority of UK house builders are
familiar with the use of traditional onsite construction in contrast with offsite production methods (Pan et al., 2007).

However, Piroozfor and Farr, (2013) stressed that the construction industry has experienced a shift from traditional methods to industrialized ways of construction largely because of the implications of the Industry Revolution’s progeny – the cheap and advanced technology. The Department of Trade and Industry has responded to this call by stating that the government is committed to accelerating the adoption of offsite manufacture techniques in house building. However, this required support from all the industry’s stakeholders to enhance a step-change to use offsite techniques across the industry. Roy et al., (2005) stated that there is a need to address the concerns of embracing technological innovation, re-examining working practices in house building and start changing a culture of the construction industry to adopt offsite techniques for the delivering new homes.

There are a number of the government and client bodies that have indicated the need to adopt offsite manufacturing technologies and they are working on ways to drive improvements across the construction industry. These include: Establishment of the Housing Forum, the Prefabulous Homes programme and prOSPa initiative.

- The House Builders Federation (HBF)/National House Builders Council (NHBC) lead Barker Committee Recommendation looking at providing solutions to the impediments of greater use of modern techniques.
- The Government Sustainable Communities Plan (GSCP) represents the adoption of the new term of offsite technologies to deliver and better quality homes.
- The Housing Forum's Customer Driven Strategy to improve the quality of homes.
- The National Audit Office (NAO) report using modern methods of construction to build homes more quickly and efficiently.
- DCLG/English Partnerships Design for Manufacture initiative to ‘showcase’ the best housing solutions.
- BURA’s Steering and Development Forum study to evaluate the opportunities and challenges of MMC regeneration.
- The establishment of Buildoffsite, an organisation to provide leadership to the offsite construction industry and a focal point for clients of modern methods.
- Over 100 organisations committed to Buildoffsite between government and client body’s to look at enhancing the offsite production methods in the construction.
- The Buildoffsite Registration Scheme for the use of offsite methods in the construction.
- The Buildoffsite Property Assurance Scheme for the use of offsite construction methods.
- The Buildoffsite R&D Tax Credit Service for using offsite technologies production in the construction.

With regard to increasing the use of offsite technologies in construction, there are more than 100 offsite production and building systems being supplied by more than 570 manufacturers and suppliers (Pan et al., 2012b). Despite the wealth of knowledge available in the UK (Taylor, 2009; Buildoffsite, 2012), its use is still limited and much lower than anticipated in house building (Zhai, et al., 2014). Despite this limitation, the use of OSM has the potential to meet increasing housing demands and benefiting the construction industry in many other ways (Rahman, 2014). It has also been widely reported that OSM can make significant improvements in house building (Pan et al., 2007; Kaufmann and Remick, 2009; Goodeir and Pan, 2010).

2.4.2 Drivers for Change to Use OSM

The Housing Forum (2004) stressed that the construction industry has come under pressure from the Government’s bodies to change and contribute to the Government and industry improvement targets by reviewing their ways of constructing and delivery of new homes. This is because there are concerns about the ability of traditional site-based construction methods in delivering the government and industry improvement demands for the future of house building sector in the UK. Egan (1998) recommended the use manufacturing processes as the way forward for improving efficiency and quality of construction. Since then there are changes occurring in the industry that have led to the use of offsite technologies including technology transfer from other industries, mass production, mass customisation, and information technology advances (Gann, 1996). However, these technologies cannot be directly applied to the challenges facing construction without those solutions being re-engineered and adopted into the construction process (Pan and Arit, 2011). Ross (2006) stated that the housing sector is changing due to market forces, driving the industry to reconsider its approach to serving
its customers and/or end users. The drivers of the use of OSM in the construction with particular reference to house building have been widely studied and well documented at various times of literature (Gibb and Isack, 2001; Pasquire et al., 2004; Ross, et al., 2006; Pan et al., 2007; Goodier and Pan, 2010; Pan and Aril, 2011; Pan and Goodier, 2012). The most frequently mentioned drivers are presented under the following headings:

- **Housing supply**

  Current housing supply is lower than that required to satisfy the demand for housing. High demand for housing in such areas as London and the South East is pushing up prices, making it more difficult for key workers and those on low incomes to find suitable accommodation (Ross et al., 2006). The Government has sought to stimulate house building rates through the development of offsite capacity (Miles and Whitehouse, 2013). Offsite manufacturing methods can be significantly faster than traditional construction methods because most of the work takes place under factory controlled environments and production processes. Buildoffsite, (2012) pointed out that factory productivity reaches up to 80% compared with 40% for a typical site production. A potential solution to successful increasing of housing supply is the offsite manufacturing (Blismas and Wakefield, 2009). Thus, the use OSM systems can contribute to improve housing supply rate in the UK.

- **Projected skills shortages**

  There is a significant shortage of skilled labour across the construction sector (Housing Excellence, 2002; CIOB, 2008; Miles and Whitehouse, 2013). The need to improve the levels of productivity within housing sector means that housing demand is unlikely to be met by conventional methods mainly based on traditional craft-skills productivity. This is challenging the industry to find alternative ways of constructing homes. The use of OSM systems has been promoted as part of a solution to address the shortage of skilled labour in construction and in particular housing (Housing Forum, 2004; Ross et al., 2006). The major reason here is that most of the work traditionally done on site by skilled labour is transferred to a factory environment where there can be more training of operatives and greater job security (Burgen and Sanson, 2006). Miles and Whitehouse (2013) also stated that offsite installations can be undertaken by specialist teams who have been trained by particular manufacturers. The main point here is that
using OSM can also be used to address skills shortages through reduction of labour on site and the use of factory labourers more effectively (Burwood and Jess, 2005). Therefore, the implementation of OSM in house building can be used as a strategy to address skills shortages in the construction industry.

- **Quality of new housing**

Achieving high quality issue is probably one of the main reasons for using offsite technologies in construction (Gibb, 1999: 40). Manufacturing facilities usually have a stable workforce that can be trained properly and are more likely to produce higher quality end products. This is because OSM products manufactured under factory controlled environments and better working conditions, specifically in terms of consistency and dimensional accuracy, lead to improved fit on site (Housing Forum, 2002). Furthermore, Blimas et al., (2006) stated that products manufactured offsite will be inspected and tested then tried in the factory before being delivered to the building site. This, therefore, can lead to high quality and very predictable quality finishes. Construction Excellence (2006) pointed out that the movement for adapting offsite manufacturing technologies has been recognized as key for integrating processes and teams around the product, and therefore leads to improved quality of the end-product.

- **Revision to Building Regulations**

Recent Building Regulations cover the entire performance of buildings (Ross et al., 2006). The industry is looking at OSM systems as a potential way of providing more predictable performance in the completed building. OSM has been promoted on the basis that it can provide more predictable building performance in completed housing compared with traditional forms of construction (Ross et al., 2006). The construction of new homes itself becomes more complicated in response to increased performance requirements under planned revisions to part L of the Building Regulations (Miles and Whitehouse, 2013). The use of OSM can lead the way forward to address the requirements of the Building Regulations in terms of efficiency and performance standards to be met in new homes.

- **Environmental performance**

There are always extensive environmental effects on building sites and surrounding areas that affect everyone directly or indirectly. However, there is no evidence to
suggest that the traditional forms of construction are capable of improving sustainability or reducing environmental impacts on construction sites. Griffith, et al., (2000) stated that emphasis is being placed on the environmental performance of buildings, not only in use but also during construction, and the environmental credentials of the materials being used. The use of offsite manufacturing can reduce CO₂ emissions from housing and subsequently reduce the end user’s carbon footprint (Kempton, 2009), and reduce the impacts on the local community (Ross et al., 2006) in terms of noise, dust and traffic movement.

Using OSM also can contribute to environment sustainability through reduction of waste off and on site and better energy performance (Jaillon and Poon, 2009). Mtech consult group (2006) claims that offsite construction can play a significant part in delivering sustainable construction, because offsite products are manufactured in factory environments under controlled processes that are delivered by skilled workers. The UK construction industry consumes more than 400m tonnes of materials each year, generating 100m tonnes of waste (WRAP, 2009). Research carried out by WRAP has found that utilising offsite techniques in construction can reduce onsite waste by up to 90% (WRAP, 2010). This is because much of the work takes place in a controlled factory environment, which makes waste segregation and recycling much easier (Yorkon, 2009). The use of offsite manufacturing therefore can offer an opportunity to reduce environmental impacts on construction sites and reduce construction waste to landfill and enhance reuse and recycling in house building.

- **Health and safety context**

The nature of traditional construction methods is a relatively dangerous activity for workers (Krug and Miles, 2013) and one of major causes of accidents in construction is falls from height. The use of OSM can reduce risks due to a reduction of the activities and construction time on site, thus improving conditions for workers (Blismas and Wakefield, 2007). Others argue that the use of OSM may not completely eliminate the risk of accidents in the processes involved, but the risks are more predictable and can be more effectively managed during the design and construction processes compared with traditional construction site (Buildoffsite, 2012). Consequently, the use of OSM is considered to be safer than traditional forms of construction.
2.4.3 **Constraints to the use of OSM**

Whilst OSM has been recognised in the UK and internationally as offering numerous benefits to all parties in the construction process, its use may also raise challenges that need to be overcome. These constraints are identified as follows:

- **The UK Capacity in OSM**
  
  The Housing Forum MMC group, (2004) pointed out that UK manufacturing facilities are not generally running at full capacity either for housing or for other parts of the construction industry. According to Housing Forum (2007), however, a number of UK companies have expanded their facilities in recent years or have begun working with other firms to set up new production facilities. This could help meet demand if the use of OSM components in housing market becomes more widespread.

- **Public perception**
  
  The social acceptability of offsite manufactured housing built in the UK has varied considerably since the Second World War (Venables *et al.*, 2004). Craing (2000) argues that it is essential to remember that housing constructed between 1946 and 1975 used both prefabricated and standardised construction, meaning that the likely lifespan is generally considered to be less than that of “traditional” built housing. Housing Forum (2002) stated that durability, life expectancy, warranties/insurance scheme, ease of repair, insurability, scope for alterations, general market appeal and pricing are key issues affecting public acceptability of OSM. The public perception and slow demand are seen by suppliers as the main limiting factor and standardisation of offsite products may limit customer choices (Ong, 2004). These attitudes all affect the public perception of offsite technologies in house building.

- **Mortgage finance for OSM**
  
  The use of offsite manufacturing has raised concern among mortgage lenders in providing loans to house builders and buyers (Housing Forum, 2004a). Mortgage lenders have basic requirements for security for a loan which are usually to do with factors such as durability, life expectancy, warranties and insurance schemes. Mortgage lenders also ask for an independent assessment for new construction methods such as OSM before they guarantee their future mortgage value (Ong, 2004), which may affect...
the acceptability of using the system. These all make mortgage lenders less inclined to give a loan to build or buy property based on offsite systems.

In order to deal with this, the UK Government and the industry are working on revision of the regulation and standards in order to address some aspects of new offsite manufacturing products. For example, the Council of Mortgage Lenders (CML) stated that it will continue working with BRE in the development of a benefit realisation toolkit which will try to address the specific issues relevant to lenders dealing with innovative housing (Ross, 2002). Examples include the Buildoffsite Registration Scheme, the Buildoffsite Property Assurance Scheme and the Buildoffsite R&D Tax Credit Service for the use of offsite methods in the construction (Buildoffsite, 2010). It is clear that the availability of such schemes will help the sector.

- **Physical Constraints**

  The offsite component and module dimensions which are fabricated is limited to the size that can be lifted and transported safely to site within the maximum width possible for road and routes (Taylor, 2009). Larger offsite components may therefore be appropriate for open sites with few movement restrictions. The issues of transportation and erection logistics need an early consideration during the design of offsite components. Elnaas et al., (2012) stated that storage of the units on building site before erection is another issue which is not recommended or practical when using OSM systems.

- **Technical Constraints**

  The use of offsite manufacturing techniques also many raise technical constraints such as the very early design freeze (Blismas et al., 2005. Indeed, the design of offsite components must be frozen before the move to manufacturing processes because it is not easy to accommodate late changes, which are costly and may cause delay. The Housing Forum, (2004) stated that the cost of OSM systems cost may currently be higher than the equivalent under traditional methods to house building (Housing Forum, 2004). Others argue that it is not necessarily an expensive option if its use becomes more widespread, and total cost comparison was done including to all aspects of the project life cycle (Elnaas et al., 2009). There is also need for larger capacity cranes, and hence potential extra carriage costs. However, it will involve far fewer uses of the crane than using traditional construction methods.
Cost

Cost has been identified as a critical barrier to the use of OSM in the construction industry. The cost associated with the use of OSM is cited as ‘high initial cost’ (Goodier and Gibb, 2007) and/or ‘higher capital costs’ (Pan et al., 2007). As a consequence of this cost barrier, many house builders and developers are unwilling to use offsite construction methods for their projects (Pan et al., 2008a). However, house builders can still benefit from an early project completion. This is due to short construction periods, reduced life-cycle costs due to better technical reliability and durability and efficient site processes, and reduced household bills due to reduced energy-in-use.

Building Regulations and Standards

House builders argue that the Building Regulations still do not meet and cover all the aspects of offsite manufacturing methods to enhance its use house building (Elnaas et al., 2012). As a result, some construction professionals avoid the adoption of offsite methods and go traditionally. While Ross et al., (2006) expressed that there is a general feeling that quality will need to improve if only to meet the higher performance standards needed to comply with the revised Building Regulations. An organisation such as Buildoffsite and its associated partners are working side by side with the government in order to close this gap of building regulations and standards to cover all OSM aspects.

The literature regarding drivers and constraints to OSM was revealed to be able to identify the competitive priorities in the construction of housing. However, the constraints together have challenged the industry with negative aspects to use OSM systems in house building. Therefore, there is still a need from the government and industry bodies to do more in order to close the gap. Thus, there may be a need for new legislation, standards and guidance in place in order to support the industry in making decisions about how best to build new houses.

2.5 Synthesis

This chapter aimed to reveal the existing gaps in our knowledge and the concept of Off-Site Manufacturing (OSM) in relation to the research problems. The chapter provides a definition for OSM and the one to be used through this research work. It also identified
the various classifications of OSM in terms of categories, types, systems and methods in relation to its use in the construction with particular reference to house building. The chapter outlined the development and manufacturing processes in the construction of house building from other industries. The concept of mass-production and mass-customisation from manufacturing industry has played a key role in the application of offsite manufacturing in house building. The potential of using off-site manufacturing in the UK house building has been explored and is considered a possibility to address some of the challenges facing the house building sector. The advantages and disadvantages of using OSM in house building have been summarised in terms of economic, social, environmental, time, quality and cost aspects.

The chapter has therefore established the current state of the art of OSM in building. It has identified the drivers for adopting OSM and the constraints that affect the use of OSM in house building. This work supports the idea that adopting OSM could be increased, but that this can only be realised with a better understanding of the decision making process by the stakeholders involved in the construction process.

Previous research has addressed the use of offsite production technologies in construction, whilst largely overlooking such technologies within the context of house building. This has led to a need to create a better understanding of decision making processes related to OSM in house building, based on the best practices. The objective of this research has been to address this gap in knowledge by developing a robust decision making model that can be used in practice to assist construction practitioners in making decisions based on adequate data to enhance the use of OSM in house building projects.

The poor adoption of OSM in house building is clearly not due to a lack of technology or knowhow, but seems to hinge on the decision about when to use OSM. The next chapter therefore will focus upon the decision making process to use OSM in construction specifically to house building and work towards addressing some of the issues raised as research problems.
CHAPTER THREE: LITERATURE REVIEW: DECISION SUPPORT SYSTEMS USED IN THE UK CONSTRUCTION INDUSTRY

The aim of this research has been to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between using OSM and TOS Production as a construction strategy for housing projects in the UK.
3.0 Introduction

The purpose of this chapter is to address and scope the gaps in knowledge highlighted in the previous chapter. It aims to critically review the concept of decisions and the decision making process to use Off-Site Manufacturing (OSM) in the construction industry with a special focus on house building. The chapter analyses the Decision Support Systems (DSSs) currently being used in the construction industry with particular reference to house building. The focus is on understanding the level of sophistication and limitations of the DSSs used to evaluate the use of OSM as a construction strategy in house building. The expected outcome is to scope the gaps in knowledge of decision making in the context of OSM in house building. The chapter is made up of three sections. Initially a generic discussion on decision is outlined, leading to an understanding of the process of decision making. The second and third sections focus on the study of the process of decision making in construction with a particular reference to how the decision to use OSM is taken in the house building industry. The aim is to analyse the weaknesses of the decision and how these could be improved upon. This research focuses on decision making process at the strategic management level of a decision for choosing a construction strategy among alternative options (OSM vs. TOS) in house building.

3.1 Definition of Decision

The Oxford English Dictionary (2006: 187) defines decision as “a conclusion or resolution reached after consideration”. Decision is the art of making up our mind about something or opinion or judgment reached after considerations of make up a composite of information, data, facts and belief surrounded the matter (Lee et al., 1999). Drummond (1996) defined decision as the final outcome of the process of mapping up the likely consequences of choosing between alternatives of action using cognitive process, memory, thinking, and evaluation of decision matter. It is the point at which a choice is made between alternative and usually competing options (Fitzgerald, 2002). Others authors such as Hamalainen, (2002) defined decision in wider outlook context in which concerned and framed by requirements and questions specifying the need to be taken in account when making a decision. These issues are shown in Figure 3-1.
These indicated requirements and questions define the context of decision which needs to be knowledge in order to make right decisions. However, the required information and answers surrounding the decision context may be different from decision to decision. It depends upon the nature of decision problem and its environment to be specified and values of its stakeholders resulted from the decision outcomes.

3.1.1 Type of Decisions

Decisions are usually with concerned issues such as people (human resources), money (budget), buying and selling (marketing), processes (operations) or how to do things (strategy and planning). In this relation, Simon (1960) states that decisions may be classified into two generic types of categories to the extent of the process of decision making that can be pre-planned. These types are programmed or non-programmed decisions:

- Programmed decisions are defined as routine, repetitive, known decision rules or procedures. These decisions can be dealt with through the use of specific handling methods and standard way determined by set guidelines. The decisions in this category often can be delegated to low levels in organisation. Alternative term for this category is ‘structured decisions’.

- Non-programmed decisions can be defined as less structured that would not have any guidelines to operate by. These decisions involve strategic level planning, because uncertainty is high, complex and decision rules not known (Draft, 2005).
There is a high degree of uncertainty often cannot be delegated to low levels. Alternative term for this category is ‘unstructured decisions’.

In general, these types of decisions are not related to computer processing but refer to the nature of decision process and the extent that the process can be pre-planned (Lucey, 1997). In addition, there are other kinds of decisions identified by Harris (2009) as follows:

- *Decisions whether* – This category is known as the yes/no decisions, decisions that must be made before we proceed with the selection.

- *Contingent decisions* – These are decisions that have been made but put on hold until some condition is met.

- *Decision which* – These decisions involve a choice of one or more alternatives from among a set of possibilities. Then, the choice is being on how well each alternative measures up to a set of predefined criteria.

These three types of decisions might be applicable to construction process, however, the ‘decision which’ can be the most relevant type because construction decisions are in most cases to be made between more than one option of decision matter.

### 3.1.2 Categories of Managerial Decisions

In the managerial and business service, there are a number of decisions that take place at each level of management in an organisation; however, each level has substantially different information requirements (Lucey, 1997). Harris (1998) has classified decision levels into three zones of management:

- **Strategic Decisions**: Decisions at highest level and concerns general directions, long term goals, philosophies and values – Where are we heading? What are overall goals?

- **Tactical Decisions**: These support strategic decisions are tended to be medium range and often have moderate consequences – e.g. what is the timescale? And to what specifications?
Operational Decisions: These support tactical decisions and usually follow known rules and techniques which include issues such as resources and management decisions – e.g. How many? What are priorities and objectives?

In any case, decision makers or managers need to set an effective strategy for their decisions across three levels. Evaluating flow information throughout the levels of decision scope should lead to successful decision making, rather than apply a rigid decision and solution (Finlay, 1994: 207). This will maximise benefits across the case because the decision made based on long and short term characteristics surrounding the problem. The managerial decisions can be also categorised in terms of knowledge about outcomes state. These types are defined as following:

- Certainty types – there is only one outcome and complete and accurate knowledge of the outcome is available.
- Risk types – there is multiple possible outcomes with each having a value and probability of occurrence.
- Uncertainty types – the number of outcomes, their values and probabilities are not known.

Decisions can be easily made where there is a clear certainty outcome or choosing from possible alternatives that it is probability of risk low for the decision matter. However, decision is not possible to be made straightforward where there is uncertainty. This is because decision by definition, means choosing the best outcomes between alternatives and if the alternatives and outcomes are not known then decision makers cannot choose between them. In this relation, Lucey (1997) stated that in practice transforming uncertainty into risk, if this was not done during decision making process could not take place in the real world where uncertainty to a greater or lesser extent, is always present.

3.2 The Decision Making

This section gives a generic brief of the concept, process, role of judgments and approaches of decision making in general terms; and outlines decision support tools and techniques used in organisations.
3.2.1 The Concept of Decision Making

The concept of decision making is an integral part of management and occurs in every function at all levels that chooses outcome which are desirable after carrying out some forms of evaluation for possible outcomes (Lucey, 1997). Decision making is the process of generating a solution to a recognised problem (Li, 2008). The decision outcome is mental processes (an action or opinion) leading to the selection of a choice of action among several alternatives of the decision environment (Kahneman and Tversky, 2000). A similar definition also provided by Ammar, et al., (2013) as a task in which the most preferred alternative from a given alternative set has to be selected. During the whole process, decision makers are making the choice based on the current situation (Li, 2008). Additionally, Harris (2009) pointed out that decision making is the process of identifying alternatives of decision matter based upon values and preferences and choosing the one with the highest probability of project success or effectiveness, and best fits with desired goals.

Simon (1951) defined decision making as rational behaviour with set parameters that contain the main features of a problem or decision matter. While, Drummond (1996) suggests that decision making process involves actions leading up to the moment of choice and beyond, this is a valid point. Decision makers must decide at point by some means to choose the outcomes which are desirable to them and to do so after some form of appraisal of the situation (Harris, 2009). Thus, the concept of decision making may be regarded as a decision matter solving activity which is terminated when a satisfactory solution is found or met, subsequently the decision is to be the final choice.

3.2.2 Decision Making Process

A considerable amount of literature has been published on the decision making process. Mullins (1996) for example pointed out that decision making process is the procedure in which information (stimuli) from the environment around us is selected, assessed and organised to provide meaning for the individual. While, Lee et al., (1999), decision making process is the way of generating and evaluating possible alternatives for the course and making choice or choices among them. Consequently, decision makers need an approach to understand decision making process for better decision outcome.
The literature has provided examples for decision making process used in all science-based professions, where specialists apply their knowledge that fit a set of indicators. Lucey, (1997) stated that making decisions occur in every function at all management levels, but all decisions have to go through a similar process at some extent. Although, there can be many decision outcomes to a given problem of course. Li, (2008) specified that there are three basic activities involved in decision making process: intelligence activity, design activity and choice activity. Choo, (2006) suggested that the central idea of decision making process is the engagement of three decision directions: decision situation, goal directed action, and information is evaluated to achieve some goals. On the other hand, Simon (1951) proposed decision making process as rational behaviour with parameters that contain the main features of a problem or decision matter. It comprises four principal phases of decision making process to arriving at the right option for decision matter as shown in Figure 3-2.

<table>
<thead>
<tr>
<th>Phase</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intelligence</td>
<td>Searching the environment for conditions calling for decisions.</td>
</tr>
<tr>
<td>2</td>
<td>Design</td>
<td>Inventing, developing and analysing possible alternatives of action. This involves processes to understand the problem, to generate solutions and testing of solutions for feasibility.</td>
</tr>
<tr>
<td>3</td>
<td>Choice</td>
<td>Choosing a course among available alternatives of action. A choice is made and implemented.</td>
</tr>
<tr>
<td>4</td>
<td>Review</td>
<td>Evaluating past choices.</td>
</tr>
</tbody>
</table>

**Figure 3-2: Simon’s phases of decision making process**  
*(Simon, 1951)*

The figure (3-3) illustrates Simon’s terminology for decision making process. There is general flow information from intelligence to design to choice to review, and at any time there could be a return to an earlier phase for review and feedback before the final choice.
In addition, a study conducted by Harris (2009) also indicated that decision making should track the following process for better decision outcomes:

- Identify the decision to be made together with the goals – It is to determine the scope and limitations of the decision.
- Get information and facts surrounding decision principles – It can be useful to consult those who will be affected by and who will have to implement the decision.
- Develop decision alternatives – it is the process of identifying a list of all possible choices that may apply on particular solution of action.
- Analyse each alternative – This should consider the negative and positive consequences.
- Rate the risk of each alternative – However, it can be there is some degree of uncertainty in any choice.
- Make the final decision – Choosing the most beneficial outcomes of decision between the alternatives which may take into account the preferences of others.

Moreover, decision making process defined by Lee et al., (1999) as an act with complete objectivity and rationality involving a systematic procedure of decision problem conditions”. They proposed its process graphically as shown in Figure (3-4),
by means of problem solving that can be incorporated with making decision process in construction.

![Figure 3-4: Proposed decision making follows processes (Lee et al., 1999: 53)](image)

The AHP theory has been applied to analyse and evaluate decisions in the construction industry on a range of problems situations, aiming to resolve decision options usually in multi-criteria environment (Turskis et al., 2009; Latorre and Riley, 2010). In addressing multi-criteria in decision analysis, the Analytical Hierarchy Process (AHP) theory has been developed based on mathematical structure related to decision making (Saaty, 1994). It has been applied to a range of problem situations: planning, selecting among options in a multi-criteria environment, resources allocations, and forecasting (Vaidya and Kumar, 2006). The primary functions of the AHP theory are structuring complexity, measurement, and synthesis of decision options (Forman and Gass, 2001), based on a pair-wise comparisons between attributes of decision problem (Vaidya and Kumar, 2006). Some of the key and basic steps involved in the AHP methodology process defined by Saaty, (2008) in order to make decision in an organised way to generate priorities. These steps are as following:

- Define the problem and determine the kind of knowledge sought.
- Structure the decision hierarchy from top with decision goals.
- Construct a set of pair-wise comparison matrices, each element in an upper level to be compared with the elements in level immediately below.
- Use the priorities obtained from the comparisons to weight the priorities in the level immediately below for every element.
- Continue the last process of weighting and adding till the final priorities of the alternatives in the bottom level are obtained.
Making decisions using multi-criteria analysis are mainly based on terms of choosing, ranking or sorting the actions which used in various areas of human activities (Turskis et al., 2009).

All the above techniques and terminologies of decision-making process show the relationships between the problem solving process and finding best option for course, by means of their definitions that they can be incorporated with decision making process in the construction

3.2.3 The Role of Judgement in Decision Making

The decision judgement is an important part of the decision making process. Making a decision is a judgement and a choice between alternatives and is not necessary a choice between right and wrong (Lee et al., 1999). Whilst the solution is being tested and once the proposed choice seems feasible to achieve the goals, the decision can be implemented (Turban et al., 2001).

In addition, Hofstede (1981) suggested that there is a relationship between control certainty and decision making context that can be linked to way in which decision makers exercise judgement. Putting forward that judgment and control could be exerted in different ways, namely through the following:

- The degree of uncertainty in the objectives to be achieved
- The measurability of the performance to be controlled
- The extent to which the outcomes of activities are known
- The degree to which the activity is repetitive.

The essential of making Judgement by the decision maker should aim to eliminate bias in order to reach as rational of decision as possible before make some appraisal for available options.

Furthermore, Mallach (1994) pointed out that decision makers can make judgement along three dimensions methods:

- Rationality – the capacity to collect and analysis data based on a pre-established selection criterion for the final choice.
Politically – the ability to make decisions in a group within the organisation required individual members to compromise in the interests, goals and authority.

Flexibility – the capacity to make decisions that break the mould of tradition and structure and imply the opposite to rationality and pre-established measures.

Lee et al., (1999) stated that “individuals make value judgments by which they express preferences and make predictions that reflect what they expect to happen”. They also suggested that there are three main causes of bias can be attributed to the following:

- Probability estimation – This cause can lead to bias when assumptions are false and to neglect of base information in the estimating.
- Outcome evaluation – This can occur when the extent has an effect on the evaluation of potential outcomes. Decisions can be made in response to similar decision matters when the decision is seen in different light.
- Communication process – This cause relates to the way that messages, verbal or visual, are perceived by recipient.

There may be no right or wrong when trying to decide if judgements are appropriate for making decisions. However, decision makers may make decisions in a way that best suits them within a given decision situation and its environment. Hence, judgment system is necessary to be in place in order to guide the selection through design, choice, evaluate and then review of decision outcome or outcomes to arrive eventually at the best option for decision matter. This is needed especially with decision situation occur in the face of uncertainty or multi-criteria such as construction decisions in order to eliminate the risk of choosing or making wrong decisions. Decision makers, therefore, should have full attention to the quality of their decisions with due regard for all project stakeholders’ interest. They are assumed to select the most efficient alternative for particular case or project to maximise the amount of decision outcomes for a given input.

3.2.4 Decision Making Approaches

Decision making can be classified into three categories: individual, group and authoritarian.
Individual – This category individual makes decision based on personal values, preferences and understanding of the problem.

Group – Many decisions can be made in group settings. There are many inputs in this approach which tend to reduce cognitive basis and decisions made based on combined ideas, skills and abilities.

Authoritarian – This approach decision maker relies on the head or leader of the group’s team. The group creates ideas and discussed then the designated leader makes the final decision. The leader though must explain the chosen course among options in order to obtain acceptance of the outcome.

Individual decision making approaches can make the final decision quicker to arrive at than via a group process, especially when time is limited time. It also can work effectively for leaders when group team’s inputs are not required. Group decision making can have a broader perspective and consider more alternatives and facts influenced by team involved in. However, group decision making often work slower than individuals (Simon, 1960). While, authoritarian decision making is typically utilised more when there is a crisis or urgent response needed of a matter (Cardus, 2010).

Decision makers, however, may face a range of constraints during the evaluation stage of decision to meet its strategies (Lucey, 1997). For instance, there may be inaccurate definition of the decision matter, lack of alternatives, limitation of the decision makers’ perceptions or incompatibility between attitudes. These issues influence on the decision outcome of its matter. The construction industry is characterised by its nature of operation (Ng et al., 2001). However, construction decisions are often described as difficult and complex in nature (Abdullah and Egbu, 2011). This is because most decisions typically involved issues such as uncertainty, complexity, risk consequences, alternatives and interpersonal issues.

3.2.5 Decision Support Tools and Techniques

There are many different types and levels of decision support tools, techniques and systems that have been used in organisations. Lucey, (1997) states that in broad terms the organisation’s Management Information System (MIS) can perform one of two functions with respect to decision making. Firstly, it supplies information, explores
alternatives, and provides support where the manager takes decision. Secondly, it takes the decision itself, and this is only appropriate with routine operational decisions where the rules are known.

These types of decisions are routinely being taken by computerised MIS, as part of the transaction processing of decision. Semi-structured and unstructured decisions can exist at operational levels, and these decisions have to be taken by managers who involved in decision making process but they need data for assisting and evaluating the likely outcomes of available alternatives. Figure (3-5) illustrates the relation between decision making and information systems support at the three management levels for a decision.

<table>
<thead>
<tr>
<th>Levels</th>
<th>Decision Types</th>
<th>Information Systems Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic Management</td>
<td>Unstructured</td>
<td>Executive Information Systems</td>
</tr>
<tr>
<td>Tactical Management</td>
<td>Semi-structured</td>
<td>Expert Systems, Decision Support Systems</td>
</tr>
<tr>
<td>Operational Management</td>
<td>Structured</td>
<td>Transaction Processing, Automatic Decision-Making, Or/And Accounting Models</td>
</tr>
</tbody>
</table>

Figure 3-5: Decision-Making and MIS support  
(Adopted from Lucey, 1997: 150)

The figure provides an overview of various aspects of MIS; transaction processing and decision support systems used in relation the three levels of management in organisational decisions. At a strategic level, decisions usually involve unstructured and semi-structured decision types which may need an executive, expert system and Decision Support Systems (DSSs) for evaluating decision among alternative methods.

In general terms, there are number of systems and models in relation to decision making process used as evaluation techniques to help practitioners for making decisions. These are as following:

- Prescriptive model – This is model is capable of automatically selecting the best option. These techniques are well defined and structured decision making process as an entirely rational process (Lucey, 1997). Examples include linear
programming, cost/profit analysis, statistical decision theory, investment appraisal techniques, etc. They are optimising techniques which assume that conditions of certainty or risk exist.

- **Descriptive models** – These have been developed to explain actual behaviour in decision making. In this case actual decision making is less structured and is not completely rational (Lucey, 1997). In practice, decision makers simplify the factors involved because of practical difficulties. They are prepared to accept a satisfactory solution rather than attempt to find the theoretical optimum.

- **Bounded model** – This model uses with limits and boundaries that managers do not have time or cognitive ability to generate complete information with complex decisions (Lussier, 2005). The managers should be satisfying and selecting the first course of action among alternatives that is satisfactory or good enough under circumstances (Weihrich and Koontz, 2005).

- **Rational model** – The use of rational model is more suited to operational and tactical levels of management, where the factors are clearer with less uncertainty. Lucey (1997) emphasised that extra care is necessary to ensure that the particular ‘rational’ decision making technique can be used to suit the individual circumstances. The results conducted from a rational technique are treated as one of many types of information and management may adjust to the apparent ‘optimal’ decision. These could include conflicting objective, uncertainty, social, psychological and political considerations.

- **Classical model** – This model is based upon economic assumptions to fit organisations’ best economic interests. Managers make decisions based on their own ranking and preferences. It is considered to be normative which follows standards and rules driven by organisation (Daft, 2005). Li (2008) suggested that the classical model of decision making has always integrated the concept of rationality within the whole process of discussions and prescriptions.

- **Political model** – This model do not focus on a single issue but on many intra-organisational problems that reflect their personal goals. This concept of decision making as political process emphasises by the natural multiplicity in complex
environment of organisation’s people interests, ambiguous of information, limited
time and resources, and process of relevant information (Daft, 2005).

- Administrative model – This model is based on the actual behaviour of decision
  makers. It is used in making decisions in difficult and complex situations which
  characterised by none-programmed, uncertainty and ambiguity (Weihrich and
  Koontz, 2005). Decision will be made based on administrative man who satisfies
  with course of action. Thus, a satisfying decision is one which broadly satisfies the

There is little evidence to suggest that these decision support tools are applicable for
evaluating construction decisions. Perhaps this is because the models and techniques are
based on objective and subjective evidences rather than adequate data. These include
conflicting objective, social, psychological and political considerations. Various
managerial or organisational models such as descriptive and rational models have been
considered throughout the development of this research aim. Descriptive models are
concerned on the actual behaviour of decision makers in decision making, whilst
rational models are best suited to tactical and operational levels, where the effected
factors are clearer with less uncertain. The focus of this research is on making decisions
at a strategic level of management, where actual decisions are less structured and not
completely rational; however, a ‘Rational model approach’ is exactly what this work
hopes to achieve.

3.3 Decision Making in Construction

This section looks at decision making in more details in the context of the construction
industry, with a special focus on the pre-project phase. The decision to focus on pre-
project phase is informed by the fact that the decision to use OSM may be most
appropriately taken at early stages of a project.

3.3.1 Construction Decisions

The successful completing of a construction project is mainly impacted by making the
right decisions (Mohemad et al., 2010), where the construction professionals apply their
knowledge that fit a set of indicators for decision relying upon analysis of amounts of
information, facts and belief (Armstrong et al., 1999). Construction business is in
competitive market place and its success is depended on the quality of decision and decision making knowledge (Buildoffsite, 2010), which characterised by a decision statement, a set of alternatives and a set of selection criteria (Mallach, 1994). However, construction decisions are often described as difficult and complex in nature (Abdullah and Egbu, 2011) because most decisions typically involved the following issues:

- Uncertainty – Many facts may not be known.
- Complexity – Project leaders have to consider many interrelated factors.
- Risk-consequences – The impact of the decision may be significant.
- Alternatives – These are the possibilities one has to choose from, each has its own set of uncertainties and consequences.
- Interpersonal issues – It can be difficult to predict how other people will react with its outcomes.

Decision making in one of the most central processes in organisations and a basic task of management at all levels (Li, 2008). The complexity and difficulty of decisions can be depended upon decision makers’ knowledge about the matter, how well project data surrounding its defined and how clear the project goals are. It requires the construction practitioners to choose option between possible alternatives based on a wider variety of policy, economic, environmental and technical considerations (Turskis, 2009), which requires input of information at different stages of decision process (Best et al., 2005). The outcomes of which will be used in the comparison process between possible alternatives on whether one’s choice of decision course will lead to benefit or harm the project outcomes.

There are many decisions to be made throughout construction project life-cycle stages. Simple decisions usually need a simple decision making process (straightforward), however, difficult complex with multiple objectives may rely upon decision support techniques to proceed (Lee et al., 1999). There are five steps suggested by Stejkskal (2012) to make decision between various choices in the construction. These steps are usually involved the analysis of the current situation, establish benchmark, consider relevant data, set/define key performance indicators (KPIs), and put evaluation processes in place that can deliver the data.
In construction, many decisions are too complex or too important for decision makers to make choices between possible alternatives based just on instinct and past experiences (Pan et al., 2008a). Each construction project has unique characteristics and various stakeholders with different interests. Thus, decision maker’s task is to choose the right option for each decision situation that suits all parties and leads to maximise overall long-term and short-term project’s outcomes. Making decisions may be also influenced by how well practitioners know about decision support techniques that can help them to evaluate appropriateness of decision course. Decision support systems (DSSs) therefore, can play an essential role in construction in order to assist practitioners and ensure the confidentiality and transparently in making decisions.

3.3.2 Decision Support Systems Used in the Construction

Decision Support Systems (DSSs) bring together human judgements and computerised information a semi-structured or unstructured situation (Turban, 1995). DSSs can structure the decision making process and allow the decision makers to understand the nature of problems better so that can make better decision (Turban and Aronson, 2001).

Many IT based DSSs have been developed in construction to support its practitioners in making decisions (Li and Love, 1998). As an interactive computer based system, decision makers use data and models to solve situation with varying degrees of structure: structured, semi-structured or unstructured decision problems, and finally focus on effectiveness rather than efficiency in decision processes (Turskis et al., 2007). In assisting decision makers DSSs act as supporting tools by given suggestions especially when fragmented information and complex problem are involved (Mohemad et al., 2010). Druzdzel and Flynn, (2002) claimed that DSSs are gaining an increased popularity in various fields including engineering and construction. They can aid human cognitive deficiencies by integrating a range of sources of information, aiding the process of structuring decisions based on knowledge systems base. With regard to the applications of DSSs, Druzdzel and Flynn, (2002) also stated that DSSs increase productivity, efficiency and effectiveness, allowing to make optimal choices among several alternatives. Therefore, it can set work definition for DSSs throughout this research as those tools, models and systems used by managers during the construction process which are suitable to evaluate a specific decision matter, with an objective of aiding users in judgment and making choice activities more easily for decision situation.
Through project life cycle many difficult or complex decisions for decision makers need to be made, especially at pre-project phase and pre-construction phases. There are many different types of decision support systems and models have been developed and used in the construction industry. These types of tools can be defined or categorized based on their structure and output. Construction decisions are about the process of identifying possible alternatives for decision situation based upon values and preferences and choosing the best option with the highest probability of project outcomes. Anumba et al., (2000) pointed out that knowledge based Decision support systems can be applied across a wide range of applications in the construction. They are widely used to evaluate building, product, facility and service, or/and supply decisions. Examples of decision support systems and techniques which have been used in the construction sectors include:

i. Decision Tree – This technique is concerned with choices under certainty, which are value support system and specifically a decision analysis tool. Often decisions tree are not taken in isolation but as part of a sequence. In such situation the analysis can usefully be presented graphically form of showing a sequence of inter-related decisions and outcomes (Lucey, 1997). Using, decision trees are excellent weighting and ranking techniques for helping project leaders to choose between several alternatives of action. They provide a highly effective structure that managers can lay out options and investigate the possible outcomes of choosing options. They also can help to shape a balanced picture of the risks and rewards associated with each possible course of action.

ii. Value Engineering (VE) – Value engineering or value analysis is management technique that seeks the best functional balance between cost, reliability and performance of a product, project, process or service. It is an organized approach to the identification and elimination of unnecessary cost. Since there is usually a limit placed on time and budget, there is a high probability that most designs will contain some difficult costs to eliminate without further examination. VE is this examination (Lucey, 1997). The VE team is independent of the design team, as extension of the team. The VE team analyses the project from a function/cost point of view, providing alternative design suggestions that may improve performance, construction and life-cycle costs.
iii. Client’s Value System – The client’s value system is a complex algorithm with variables related to time, cost and quality issues. This system is used usually during the pre-project phase of briefing development stage by the architect. It is obviously more satisfactory and compression tool for all variables/factors that concern the project. In order to derive a client’s value system, a paired comparison exercise is undertaken using a matrix of boxes. Each box represents a capital letter (Code) and a question phrased, which is more important to you for desire project outcomes. In this way, the code inserted in the box represents whichever factor is the more important, and so on. The number of occurrence (times) that each code appears is entered in the total box and likewise for all of the other headings. Murray and Langford, (2004: 57) stressed that the paired comparison approach is a particularly satisfactory method of deriving a client’s value system in workshop environment judged by the fact that clients generally agree with the summary or outcomes.

Currently, sustainable performance of buildings has become a major concern. Architecture, Engineering and Construction (AEC) professional in the UK and internationally (Zanni et al., 2013). The construction industry is facing increasing pressure to address environmental performance earlier in the design process (Baba et al., 2013). With increasing the need, there are a number of support systems and tools have been developed to fit the purpose for evaluating building performance and sustainable design, include:

i. Building Information Modelling (BIM) – the use of BIM has the potential to enhance the quality of information provided for making critical decisions regarding a building’s environmental impact and sustainable design (Dowsett and Harty, 2013). BIM can promote integration among building professionals and improve design goals by allowing multi-disciplinary information to be integrated in the model (Zanni et al., 2013). This creates an opportunity to conduct the analysis throughout the design process, concurrently with the production of the design documents of project.

ii. The Building Research Establishment Environmental Assessment Method (BREEAM) – BREEAM is a process and its ability to change prevailing perception and practices regarding sustainable construction (Schweber, 2013).
BREAM is a sustainable analysis tool that can aid professionals in predicting a building’s performance from early design stages and significantly improve both quality and cost during its life cycle (Zanni et al., 2003). It is used, for instance, to evaluate energy consumption, material use, water efficacy, and indoor visual and thermal comfort.

iii. There are other sorts of decision support systems which are commonly used to evaluate design decisions at early design stages in the construction industry. Design task essentially involves decision making processes that require evaluation, comparison, and selection of design alternatives as well as eventual optimisation from a systematic perspective (Zha et al., 2008). This requires a careful analysis and evaluation of all proposed design alternatives and options throughout the different stages of building design (Baba et al., 2013). Examples of these design support tools include: Architecture Design Support System (ADDSS) Tool, Compromise Decision Support Problem technique (cDSP), A Hybrid Decision Support Model, and Fuzzy Synthetic Design Model (FSD).

iv. Other tools have also been developed for supporting building design processes in construction (Baba et al., 2013). These tools include: Building Performance Simulation (BPS), Building Performance Energy Simulation (BPES), and Building Energy Management and Control System (BEMCS). These tools are computer-based applications in building design that are used to simulate the energy performance analysis for design.

These tools and techniques are designed and developed to improve the quality of decision making in the context of design/architecture in the construction industry to assist those involved in the design process in making decisions between options. Their overall aim is to enhance better choices to achieve such as aesthetics values, cost gains or environmental impacts reductions. However, there is no evidence found to suggest that they are designed in the context of offsite construction or suitable in making decisions between alternative construction strategies or methods for construction projects.

In addition, there are other types of decision support tools such as cost/value modelling available, which are commonly used in the construction industry. They have been categorised under a range of headings drawn from a range of publications (Ashworth, 1986; Skitmore and Patchell, 1990; Laing et al., 2008) as following:
Heuristics methods – these methods of cost assessment, the general relationships between cost, location building height, width and structural spacing have been long understood. The results from heuristic methods were comparable to those achieved using more apparently rigorous mathematical models.

Empirical Methods – The use of empirical methods of estimating is usually explored at a later stage of a project. Although, a major aspect of these models is that they are relying on the full cost analysis of selected case studies, including construction method, finance and costs in use.

Simulation Methods – These models are used where the system of variables is complex. These methods are useful where a degree of uncertainty and risk is inherent in model. For example, the effect of prefabrication of construction time or cost might well be great, but is difficult to isolate from a number of workmanship and durability. Although it is important that some consideration is made of the concepts, uncertainties remain.

Algorithmic Methods (including regression analysis) – the implementation of an Algorithmic Techniques analysis requires that a sufficient size and quality of data set is available, within which a discrete measured variable can be compared against various criteria.

These systems and tools have been designed to improve the quality of decision making and implementation by assisting decision makers to improve decision making process to achieve the desired goals of a project. Despite, this body of knowledge available within the construction industry, literature review revealed that there was no evidence to suggest that the existing decision support systems and tools can be suitable to evaluate decisions for using OSM in house building. Although some of these support systems and techniques have been reviewed and considered in the design and achievement of the aim of this research – the development of the Decision Support Model (DSM) in chapter 7. For instance, Simon’s and Lee’s terminologies of decision making process have been adopted throughout the design and achievement of the concern of this research aim ‘DSM’. Client’s Value System also has been adopted in developing the evaluation methodology of variables/factors based on paired-wise compression for making decisions in the ‘DSM’. The evaluation methodology of the ‘DSM’ have been also considered Mallach’s and Lee’s judgement dimensions through the design, choice,
evaluation and review of decision outcome or outcomes that can be linked to the way in which decision makers exercise judgement to make the final choice.

3.4 Decision Making Process to consider the use of OSM in House Building

This section investigates decision support systems and techniques that used in the construction to support the practitioners to evaluate and make decision to use OSM as a strategy for house building.

3.4.1 Knowledge-based Existing Decision Support Systems and Techniques

Construction decisions are usually complex and variable in nature due to inherent risk and uncertainty associated construction process (Abdullah and Egbu, 2011; Ozorbon, 2013). Many researchers have examined various decision making theories and decision support systems in the construction industry to assist its practitioners for making their decisions. Therefore, decision support systems and models are used in order to facilitate long-term planning and priority setting among competing alternatives of decision (Ammar, et al., 2013). All possible alternatives of decision must be evaluated and compared according to many criteria for better decision outcome (Turskis et al., 2009).

In general terms, DSSs can be used to structure the decision making process, improve the quality of the information on which the decision is based (Turban and Aronson, 2001). DSSs provide support at all levels of management and the decision maker has complete control over all steps of the decision making process. However, DSSs do not replace the decision maker tasks (Turban, 1995). DSSs are best conducted during the viability, feasibility, and conceptual design stages of project in which most (Ammar, et al., 2013). This can allow practitioners to understand the decision problem’s perimeters and make better choices based on decision knowledge base. Literature review has revealed that there are a number of decision support tools and methods have been developed to assist decision makers to evaluate the effectiveness of using OSM in the construction. These systems are used to support decisions for chosen best option for a project including construction strategy, building system or method, and materials selection among possible alternatives.
(Mtech Group, 2004) indicated that there are over 100 offsite building systems available in the UK market, also Venables et al., (2004) stated that over 300 manufacturers and suppliers in the UK. With this range of OSM alternative building systems and suppliers can make the suitability of a decision support tool even more difficult to evaluate the effectiveness between possible systems and choose from, for a particular project. Each DSS is unique and has its own characteristics, variables and criteria designed for (Lee et al., 1999), and not necessarily to be applicable to evaluate different issues out of its environment. Literature revealed that there are a number of decision support systems and tools that have been designed in the context of OSM technologies in construction. These techniques aimed to assist the practitioners to select an appropriate OSM system, method or materials for a particular project between alternatives in order to optimise its use in construction.

Table (3-1) show a list of latest decision support tools and models that have been developed in relation to the use of off-site technologies in construction with a particular attention to house building. The Mtech-Group DSS has been designed and developed to assess different OSM systems and their suitability for a construction project. The evaluation process of this system is following a logical sequence of a number of steps as shown in the table. However, there is no evidence found to suggest that the process provided by Mtech Group (2004) is designed to evaluate purposely decisions to use OSM in the context of house building. CIRIA Offsite Project Toolkit has been designed to develop a strategy for implementing and optimising the benefits of standardisation and pre-assembly (S&P) in construction. The toolkit is used by project teams and clients throughout a project from inception to completion (Gibb and Pendlebury, 2003). It helps decision makers to assess the potential benefits of using S&P based on the evaluation of the key drivers and constraints of options across project stages and measure the outcomes. The use and benefits of the toolkit has been demonstrated in the construction industry (Gibb and Pendlebury, 2003). However, the toolkit has not been designed to evaluate purposely OSM decisions in the context of house building in particular. The evaluation processes adopted in the Mtech-Group and CIRIA toolkit techniques do not seem to present the evaluation process in complete multi-criteria decision analysis.
Table 3-1: Recent Decision Support Systems (DSSs) to OSM

<table>
<thead>
<tr>
<th>DSSs</th>
<th>Use</th>
<th>Purpose</th>
<th>Description/Processes</th>
</tr>
</thead>
</table>
| Mtech Group – Decision support system | Construction | Assessing the suitability of different OSM systems for a project | **Criteria:**  
  - Determine the project’s specific factors  
  - Identify the expertise level of using OSM with the team & supply chain  
  - Establish possible alternatives of OSM systems & techniques for the project  
  - Appraisal & evaluate each OSM option with the team  
  - Sensitivity analysis & monitoring the findings  
  - Prepare a strategy for the design, procurement & construction.  
|       |                |                                                                         | **Model:**  
  - Choose drivers & constraints  
  - Rank drivers & constraints  
  - Review overall project process S&P strategy  
  - Choose performance indicator(s)  
  - Create expected S&P benefits  
  - Measure S&P benefits, or  
  - Generate S&P indices  
  - Specific benefit resulting – monetary/efficiency values & performance/qualitative values  
  - Develop strategy  

| CIRIA Offsite Project Toolkit | Construction | Optimising the benefits of standardisation & pre-assembly (S&P) | **Matrix:**  
  - Establish the decision context  
  - Identify options/systems  
  - Identify Criteria  
  - Weighting  
  - Scoring  
  - Combine the weights & scores  
  - Examine the results  
  - Sensitivity analysis & monitoring the findings  
  - Making a decision  

| Build System Selection (BSS) Tool | House-building | Improving build system selection among possible offsite systems | **Criteria:**  
  - Building design identification  
  - Develop criteria for selection  
  - Establish alternatives of IBSs  
  - Allocating importance weightings  
  - Normalising criteria scores  
  - Evaluating options  
  - Formulating the optimum solutions  
  - Making final selection  

| Analytical Hierarchy Process (AHP) | House-building | Selecting type of industrialised building systems (IBSs) | **Matrix:**  
  - Establish the decision context  
  - Identify options/systems  
  - Identify Criteria  
  - Weighting  
  - Scoring  
  - Combine the weights & scores  
  - Examine the results  
  - Sensitivity analysis & monitoring the findings  
  - Making a decision  

(Mtech-Group, 2004)  
(CIRIA, 2005)  
(Pan et al., 2008b)  
(Abdullah & Edgu, 2011)
Pan et al., (2008b) has also considered the multi-criteria analysis in the development of their Build System Selection (BSS) tool shown in the table above. The BSS has been designed to improve building system selection process at early design process for using off-site systems in house building by introducing a transparent structured decision making matrix. The methodology has been developed to evaluate over 60 value-based criteria which emerged into eight themes of criteria for building system selection including cost, time, quality, health and safety, sustainability, process, procurement and statutory acceptance (Pan et al., 2008b). These decision criteria themes, in structure of a value tree were used in the analysis process of alternative off-site systems for a project. In this approach several methods were used for weighting decision criteria include top-down direct rating, bottom-up direct rating, point allocation and analytical hierarchy process. Further, direct rating and pair-wise comparison were used as scoring methods. The BSS matrix can be used to help structure the decision maker’s thinking and making decision based on practical decision criteria between alternative off-site systems in house building. However, the BSS matrix has not been designed to evaluate the use of off-site systems against traditional onsite construction methods in house building.

This body of knowledge of existing decision support systems and multi-criteria analysis tools appears to have looked at the area of supporting decisions that evaluates the effectiveness by comparing between OSM systems themselves rather than alternatives to OSM. Thus, there are no specific decision evaluation tools found that are reliable to support the decision to use OSM against Traditional On-Site (TOS) forms of construction in house building. This may be a reason that house builders are restricted to use TOS methods in their projects due to the lack of suitable DSSs within the industry to evaluate the use of OSM.

3.4.2 Limitations and Levels of Sophistications of the Existing DSSs

Due to the complex nature of construction decisions, making decisions to use OSM a construction strategy may be mainly based on the support of the guidance and decision support tools to do so. However, there is a doubt that the existing DSSs available within the industry may or may not satisfy the need of its practitioners to compose their decisions. Pan et al., (2008b) stressed that there is a lack of rational, robust and balanced decision criteria to choose a building system between alternative construction systems in house building. The housing practitioners are still making decisions mainly
relied upon subjectivity, building up their past experience and informal group discussion (Pan et al., 2008b) and many decisions are taken with imprecise or incomplete information (Ammar, et al., 2013). Authors argued that there is a lack of trust in the existing support and evaluation tools for its suitability and usability (Pan et al., 2007; Meling and Sandberg, 2009), and lack of confidence (Buildoffsite, 2012) in making decisions to use OSM among the industry practitioners. The consequence of this is that a numerous decision support techniques and tools proposed for assisting in making decisions their use in practice is very limited. This limitation may be due to no formal measurement techniques reliable exist of these support tools for evaluating the use of OSM as alternative construction strategy for house building.

The use of DSSs or tools is often argued as the best approach to rationalise the best solution. However, due to the current industry scenario, experience of individual decision maker and heuristics seem to be the dominate approach in decision making among housing industry (Abdullah and Egbu, 2011). The current DSSs also have been criticized for their complexity or/and amount of data required. Thus, there is a demand within the industry for a systematic and affective evaluation tool for selection of sustainable and efficient technologies to use in house building (Pan et al., 2012b). This research suggests that providing such a decision system or tool could help housing practitioners make decisions upon the most appropriate construction method, based on specific project criteria.

### 3.4.3 Existing Knowledge of Decision Making Factors

Others argued that the decision criteria practice used to select the optimal building system/method are still primarily cost-based rather systematic value-based evaluation in the construction industry (Pan et al., 2012b; Zhai, et al., 2014). There is also lack of existing value-based decision criteria which leads to inability to effectively comparison offsite manufacturing production with conventional construction methods (Pan et al., 2012b). Making such decision must be drawn from an understanding of the factors important a given situation, rather than relying on a general support techniques (Laing et al., 2008), and adequately account for all the main factors (Blismas et al., 2006). Obtaining the correct sources of information and data that will be used as inputs for a decision making system also can have most impact on decision outcomes. Mtech-Group, (2004) emphasised that the construction practitioners should avoid copying the
factors and issues that used for evaluating a decision from one project across another. Each project should be considered on its own merits based on a close consideration of the client’s business needs and the specific aims for project (Gibb, 1999: 32). This is because each project is unique and has specific requirements and stakeholders with different interests of a project. The factors that considered for project and led to arriving at specific decision outcome are not necessary to be repeatedly applicable to another project. The impacts of the factors that had most influence on decision outcome and led to the right selection between alternatives on one project are not necessary have the same impact to the next project. In addition, Pan et al., (2012b) stated that there should be more quantitative evaluation base on the weights of decision criteria/factors in a broader context of a project.

3.4.4 Existing Knowledge of Decision Making Strategy

House building is as any other buildings which are complex objects constructed from parts and components, and labour activities with service lives that required the right design and construction strategies to militate against for instance the cost, time and quality of accommodating strategy (Schmidt III, et al., 2014). However, there seem unclear how to integrated offsite production technologies into house building process (Pan et al., 2012a). There are many building methods and systems exist within the UK construction industry (Mtech Group, 2004), but a choice occurs need to be made at the first place between onsite and offsite production (Eastman and Sacks, 2008; Zhai et al., 2014). This was also highlighted in the RIBA Plan of Work (2013) that the need to consider a construction strategy including offsite fabrication before the project move to the design stage. The use of offsite technologies as a construction strategy in house building can achieve a certain level of standardisation and ‘economies of scale’ (Khalili and Chua, 2013). A number of studies that have developed guidance and decision support tools to choose between OSM vs. Traditional On-Site (OSM) building systems, however, what appears to be lacking is any specific decision system, particularly aimed at the house building sector. There is not yet an established guidance or decision support tool to help practitioners in making decisions to choose between to use OSM or TOS production as a construction strategy for house building.

The construction industry is a diverse and project-based industry (Ozorhon, 2013), and the use of new technologies is co-created in a multiparty environment and shaped by the
requirements of the project (Ozorhon, et al., 2014). Thus, it is necessary to bring the full benefit of OSM early in the project strategic level (Buildoffsite, 2008). Utilising innovation such as OSM in construction is a key at project level, and it is essential to identify the components and factors for successful implementation (Ozorhon, et al., 2014). Much offsite technologies is co-developed at project level which construction firms always innovate at this level (Ozorhon, 2013). However, most of existing literature has focused on the firm/organisational level to adopt innovation and offsite technologies in construction, with largely being ignored at the project level (Ozorhon, et al., 2014). Thus, it is essential that the use of new technologies such as OSM to be analysed and evaluated at the project level and should take into account involvement of all project stakeholders and their interrelationships in the process (Ozorhon, 2013).

Successful implements of offsite technologies at a project level will be reflected on the organisation level, and subsequently on the industry level. The consequence of this is that the decision to use OSM as a construction strategy needs to be viewed from a project-wide perspective and will, perhaps, depend on conditions of certainty or uncertainty, and evident in the decision making process. This can help to ensure that the clients’ requirements are understood, key decisions are made and the objectives of project are met at early project stage.

3.4.5 Existing Knowledge of Decision Making Process

Many decisions are too complex or too important for decision makers to make choices between possible alternatives based just on instinct and past experiences (Pan et al., 2008b). Construction decisions are often described as difficult and complex in nature (Abdullah and Egbu, 2011). Construction decision making needs to be taking in context with the issues such as dynamicity and complexity; often involving a large number of stakeholders with different interests (Pan et al., 2012b). This is because the nature of the construction industry is diverse, and project-based industry i.e. part manufacturing, part construction and part services (Ozorhon, 2013). As a part of the industry, the house building sector consists of a complex mixture of people, plant, materials, locations, and new technologies in place (Schoenwitz, et al., 2012). Unlikely other industries, construction involves production of unique projects on site by a variety of teams that are brought together temporary for each project (Ozorhon, et al., 2014). Thus, adopting offsite technologies in construction is joint activity with a number of participants
(Ozorhon, 2013), all of whom has a different role and responsibility in the process and make decisions throughout a project life cycle stages (Ozorhon, et al., 2014).

The key challenge here is to identify the way in which project stakeholders (e.g. clients, developers, contractors and architects) make decisions to meet project objectives and eventually customers’ expectations (Schoenwitz, et al., 2012). Each has a critical role to play with the adoption of offsite technologies in construction (Hedgren and Stehn, 2014). However, clients within the UK construction industry prefer to keep control over decisions and making decisions over the ‘construction strategy’ directly based on realised benefits of using offsite production technologies rather than carrying an assessment or applying sufficient knowledge (Cox and Piroozfor, 2011). The decision makers’ heuristics are used to make judgments just based on selective use of information and mainly qualitative reasoning for comparison of the alternatives’ subjectivity determined values (Hedgren and Stehn, 2014).

The slow uptake of offsite production in house building is also due to late decisions which are often made by those who involved in the construction process include clients, house builders and professional advisors (Pan et al., 2012b). For the greater use of offsite production in house building, the key decision must be made earlier and the sooner the client’s design requirements must be frozen (Pan et al., 2012a). However, it has not been established yet at which stage exact should the key decision to use OSM be carried out among project life cycle stages of house building. There is evidences to suggest that there exist guidance and procedures for mapping project development stages in construction but fail to show exact the timing of making decisions to use OSM. For example, the current mechanisms used for mapping project development stages in construction (e.g. The RIBA Plan of Work and Process Protocol) arguably the indicated timing for decision making should be more earlier (see Fig. 1-2: 21). Therefore, there need for further investigation to identify the key player (s) who should take the decision to use OSM and the level of their influence, and the stage which should carry out in house building projects.
3.5 The Need for a Robust Decision Making System to Use OSM in House Building

The literature has revealed that there are technical limitations of decision making systems and methodology of its usability and popularity among housing practitioners and many of those systems is not widely in use. Besides, there no clear measurement method was focusing on the evaluation of effectiveness to use OSM as construction strategies based on practical factors that have most influence on decision outcomes exist. There is also a demand within the industry for a systematic and affective evaluation tool for selection of sustainable and efficient technologies to use in house building (Pan et al., 2012b). There seem the existing support systems are not based on a robust decision making methodology in the context of house building, with most heavily the decisions made based on subjectivity and gut feeling of the decision maker. This research seems to support that the uptake of OSM must be improved, and this can only be influenced by a better understanding of decision making process by the stakeholders involved in the construction process. The major issue can, however, be to determining project characteristics that make the best choice between alternative construction strategies based on the best practices in the context of house building.

It appears as though the existing body of knowledge of decision support tools and techniques used in the construction industry cannot fulfill all the function required by the practitioners to evaluate their decisions regarding when to use OSM in house building. The new proposed decision support model or system needs to be user friendly interface to assist the practitioners in making decision based on adequate industry data against any given project within its environment. Literature has shared that the construction industry has so many sophisticated decision support models and systems that are rarely used or at all also to their complexity or poor user-friendliness. This is an issue that this research takes very seriously particularly that the output is expected to be used at senior or strategic management level.

This research suggests that the key research question becomes; Why is the uptake of Off-Site Manufacturing (OSM) as a construction strategy in house building limited?
3.6 Synthesis

As the meaning of understanding the significance of making a decision, this chapter has defined the concept of decision and decision making, types and categories of decisions, decision making process and the role of judgement in general terms of managerial decisions and in construction in particular. The chapter has also presented the need to develop a robust decision making tool or model for supporting the use of OSM as alternative construction method for house building into three areas. Firstly, the chapter has identified the need for a better understanding of the decision making process to arrive of decision to use OSM as a construction strategy. Secondly, it has investigated the existing knowledge of decision support systems and techniques in terms of their reliability and limitations to evaluate the use of OSM in house building. Thirdly, it has revealed the current decision making processes and procedures adopted by project stakeholders to derive at decision to use OSM in house building.

This research focuses on decision making process to use OSM at the project strategic-level, where decisions are usually involved unstructured and semi-structured decision types that need an executive data, expert systems and decision support systems for evaluating the decision among alternative methods. The objective of using decision support systems is to assist the practitioners in making decisions due to the complex nature of the construction industry. However, the currently support systems and tools used within the industry have not been fully appreciated by its practitioners in making decisions on whether to use OSM or TOS production in housing projects, even though, a few of them were designed to optimise the use of OSM in the context of house building. In order to develop a new robust evaluation model, this research requires further primary data from house builders that can be then allowed decisions to be made by stakeholders in a coherent way based on adequate and practical data rather than subjective evidences in the context of house building. This is illustrated in Figure 3-6 where three components have been identified: the decision, the decision maker, and the decision-timing.
Figure 3-6: Summary of questions and requirements for decision to use OSM in house building

This research suggests that here still appears to be a need for a specific decision support tool based on robust decision factors that evaluate the use of OSM against TOS production as a strategy for the construction of house building.

In order to address these components, it requires further an investigation of the current state of decision making process in house building industry. Thus, the next chapter therefore will present the research methodology and methods for primary data collection and analysis to fit the purpose.
CHAPTER FOUR: RESEARCH METHODOLOGY

4.0 Introduction

The research problems highlighted in chapter one have been investigated and a research problem established; *Why is it that the uptake of Off-Site Manufacturing (OSM) as a construction strategy in house building is limited?* The aim of this chapter is to address the research question and establish the factors that affect the use and adoption of OSM. This section of the thesis will outline the methodological approach used throughout this research and include the methods for data collection and analysis, involving both qualitative and quantitative approaches. A road map has been developed with all processes, methods and procedures explained. The ethical considerations of the research process were also explained within this chapter. Mixed research methods were employed for data collection and analysis in order to explore the experience of construction practitioners on the use of OSM in house building. The chapter also discussed the methods used for data analysis. A number of research methods were conducted for data collection using semi-structured interviews, questionnaire surveys and project case-based precedence review. The findings were then used to develop a Decision Support Model (DSM), and finally, case studies were used to test the validity of the decision evaluation model and make recommendations for further improvements (chapter 7 and 8).

4.1 Epistemology and Ontology

This section outlines the philosophical position of the research and the rationale for this. Epistemology is the philosophy of knowledge or how we come to know (Trochim, 2000). Epistemology is intimately related to ontology and methodology as ontology involves the philosophy of reality, epistemology addresses how we come to know that reality, while methodology identifies the particular practices used to attain knowledge of it (Krauss, 2005: 759). Knight and Turnbull (2008: 65) describe the importance of a clear understanding of epistemology in any academic research undertaken as at completion the research will contribute to knowledge. The term epistemology is derived from the Ancient Greek words episteme, which means knowledge, and logos, which can
be approximated to the word account. As a sub discipline of modern philosophy, epistemology is principally concerned with theories of knowledge, its limits and how we acquire it.

A number of research paradigms exist which suit different types of methodological approaches to research, these can be broadly categorised into positivism, interpretivism and critical theory or postmodernism. A research paradigm, or interpretive framework, contains the researcher’s epistemological, ontological and methodological premises and can be thought of as a basic set of beliefs that guides action (Guba, 1990: 17). There are differences between these paradigms in terms of their assumptions, goal, nature of knowledge or from theory, knowledge, position of researcher, theories, criteria for assessment, research method and type of analysis.

Positivism assumes an objective world hence it often searches for facts conceived in terms of specified correlations and associations among variables (Gephart, 1999). Healy and Perry (2000) describe how positivism predominates in science and assumes that science quantitatively measures independent facts about a single apprehensible reality. The data and its analysis are value free and data do not change because they are being observed. Positivism is a position that holds that the goal of knowledge is simply to describe the phenomena that we experience. The purpose of science is simply to stick to what we can observe and measure. Science is largely a mechanistic or mechanical affair in positivism. Deductive reasoning is used to postulate theories that can be tested. Based on the results of studies, we may learn that a theory does not fit the facts well and so the theory must be revised to better predict reality. The positivist believes in empiricism, the idea that observation and measurement are at the core of the scientific endeavour.

Critical theory is a tradition developed by the Frankfurt School in Germany based on the German tradition of philosophical and political thought stemming from Marx, Kant, Hegel and Max Webber. Critical theorists departed from Marxist orthodoxy on many issues but maintained a focus on the changing nature of capitalism and the forms of domination, injustice and subjugation capitalism produced. A basic assumption of the critical tradition is that the material world we encounter is both real and is produced by and through capitalist modes of production (Gephart, 1999). While, Interpretivist research is fundamentally concerned with meaning and it seeks to understand social
members’ definition of a situation (Schwandt, 1994). Interpretivists assume that knowledge and meaning are acts of interpretation hence there is no objective knowledge which is independent of thinking, reasoning humans (Gephart, 1999). Interpretivism often addresses essential features of shared meaning and understanding whereas constructivism extends this concern with knowledge as produced and interpreted to an anti-essentialist level. Constructivists argue that knowledge and truth are the result of perspective hence all truths are relative to some meaning context of perspective (Schwandt, 1994).

4.2 Research Methodological Approaches

There are a number of strategies for data gathering in construction research, broadly categorised into the quantitative, qualitative and mixed approaches. This research has used mixed approach for data collection and analysis. For the purpose of charity and fortification of this choice, the following sub-sections explain all these approaches:

4.2.1 Quantitative Approach

Quantitative research approach is ‘objective’ in nature (Naoum, 1998: 38). It collects and analyses numerical data (Farrell, 2011: 6). It concentrates on measuring for example the scale, percentage, range and frequency of phenomena (Fellows and Liu, 2008: 26). Creswell, (1994: 73) defined quantitative research as an inquiry into a social or human problem based on testing a theory composed of variables, measured with numbers, and analysed with statistical procedures in order to determine whether the hypothesis or theory holds true. Burns and Grove, (1991) defined the approach as systematic process in which numerical data are utilized to obtain information about the subject being researched. According to Naoum, (1998: 40) and Fellows and Liu, (2008: 97), quantitative approach is selected under two circumstances of research:

- When research wants to find facts about a concept, a question or an attribute.
- When research wants to collect factual evidence and study the relationship between these facts to test a practical theory of hypothesis with theories and the findings of any research executed previously – literature.

In addition, Creswell, (2009: 12) pointed out that the data obtained in quantitative research is classified under two strategies of research: firstly, experimental research
which seeks to determine if a specific treatment influences an outcome, using true experiments. Secondly, survey research: provides numeric description of trends, attitudes or opinions of a population, using questionnaires and structured interviews for data collection.

4.2.2 Qualitative Approach

The word ‘qualitative’ is used to describe research which emerges from observation of participants (Oakley, 1994). Qualitative research is ‘subjective’ in nature (Naoum, 1998: 40). The qualitative approach involves the collection and analysis of words data (Farrell, 2011: 6). This approach relies on text and image data, have unique steps in data analysis, and draw on diverse strategies of inquiry (Creswell, 2009: 173). It seeks to gain insights and understand the people’s perceptions, opinions and views of a subject, giving due emphasis to the views and experiences of the participants, in order to develop ways to improve subject being studied.

Fellows and Liu, (2008: 91) stated that the qualitative data gathered may be unstructured in nature, but can be detailed and hence rich in content and scope for appropriate use. Naoum, (1998: 40) pointed out that the data gathered in qualitative research is classified under two categories of research:

- Exploratory Research: used when there is a limited amount of knowledge about research topic – the interview method is usually selected for a clear and precise statement of the recognised problem.
- Attitudinal Research: used to subjectively evaluate the opinion, view or the perception of a person, towards a particular object (attribute, variable or factor).

Knight and Ruddock (2008: 112) highlighted that qualitative interview seeks to describe and understand the meanings of situations. It is particularly useful for getting the story behind a participant’s experiences. Moreover, Creswell, (2009: 13) claimed that there are viable ways to conduct qualitative data include: case studies research which is a strategy of inquiry in which the researcher explores in depth a process, event, activity, or individuals. Collecting detailed information using a variety of data collection methods over a sustained period of time.
There are three categories of collecting and analysing qualitative data: focusing language based, descriptive or interpretive, and theory-building (Tesch, 1991). Building theory out of the data collected during the research; grounded theory is the best example of this category (Knight and Ruddock, 2008: 87). Grounded empirical approach is a methodology which involves a systematic process of gathering and analysing a fixed set of data to develop a theory based upon the data (Hunter and Kelly, 2008: 86). The theory may then be used to explain phenomena rather than just a set of findings. If the data has been analysed without a preconceived theory or hypothesis, that theory is truly ‘grounded’ in the data because it came from nowhere else (Allan, 2003).

Douglas, (2003) pointed out that there are three categories of data used in grounded theory: field data (notes), interview data (notes, records, transcripts), and an existing data (literature). If the research involves qualitative data which conducted from case studies or interviews then data available should be sufficient to generate theory (Douglas, 2003). Esteves et al., (2002) suggested that the number of case studies or interviews used to generating theory is not an important consideration when generating theory. The advantages with the use of case studies in theory building is the close link with reality where the theory is likely to be novel, testable, and be empirically valid (Eisenhardt, 1998). Naoum, (1998: 40) pointed out that the raw data provided in the exploratory research will be exactly what interviewees have said or a description of what has been observed in case studies. The data gathered using qualitative approach can later be ‘quantified’ to some extent depends upon the type of data required to draw a conclusion

4.2.3 Mixed Methods Approach

Mixed methods research is an approach to inquiry that combines or associates both quantitative and qualitative methods of research (Creswell, 2009: 4). Fellows and Liu, (2008: 150) outlined that the nature and objectives of research work together with the (consequent) nature of the data collected and analytic techniques employed which determine whether the research study may be classified as qualitative or quantitative. Qualitative methods are more concerned with understanding why people behave or believe as they do. Quantitative methods, on the other hand, use statistics and numbers and often focus on the scale in order to establish patterns and variables in relation to particular phenomena. Creswell, (2009: 230) pointed that mixed approach is a common
research style to conduct research that requires collecting both quantitative and qualitative data sequentially.

In addition, Creswell, (2009: 206) outlined that there are four important aspects to be considered that influence the planning and design of procedures for a mixed methods approach. These are timing, weighting, mixing and theorising.

- **Timing** – timing of collecting qualitative and quantitative data needs to be considered, whether it will be in phases (sequentially) or gathered at the same time (concurrently).
- **Weighting** – this is given to qualitative and quantitative approach in particular study. In some studies, the weighting might be equal, in other studies; it might be emphasise one or other. A priority for one type may depend on the interest of the research and what the investigator seeks to emphasise in the study.
- **Mixing** – mixing the data (mixing the research questions, philosophy, and the interpretation) is difficult at best when one considers that qualitative data consists of text and images, and quantitative data numbers. Mixing the two types of data might occur at several stages: the data collection, the data analysis, interpretation, or at all phases. This means that either the qualitative and quantitative data are actually merged on one end of the continuum, kept separate on the other end of the continuum, or combination in some way between these two extremes.
- **Theory** – all researchers bring theories to their inquiries, and these theories may be made explicit in a mixed methods research or be implicit and not mentioned.

There are different interfaces between quantitative and qualitative research, each approach may be somehow quantifiable (Naoum, 1998: 43). Table 4-1 summarises some comparisons between quantitative and qualitative research.

Fellows and Liu (2008: 26) outlined that quantitative data would comprise time and cost performance derived for instance from case study project records – predicted vs actual; quality may be considered from updated records, due to defects recorded later on, measured by numbers and values. In contrast, qualitative data could present participant’s views and opinions with respect to the performance criteria of cost, time and quality. Creswell, (2009: 15) highlighted that it is useful to consider the full range of possibilities of data collection approaches – quantitative, qualitative and mix.
Table 4-1: Differences between Quantitative and Qualitative Research

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Quantitative research</th>
<th>Qualitative research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role</td>
<td>Fact-finding based on evidences or records</td>
<td>Attitude measurements based on opinions, views and perceptions measurements</td>
</tr>
<tr>
<td>Relationship between researcher and subject</td>
<td>Distant</td>
<td>Close</td>
</tr>
<tr>
<td>Scope of findings</td>
<td>Nomothetic</td>
<td>Idiographic</td>
</tr>
<tr>
<td>Relationship between theory and research</td>
<td>Testing/Confirmation</td>
<td>Emergent/development</td>
</tr>
<tr>
<td>Nature of data</td>
<td>Hard and reliable</td>
<td>Rich and deep</td>
</tr>
</tbody>
</table>

(Adopted from Naoum, 1998: 43)

At the data collection stage, it is more important to distinguish between research methods that yield structured and unstructured data than between methods that are quantitative or qualitative (De Vaus, 2002: 5). Table 4-2 illustrates the relationships between the three approaches for data collection strategies. The methods chosen for collecting data may impact upon the analyses which might be carried out and, hence, the results and reliability of the research being undertaken. Thus, it is important that the validity and applicability of results and conclusions are appreciated and understood.

Table 4-2: Quantitative, Mixed, and Qualitative Methods

<table>
<thead>
<tr>
<th>Quantitative Methods</th>
<th>Mixed Methods</th>
<th>Qualitative Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-determined</td>
<td>Both pre-determined and emerging methods</td>
<td>Emerging methods</td>
</tr>
<tr>
<td>Instrument based questions</td>
<td>Both open-ended and close-ended questions</td>
<td>Open-ended questions</td>
</tr>
<tr>
<td>Performance data, attitude data, observational data, and census data</td>
<td>Multiple forms of data drawing on all possibilities</td>
<td>Interviews data, observation data, document data, and audio-visual data</td>
</tr>
<tr>
<td>Statistical analysis</td>
<td>Statistical and text analysis</td>
<td>Text and image analysis</td>
</tr>
<tr>
<td>Statistical interpretation</td>
<td>Across databases interpretation</td>
<td>Themes. Patterns interpretation</td>
</tr>
</tbody>
</table>

(Adopted from Creswell, 2009: 15)

Table 4-2 provides the characteristics of each individual approach based upon data collection, nature of research and the type of required data. There are a number of strengths and weaknesses of using mixed methods approach for data collection to
conduct a research (Burke-Johnson and Onwuegbuzie, 2004), these are summarised in Table 4-3. Follows and Lui, (2008: 28) argued that the best studies comprise the analysis of both quantitative and qualitative data. In addition, Creswell, (2009: 203) suggests that employing mixed approaches has gained popularity among research recently. This popularity is because research methodology using mix approach utilises the strengths of both quantitative and qualitative research.

Table 4-3: Strengths and Weaknesses of Mixed Methods Research

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Words, pictures, and narrative can be used to add meaning to numbers</td>
<td>Can be difficult for a single researcher to carry out both qualitative and quantitative research, especially if two or more approaches are expected to be used concurrently; it may require a research team</td>
</tr>
<tr>
<td>Numbers can be used to add precision to words, pictures and narrative</td>
<td>Researcher has to learn about multiple methods and approaches and understand how to mix them appropriately</td>
</tr>
<tr>
<td>Can answer a broader and more complete range of research questions because the researcher is not confined to a single method or approach</td>
<td>Methodological purists contend that one should always work within either a qualitative or quantitative paradigm</td>
</tr>
<tr>
<td>A researcher can use the strengths of an additional method to overcome the weaknesses in another method by using both in a research study</td>
<td>Some of the details of mixed research remain to be worked out fully by research methodologist (e.g. problems or paradigm mixing, how to qualitatively analyse quantitative data, how to interpret conflicting results)</td>
</tr>
<tr>
<td>Can provide stronger evidence for a conclusion through convergence and corroboration of findings</td>
<td>More expensive</td>
</tr>
<tr>
<td>Can add insights and understanding that might be missed when only a single method is used</td>
<td>More time consuming.</td>
</tr>
<tr>
<td>Qualitative and quantitative research used together produce more complete knowledge necessary to inform theory and practice.</td>
<td>(Adopted from Burke-Johnson and Onwuegbuzie, 2004: 21)</td>
</tr>
</tbody>
</table>

4.3 Ethical Considerations

This section explores the ethical considerations of the research. One of the important concerns in research is that ethical issues need to be considered in any research work. Ethical issues will undoubtedly emerge between the researcher and research participants and in the research more widely. Fellows and Liu, (2008: 246) suggested that there are ethical considerations relating to everything people do and consider doing it. In this research, an attention which is given to ethics focus on integrity in collecting data from practitioners in the construction industry and the store, use and disposal of those data. It is also important that consider other aspects of moral and ethical concerns for research,
including the use of the other people work, confidentiality, analysing data, disseminating results and findings. Fellows and Liu (2008: 256) outlined that confidentiality is a similar ethical issue to anonymity: anonymity refers to persons and organisations whilst confidentiality relates to the data. The two issues are closely related such that confidentiality concerns neither revealing data to anyone nor using the data for purposes other than those for whom the respondents have given permission. Thus, both confidentiality and anonymity are important components of research ethics, the moral underpinnings of which dictate that the express, informed consent of the respondents must be obtained and adhered to rigorously.

The Economics and Social Research Council (ESRC) defines Research Ethics, according to Fellows and Liu (2008: 250), as the moral principles guiding research from its inception through to its completion and publication of results and beyond. There are key principles of research ethics the ESRC expects to be addressed whenever possible to any research work:

- Research should be designed, reviewed and undertaken to ensure integrity and quality.
- Research staff and subjects must be informed fully about the purpose, methods and intended possible uses of the research, what their participation in the research entails and what risks.
- The confidentiality of information supplied by research subjects and the anonymity of respondents must be respected.
- Research participants must participate in a voluntary way, free from any coercion.
- Harm to research participants must be avoided.
- The independence of research must be clear, and any conflicts of interest or partiality must be explicit.

In addition, there are many ethical issues that may arise during stages of research; therefore, researchers need to protect their research participants. It is important to develop a trust with them, promote the integrity of research, guard against misconduct and impropriety that might reflect on their organisations or institutions and cope with new challenging problems (Creswell, 2009: 87). Ethical responsibilities in research extend to various types of people, all of whom may be affected by the research itself, research activities or research results (De Vaus, 2002: 59). Therefore, there are many
ethical issues of research that should be considered during development of research process. These ethical considerations provided by Creswell, (2009: 88) in five stages:

- Ethical issues in research problem – in writing an introduction to a study, the research identifies a significant problem or issues to study and its importance. It is important that to identify a problem that will benefit individuals being studied.

- Ethical issues in the purpose of research – in developing the purpose statement for study, proposal developers need to convey the purpose of the study that will be described to the participants. It is also important for researchers to specify the sponsorship of their study.

- Ethical issues in date collection – researchers need to respect the participants and the sites for research. Many ethical issues may arise during this stage of the research (Do not put participants at risk). Some participants may not want to have their identity remain confidential. By permitting this, the research allows the participants to retain ownership of their voices and expert their independence in making decisions.

- Ethical issues in Data analysis and interpretation – In anticipating a research study consider: protect the anonymity of individuals, roles and incidents in the project. Data once analysed and need to keep it for a reasonable period of time then should discard the data and in the interpretation of data, researchers need to provide an accurate account of information.

- Ethical issues in writing and disseminating the research – the ethical issues do not stop with data collection and analysis; ethical issues apply also to the actual writing and dissemination of the final research report.

Each of these ethical issues has been considered throughout this research process. Confidentiality and the right to privacy were fundamental ethical tenants of this research. This has been particularly important to ensure that subjectivities and bias has been understood and controlled throughout the research methods used in this research to data collection and data analysis. Furthermore, it has been ensured confidentiality of participant’s names and company’s in order for them to feel comfortable disclosing sensitive information. All participants are formally invited and a consent form is given for their consideration and full acceptance before engaging with the research project.
4.4 Methodology: Research Approach and Design

It is essential to understand the nature of research, development and the terminology of its operation. Research methodology refers to the principles and procedures of logical thought processes which are applied to a research investigation (Follows and Liu, 2008). This research adopts mixed methods both (quantitative and qualitative approaches) for primary data collection and analysis. The rational and fortification for this approach is outlined in the following sub-sections:

4.4.1 Rational for using Mixed Methods Approach

The concept of mixing different methods is usually used in order to examine multiple approaches to primary data collection such as observations and interviews (qualitative data) combined with surveys (quantitative data) (Creswell, 2009: 14). The emphasis of using mixed methods is to expend further knowledge from one to another, thereby consolidating findings from a variety of data sources. Thus, it is important to consider what data are required and alternative sources for data collection during the design and planning stage (Follows and Liu, 2008: 147).

There is much scope for the use of mixed methods approach and that a number of benefits can be gained from applying the approach to data collection. The results obtained from one method can help identify participants to study or questions to ask for the other methods, further can be merged into one large database used side by side to reinforce each other (Creswell, 2009: 14). The results from individual approach can help develop or inform the other approach (Greene et al., 1989). Thus, the mixed methods approach was applied in the research by which to capture the best of both quantitative and qualitative approaches to data collection. Each research has its own nature and unique inquiry to conduct mixed approaches for data collection, Morgan, (1997) stated that it is not necessary to conduct qualitative data to be first and quantitative data second, nor vice versa. Furthermore, the procedures of collecting data with mixed approaches can be occurred in sequential, concurrent or transformative manners (Creswell, 2009: 203). As a consequence, the mixed methods approach is particularly useful to be adopted in this research where its nature required a number of different data and phases for collection (See figure 4-1). This research seeks house builders input which firstly requires to carry on an investigation addressing the use of Off-Site Manufacturing (OSM) in house building, and secondly another investigation addressing
on the use of Traditional Onsite (TOS) in house building. The outcomes of which will be then validated at different stage throughout the research process.

There are numerous published research studies that have incorporated mixed methods in the construction industry research (Naoum, 1998). There is evidence to suggest that mixed approaches have been used for data collection to conduct research in the area of off-site manufactured technologies in the construction industry. For instance, a pilot study by Gibb et al., (2001) looked at developing a methodology for measuring the benefits of pre-assembly and standardisation for construction projects. The mixed approach applied by Danby and Painting, (2006) in their study which looked at the interface problems with volumetric prefabrication systems in the construction projects. Pan et al., (2007) adopted the mixed methods approach for example on a study addressing perspectives of UK house-builders on the use of modern methods of construction. The same approach has been used by Pan et al., (2008b) to conduct a research that aims to develop a decision matrix for building system selection in housing construction. Considering the benefits and reasons of using the mixed approaches and the experiences of previous researchers have led to this research to adopt the same approach.

4.4.2 Research Methods for Data Generation

This section introduces the research methodology design and maps up its process for data collection throughout this study. Noaum, (1998: 53) suggested that the approach to be adopted for collecting data depends on the nature of the investigation and type of data and information required for research. There are two general approaches for data collection to conduct a research, namely desk study (secondary data gathering) and fieldwork study (primary data gathering). The approach of secondary data collection and its outcomes has been covered earlier-on in this thesis (in chapter 1, 2 and 3) which has identified the knowledge gaps and research questions. This section focuses on the design of the process of collecting primary data by the use of quantitative and qualitative approaches of the research inquiry.

De Vaus, (2002) stated that the relevant data can be collected for a research work by different techniques and in many studies it may be appropriate to use a range of research methods such as questionnaires, interviews and case studies. Noaum, (1998: 53) highlighted that postal questionnaire is an impersonal survey that is suitable for a
descriptive or analytical survey, while interview personal survey is a face-to-face situation that is suitable for case study research and studies that require respondents consistent characteristics. The features of these techniques are showed in Table (4-4); it provides contrast explanation and the strengths and weaknesses of interviews and questionnaire surveys, and case studies/project cases research.

The Table 4-4 illustrates that each research method has its own characteristics and specific required data to the inquiry of the research problem. However, it is important that gathering the relevant data may depend on choosing the right research methods. This means that research methods adopted for a research project are not necessary to be applicable for collecting data to another research project.

Table 4-4: Comparison between interviews, questionnaires and case-based precedence projects review techniques

<table>
<thead>
<tr>
<th>Features</th>
<th>Interviews</th>
<th>Questionnaires</th>
<th>Project-cases review</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify of respondents</td>
<td>Known</td>
<td>Unknown</td>
<td>Known</td>
</tr>
<tr>
<td>Interaction between interviewer and respondent</td>
<td>Close</td>
<td>Distant</td>
<td>Close</td>
</tr>
<tr>
<td>Time involving the researcher</td>
<td>Long time to go through the interview</td>
<td>Short time</td>
<td>Long time to go through the interview</td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
<td>Significantly lower than the interviews</td>
<td>High</td>
</tr>
<tr>
<td>Sample</td>
<td>Small</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Quality of information</td>
<td>Deep and detailed</td>
<td>Rich</td>
<td>In-depth detailed interviews, documentary evidence &amp; observation</td>
</tr>
<tr>
<td>Skill and experience</td>
<td>The interviewer needs to have the skill to ask questions</td>
<td>No skill required</td>
<td>The interviewer needs to have the skill to ask questions</td>
</tr>
<tr>
<td>Control of the process</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Allows great flexibility to reword questions and clarify terms that are not clear</td>
<td>Low rigid. The answers are accepted as questions are worded</td>
<td>Allows great flexibility to reword questions and clarify terms that are not clear</td>
</tr>
<tr>
<td>Analysis of the results</td>
<td>Difficult and becomes complicated in the unstructured interviews</td>
<td>Easy to analyse</td>
<td>Difficult and becomes complicated in the unstructured interviews</td>
</tr>
<tr>
<td>Interviewer bias</td>
<td>The flexibility of interviews allows for bias</td>
<td>If sample is selected appropriately, there should be no bias</td>
<td>There will be less flexibility of interviews of case that may not allow for bias</td>
</tr>
</tbody>
</table>

(Adopted from Naoum, 1998: 63)
Creswell, (2009: 206) highlighted that mixed methods approach for data collection can employ two or more research techniques. This research has employed mixed research methods for primary data collection using interviews and questionnaire along with case based precedence projects review techniques. Using mixed research methods can be used as a strategy to reduce or eliminate disadvantages of each individual method, whilst gaining the advantages of each and the outcomes of which will be combined.

Each of these research methods has its own purpose why adopted for data collection data at particular stage throughout this research work.

4.5 The Process of the Primary Data Generation, Collection and Analysis

There were a variety of research methods involved in data collection, using interviews survey, questionnaires survey and case based precedence projects review. The mixed approach of research methods has been used to gain the most appropriate data to fulfil the aim of the research. For the purpose of charity and fortification of this choice, the following sub-sections explain all the three methods:

4.5.1 Interviews Survey

The interview survey was designed to build upon the information and issues gathered from in-depth literature review that led to the need for additional primary data within house building sector. In order to obtain a full range of house builders’ opinions and views on the use of OSM currently experienced, the interviews research survey was employed.

The interviews research can take a variety of forms which grouped into three main types from structured, semi-structured to unstructured. Each type has its own strengths, weaknesses and preferred usage. This research has used a semi-structured interview type for data collection which carried out with a sample of house builders either face-to-face or over the phone or skype calls. A list of questions has been sent to the interviewees in advance. The interviews questions were included ‘closed-ended’ and ‘open-ended’ questions in the survey and a degree of flexibility for most of cases in order to explore and investigate into issues as they arise. The interviews approach has employed for data collection throughout the research to fulfil the following main reasons:
- It enables to identify in depth issues reported in existing literature by construction professional associated with the use of OSM and decision making process used in construction industry.
- It is most suited to qualitative type of data that the research is needed at the start of data collection for using OSM in construction with particular in house building based on opinions and views of the construction practitioners.
- It allows a greater depth of knowledge to be gathered and gives the flexibility to extend the research further.

4.5.1.1 **Aim of the Interviews**

The interviews research was carried out in order to explore and establish the current understanding of decision making process and further explore how decisions to use OSM are currently being made within the industry. It was also used to identify the drivers and constraints to OSM, and the factors that have most influence on decision to use OSM in house building. The interviews were carried out with house builders either face-to-face or over the phone or Skype calls, using semi-structured interview type.

4.5.1.2 **Identification and Selection Criteria of Interviewees**

Mason (2006) set a definition for sampling and selection of research participants as principles and procedures used in order to identify, choose, and gain access to relevant data source for research project. The interviews were carried out with 30 participants; they were key reference in house building sector or members of Buildoffsite organisation that had responsibility of making company decisions to choose a construction strategy in their developments. From the extensive literature search across many disciplines and sources, including journals, conference papers and articles from industry institutions and academic publishers covered or related to the use of OSM in construction industry found that the Buildoffsite (BoS) is an organisation leading the off-site industry in the UK. DTI (2006) highlighted that the establishment of BoS organisation is to provide leadership to the off-site construction industry and a focal point for clients of modern methods in order to encourage its use in the industry. The BoS is exclusively and uniquely focused on off-site construction solutions, a network of members and associates, a group that includes leading clients, designers, contractors and manufacturers; and supported by the government (Buildoffsite, 2010). They all are working to together to achieve a step-change in the take up of off-site construction
solutions across all sectors of the UK construction industry. Knight and Ruddock (2008: 113) stated that if the selected interviewee is an expert on some particular topic or possesses some special skill or experience, his or her responses may be ‘facts’ or ‘opinion’.

A total of 30 interviews were conducted using semi-structured form with leading housing practitioners and members and stakeholders of BoS. All the interviewees were senior managers and directors with responsibility for making decisions associated with construction strategy including: clients, contractors, consultants, project managers, design managers and construction managers. Each participant was chosen by using the following selection criteria:

- Work experience 10 years or over in the industry.
- The experience based on the UK house building industry.
- Senior management members and has a role in making decisions associated with construction strategy.
- Familiar with OSM used in the UK construction industry.

It was preferable that interviewees were based England in order to make travelling to conduct the interviews practical within the time limitations and cost consideration. It was also necessary that the interviewees have a construction related degree or equivalent qualification and had at least 10 years’ experience in the construction industry to ensure that they had relevant experience to contribute to the research. Beneficial if they had also experience of both Off-Site Manufacturing (OSM) and Traditional Onsite (TOS) methods based on the UK construction industry. For the purpose of confidentiality, all selected participants were assured that no names of themselves or their companies were published in any of the data resulting from the survey throughout the research stages.

The interviews structure was based on providing data on the overall facts and opinions of the industry practitioners on the use of OSM in house building. All of the interviews were note-taken and audio recorded where possible and then transcribed exactly for analysis. A list of interview questions arranged in reasonably order of the research inquiry and was sent via email in advance to the research participants to offer enough time for them to think and prepare for answering the questions more effective.
4.5.2 Questionnaire Survey

Having established a robust set of factors and information obtained from the interviews survey that have most influence on decision to use OSM in house building, the questionnaire surveys were designed to build upon these findings for further investigation.

Questionnaire survey is a research instrument intended to measure something within a defined population being studied which may include behaviour, beliefs, knowledge, attitudes and attributes of respondents (De Vaus, 2002: 95). In this research, the questionnaire approach was implemented to establish the impacts of the factors on decision of both to use OSM and TOS as a construction strategy for a project. There were a number of key reasons that the research has adopted questionnaire surveys for data collection:

- Questionnaire beings simple to administer, cost effective and respondents have more time to response.
- It enables information to be gathered from different construction practitioners from various organisations all over the UK, practically within the time limitations.
- It allows data to be quantified and presents frequencies, averages and percentages of claims of identifying attitudes.
- It enables a direct study and comparison with precious obtained data of off-site house building.

4.5.2.1 Aim of the Questionnaire

There were two questionnaire surveys conducted using the factors and key information obtained from interviews survey. First survey was targeted at members and stakeholders of Buildoffsite (BoS) with aim to validate the findings seeking quantitative data in order to identify the frequency and significance of the identified factors on decision to use OSM in house building. The survey was also used to identify who has the most influence on decision among project team and to inform at which stage the decision has been made, and key lessons learned from decision outcomes of using OSM as a construction strategy. Second survey was targeted at key references in the construction industry involved directly in house building in order to measure the impact of the identified factors on decision to use Traditional On-Site (TOS) as a construction
strategy. The both questionnaire surveys have been designed to include more closed-end questions than open-ended questions. The open-ended questions type has been considered in order to explore any suggestions that may the research has overlooked. The questionnaire surveys were piloted on several members of academic staffs in the area of construction management, in order to ensure that they were clear and concise before send it out. Packages of questionnaire surveys are provided in appendixes section (B and D).

4.5.2.2 Identification and Selection Criteria of Participants

Hoxley, (2008) suggested that researcher should set up a sampling frame which is a list of cases of the population in order to select a sample to represent that population of a research survey. The first questionnaire survey was sent out to 75 practitioners of members and stakeholders of Buildoffsite (BoS) that have not invited to interviews survey. The members and stakeholders of BoS are the key references leading the UK offsite industry. Thus, the researcher has selected participants from those members and stakeholders involved in house building to carry on questionnaire survey.

From the extensive literature search across many disciplines and sources found that Building Magazine publishes lists of the top UK construction parties and stakeholders annually include contractors, house-builders, consultants, etc. The Building Magazine is an institution leading the UK construction news (Building Magazine, 2011). The research has considered the top 150 UK housing contractors and developers as sampling frame. Thus, the second survey then targeted the top 75 practitioners involved directly in house building among the sampling frame to represent the population. They were also subject for the following selection criteria of the research design:

- Work experience 10 years or over in the construction industry.
- The experience based on the UK construction industry, particularly in house building.
- One of top senior management members and has a role of making company decisions.
- Familiar with the use of both OSM and TOS construction strategies used in the UK construction industry.
The selected sampling participants were assured of confidentiality during the survey process; thus, no names of respondents have been published in any of the data resulting from the questionnaires survey. This research was aiming to receive at least 30 questionnaires responses for each survey to be equivalent to the 30 interviews conducted of OSM study.

In order to triangulate information obtained from the both questionnaire surveys; 15 projects were selected from both OSM and TOS developments to review ‘current’ decisions and historic actions taken using ‘case-based precedence review’.

4.5.3 Case-Based Precedence Projects Review

Case-based precedence projects review was conducted as a strategy used to study an experimental theory comprising several different combinations of data collection sources include: documentary evidence, interviews, questionnaires and observations. This research has focused on the investigation of typical domestic house building projects consisting of one to four bedrooms homes, flats, apartments or accommodations. There were a number of key reasons that the research has adopted this approach incorporated with interviews and questionnaire surveys for primary data collection:

- It enables to gain and analyse data occurred if real projects which is essential for the strength of results and development of the model.
- It allows the investigation to carry out using various techniques for data collection include: documents, interviews and observations of project.
- It shares simple facts and impacts that they had upon project when considering on whether to use OSM or TOS as a construction strategy.

The same questionnaire surveys (4.5.2) were used and filled in by key participant for each project case based on the information and the impacts had upon each project. Firstly, 15 project cases were carried out incorporation with questionnaire survey of OSM and secondly, 15 project cases were carried out incorporation with questionnaire survey of TOS for further investigation. The results obtained of which used for the final analysis of the study in order to establish the significance of a robust data set of factors that have most influence on decision to use OSM and TOS in house building.
4.5.3.1  **Aim of Case-based Precedence Projects Review**

The aim of conducting the case based precedence review analysis was to validate the findings and identify the frequency with which the previously identified robust data set of factors occurred in real-life or recently completed projects. This is to determine comprehensive criteria used and establish the impact of each factor had upon decision when choosing to use either OSM or TOS as a construction strategy in house building projects. The use of case-based precedence review approach allowed the researcher to conduct data from three different sources of each project case, desk study of case’s documents, interview with participants and observation of project on field when possible.

The participants for interviewing of each case was carried out with more than key participants, representing different perspectives on the case and then were incorporated to filled in the questionnaire survey. They include clients, project managers, architects and contractors, depending upon the availability of the project team at the time of the investigation. This was considered in order to develop a fuller picture of the situation for each case to explore the key facts that has upon decision making process employed on whether to use OSM or TOS as a construction strategy for selected projects.

4.5.3.2  **Identification and Selection Criteria of Project Cases**

There were 30 projects cases reviewed, 15 projects based on OSM and 15 projects based on TOS production of house building. The OSM projects were range of building systems include volumetric, none-volumetric to modular building. On the other hand, TOS projects were based on traditional forms of construction. Each individual project case shared the simple facts that they had upon decision outcome during the evaluation stage to use OSM or TOS as a construction strategy.

It has been mentioned earlier in section (4.5.1.2) that the BoS organisation is leading the UK offsite construction industry. The BoS is also organising clients’ events and show projects and case studies based on OSM system from different construction sectors regularly. The project cases are often either on-going life projects or recently completed projects. Thus, there were 15 cases housing projects based on OSM systems which have been selected available at the time of taken the investigation. The investigation of these projects cases was either arranged with the presenters in such BoS’s events or arranged
at the time of conducting interviews survey with the interviewees from housing projects of their companies.

While, the 15 project cases based on TOS have been selected from house building developments of the top UK house builders. The selected projects were primarily made either through contact via email or over phone-calls with their companies. The investigation then has been organised directly with key participants of the development departments involved in making company decisions. These projects were also either ongoing life projects or completed recently which were available at the time of taken the investigation. The project cases also were subject to meet the following selection criteria:

- Type of housing projects (e.g. homes, flats, apartments or accommodations).
- Based in the UK house building industry.
- Different locations and logistics issues.
- Completed recently or under construction projects.
- Projects based either on OSM or TOS methods for the construction.
- Based on construction methods/systems familiar in use with the house builders.
- Participants have/had experience and role of company making decisions.

With regard to required number of project cases for research, Peroverbs and Gameson, (2008) stated that there are advantages in being able to compare and contrast findings from one case to a similar or related case. However, this has to be balanced by the distribution of resources across two or more cases, which can affect the depth of investigation and some extent the validity of research findings. Furthermore, Fellows and Liu, (2008: 64) pointed out that “there is debate concerning how many case studies are necessary to yield a robust piece of research, generating theory is difficult if fewer than four case studies are used, ... there is no ideal number of cases, a number between four and ten usually works well”. Consequently, Proverbs and Gameson (2008: 27) emphasised that “with multiple case studies, the results will always be more compelling/strong, assuming that they are in support of each other and therefore easier to defend”. Considering these issues, this research has been conducted 30 project cases to be reviewed, 15 cases based on OSM and 15 based on TOS construction methods that were available and met the selection criteria to be investigated.
In addition, it was preferable that selected project cases were located in England in order to make travelling to conduct the interviews (if possible) practical within the time limitations and cost consideration. It has been though conducted two cases among the selected projects in Wales. However, it has not been conducted any cases in Scotland and North Island for the above reasons and ideally might be there are some differences of decision making process and procedures that affected by the variation of Building Regulations applied in these areas.

The data obtained from the review of projects case based precedence which was used and incorporation with data generated from sending out questionnaire surveys of both OSM and TOS investigations in order to establish the significance of the robust set of factors on decision for the final analysis. All the project cases were conducted of both OSM and TOS studies have been indicated and labelled from PC1 to PC15 maintain anonymity throughout the data collection and analysis of the research stages.

4.6 Phases of the Research Process

This section presents the research phases adopted for the research for the data collection and analysis used to achieving its aim. The data has been obtained using secondary and primary data sources. There were three main phases included for data collection and analysis throughout the research stages which employed different research methods. Figure 4-1 shows the outline of adopted research methodology and research road map. It illustrates the phases and stages of data collection using different types of research methods. The inquiry based on the assumption that collecting various types of data best provides an understanding of the research questions. These phases are detailed as following:

4.6.1 Phase One (Exploratory Research)

This phase concerns the secondary data collection which addressed in preceding chapters (1, 2 and 3). The purpose of undertaking exploratory research is to provide documentary evidence of the subject matter of the research and to provide a wider understanding of key issues. This phase involved literature search and review across many disciplines for secondary data collection related to the use and characteristics of Off-Site Manufacturing (OSM) in construction and decision making process for its use.
The aim of this research has been to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between using OSM and TOS Production as a construction strategy for housing projects in the UK.
in house building. This initial literature review identified the problems and issues currently the construction practitioners experienced in using OSM as an alternative construction methods in construction with particular reference to house building, the gap of knowledge and research question have been identified. Building upon the findings of revealed literature, the research aim and its objectives have developed. This phase has been discussed in more details in chapter 2 and chapter 3.

4.6.2 Phase Two (Primary Data Collection)

There were three stages involved in the primary data collection of this phase, using interviews and questionnaires (house builder’s and projects case-based precedence review) surveys:

- **Phase Two-One (Interviews – OSM)**

The interviews survey was designed to build upon the information gathered from the literature review of using Off-Site Manufacturing (OSM) in construction with particular reference to house building and addressing the research questions in the investigation. The study begins with a broad survey conducted using personal semi-structured interviews for data collection in order to generalise results to a population from house builders on the use of OSM in house building.

The interviews survey was targeted key references of stakeholders and members of Buildoffsite (BoS) organisation involved directly in house building. The interviews were carried out with senior managers with responsibility of making company decisions within their developments include: clients, project managers, architects, contractors and consultants. It aims to identify key issues related to areas of decision making to the use of Off-Site Manufacturing (OSM) in house building include: drivers, constraints and factors that need to considered at the evaluation stage of decision. It was also to explore the views and opinions of the participants on the use of OSM in house builders and how decisions to use the system were currently being made in the context of house building. The identified findings were qualitative data in nature.

- **Phase Two-Two (Questionnaire survey – OSM)**

The questionnaire survey was designed to build upon the information gathered from the interviews of using OSM in house building, seeking quantitative data. The questionnaire
(a postal questionnaire) firstly was sent out to key references of members and stakeholders of Buildoffsite (BoS) involved directly in house building within the UK construction industry. The key participants were invited in advance if they would like to take part of the research survey by either email or when meeting with them in such industry events. The questionnaire survey aims to validate and establish the impact of key (themes) factors identified from the interviews, and to identify the overriding factors that have most significance influence on decision. Secondly it aims to explore how decisions to use OSM were currently being made within the house building sector and project stage which making decision carried out and key decision makers and their level of influence on the decision making process. A package of the questionnaire survey can be found in Appendix B.

Secondly, the questionnaire was also used to conduct case-based precedence review by studying 15 house building projects constructed using offsite manufactured systems. All the projects cases and participants were subjected to selection criteria detailed (4.5.2). The use of case-based precedence review aimed to provide comprehensive impacts of the robust set of the key factors and criteria that have been experienced in real projects and the effect of each factor had upon decision to use OSM as a construction strategy. The projects’ documentary data, interview notes and observations when possible were all considered during the completion of the questionnaire survey by key participants when possible of every project case. A list of these projects and key participants for each project can be found in Appendix C.

- **Phase Two-Three (Questionnaire survey – TOS)**

This phase involved the validity of the key factors identified from OSM research and the establishment of a means of measuring the significance of these factors on decision to use Traditional On-Site (TOS) as a strategy for construction of house building. By the same procedure used in phase two-two, the study encompassed the use of questionnaire surveys both house-builders survey and case-based precedence projects review survey for data collection of TOS. It seeks also quantitative data rather than quantitative data. The house-builders’ survey was targeted top 100 UK construction firms involved directly in house building, including clients, project managers, architects, contractors and consultants. The targeted participants were discussed in more details in (4.5.2.2). While, the second survey was completed by key participants based on case-based
precedence review, using 15 housing projects constructed based on TOS construction methods. These project cases and participants were also subject to selection criteria identified in (4.5.3.2). The data obtained of which used to establish the impact of each factor of the key factors on decision to use TOS as a construction strategy for house building.

4.6.3 Phase Three (Development and Testing of the Model)

This phase involved the development and testing the validation of the Decision Support Model (DSM). Having established a robust set of key decision factors and the Severity Indices Matrix (SIM) of the factors, showing the importance and significance indices of each factor on the decision to use OSM or TOS in house building, the DSM has been developed. Microsoft Office Excel has been used to develop platform of the DSM. It provides effective functions in describing the frequencies, importance and significance indexes of the key factors of the robust, measuring the degree of impacts on decision and drawing conclusion of recommended construction strategy for a given project. An information modelling approach of exiting knowledge was revealed and then adopted in order the new DSM to be developed based on strong knowledge base of decision support systems used in the construction industry. The new proposed DSM designed be used in practice to guide the choice between Off-Site Manufacturing (OSM) and Traditional On-Site (TOS) production as a construction strategy for housing projects in the UK. This is based on established findings and evidences that make its use more applicable and fulfil the purpose of its environment. The DSM can provide the end user with a user friendly interface to assist in making decision for using OSM or TOS against any given project within its environment. This phase is discussed in more details in Chapter 7.

The design of the research methods and its phases has been also considered all the required ethical issues to anonymity (persons and firms), confidentiality related to data conducted. Statement of anonymity has been provided to participants during investigation action for data collection or in-advance when it was necessary.
4.7 Validation of the Decision Support Model (DSM)

Validation of the key research findings with the construction practitioners at the end of research programme is an important task in order to get their feedback in which it may consider their feedback for justification of the target outcome. This section involved the validation and testing of Decision Support Model (DSM) using case studies. There were four projects analysed in order to test the validity of the model at their pre-project phase. The testing has been carried out on real life construction housing projects that are of different scales and different project conditions. The key aim has been to identify whether there were any problems concerning the reliability and workings of the model. This leads to draw conclusions of the key findings of the study and makes recommendations for future research.

4.7.1 Aim of the Validation Test

The aim of validation and testing of the DSM is to identify whether there were any problems concerning the development and workings of the model. Fellows and Liu, (2008: 118) stated that in validating a model, the model’s output resulting from known inputs is compared to realisations of the reality. On other words, it is helpful to carry out such valedictory testing for several sets of inputs and known outputs of the reality to examine consistency of the decision evaluation model over a range of conditions. It is important to recognise that testing as training of the model and it may be essential that data are used which have not been employed in building of the model (Proverbs and Gameson, 2008). In order to run validation test of the DSM, there is a need to identify a number of case studies within its environment to be used for this task.

4.7.2 Case Studies Selection

There were four housing projects at their planning stages have been used to test the validity of the Decision Support Model (DSM). The selection criteria applied on those selected case studies was the same criteria which identified and applied on the projects conducted during the data collection, using case-based precedence review (4.5.3.2) which have not been used for developing the model. These case projects were analysed in order to test the validity of the DSM. The testing has been carried out on real life house building projects at their pre-project phase. The conducted cases were located on different area, scales, and have different site conditions and stakeholders. Subsequently,
each case study had different project factors and priorities on which the decision was based to use either OSM or TOS as a construction strategy for tested projects.

4.7.3 Interviewing Decision Makers

There were different participants involved for interviewing and testing the model of each project case of the selected four projects include: clients, project managers, contractors and architects. This mix of parts involved in the validation process is to ensure that the testing runs with various users and obtain different feedbacks on its operation process and data included. The testing results provided overwhelming evidence to suggest that the model is able to produce a clear recommendation on whether to use OSM or TOS as construction strategy for each project. It has been concluded that the model works well and found to be simple to use and user-friendly. It also minimises the time and the quantity of data required by the user to complete the exercise of the evaluation on whether to use OSM or TOS as a construction strategy for a project.

4.8 Conclusion

This chapter has provided research methodology rational and strategy and research methods for data generation, collection and analysis throughout this research work. Each approach was utilising a different strategy to data collection to capture a range of empirical data as raw data and information to be used to establish the requirements for achieving the research questions and its aim. This chapter has also emphasized the ethical research issues that have been considered which used as the main aspects throughout the research design process.

This research was adopted a rage of methods for primary data collection and analysis include semi-structured interviews survey, questionnaire surveys and case-based precedence review of a number of selected housing projects. The mixed approach of research methods has been used to gather the most appropriate data that would fulfil the aim of the data collection and analysis of the research stages. It has been considered the full possibilities of data collection to understand the current issues associated with the house builders that experienced on the use of OSM and decision making processes in the context of house building. The primary data collection process has involved two
main phases driven by the nature and inquiry of the research. First phase considered the
investigation of house builders on the use of OSM, while the second phase involved the
investigation of the use of TOS in house building as a construction strategy. Both
studies have been to identify a comprehensive data set of factors and criteria used at the
evaluation stage that have most significance influence on decision on whether to use
OSM or TOS as a construction strategy for house building.

The chapter has also provided briefly a description about the process of development
and validity test of the Decision Support Model (DSM) on chosen of a number of case
studies which have not been used for developing the model. The data analysis and
results of this study are detailed and presented in Chapter 5 of OSM investigation, and
in Chapter 6 of TOS investigation.
CHAPTER FIVE: FACTORS ASSOCIATED WITH DECISION MAKING PROCESS FOR USING OSM IN HOUSE BUILDING

The aim of this research has been to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between using OSM and TOS Production as a construction strategy for housing projects in the UK.
5.0 Introduction

This chapter investigates the current decision making process used for the decision to use OSM particularly at pre-project phase of a project life-cycle. It has carried out a robust study of the current situation in the house building industry associated with decision making process for using Off-Site Manufacturing (OSM) as a construction strategy. The data collection and analysis is based on the culmination of interviews and questionnaire surveys (both house builders’ and projects case-based precedence review) carried out within the UK house building industry focusing on the use of OSM. The results of analysed data were presented using graphical representations. The chapter is in four sections: firstly, the findings of the interviews; secondly the results and analysis of the questionnaire of house builders; and thirdly the outcomes of the projects case-based precedence review conducted are presented. Each of the first three sections or parts aims at identifying the drivers, constraints and the critical factors associated with the use of OSM in house building and their impacts on decision to its use as a construction strategy. The forth section of the chapter integrates the findings of the first three parts to establish the importance and significance indexes for the key decision factors associated with the choice to use or not to use OSM as a construction strategy for a house building project.

5.1 Data Collection and Analysis: Interviews

This section provides an overview of the data collection and analysis originating from the interviews conducted on the use of OSM in construction with particular reference to house building. It aims at providing a better understanding of the decision making process to use OSM in house building and to identify the drivers, constraints and factors that influence the decision to use OSM in house building.

5.1.1 Interviews Profile

A total of 30 interviews were carried out with leading construction practitioners of the UK house building sector particularly members and stakeholders of the Buildoffsite (BoS) organisation. BoS is an organisation leading the UK offsite construction industry, providing leadership and a central point for clients and practitioners seeking to use offsite technologies and modern methods in construction. Targeting the members of this
unique organisation has given the research to the opportunity to focus on experts with robust knowledge of off-site technologies and are directly associated with the decision making process when considering the use of OSM as a construction strategy.

All the interviewees were senior managers and directors with responsibility for making company decisions including: clients, project managers, architects, design managers, contractors, construction managers and consultants. The mix of types of firms and roles of interviewees has allowed a range of views and opinions to be obtained. The interviews were carried out using semi-structured form. A list of questions has been sent to the interviewees in advance in order to enable them to prepare and gather data for the meeting. Using this approach gave the flexibility to conduct the interview not just by using face to face meeting, but also using calls over the phone and skype medias. The interviewees were selected using a robust of selection criteria (4.5.1). A reference label system was adopted to identify interviewees in order to provide anonymous to guarantee confidentiality.

The questions were guided by the findings of existing literature on the use of OSM in construction. Open-ended questions were used to provide flexibility in exploring or investigating the issues as they arise. The use of the open-end questions enabled the research to capture practical ways in which decision making process for using OSM is carried out in the various organisations or projects. The data collected was analysed using manual methods and description statistics Microsoft Excel software.

The next three sub-sections are the analysis of the key investigated areas on the use of OSM in construction with particular reference to house building. The drivers, constraints and the critical factors associated with the decision to using OSM for house building.

### 5.1.2 Drivers for Using OSM Systems in House Building

Whilst the literature review identified the drivers to the implementation of OSM in construction industry; this research has adopted these drivers with a specific reference to decision making in the context of house building.

In order to establish the current drivers to use OSM in house building, practitioners were initially asked the following open-ended question to initiate discussion and create focus on the subject. They were there asked to score (out of 100%) the 13 identified
drivers from the literature and provide from their experiences the suitable implementation strategies that should be used to realise each driver in practice.

Q: In your opinion, what are the drivers in the construction industry that encourages the use of OSM systems in house building?

The collected data were qualitative in nature, which were then analysed manually in terms of percentages of claims - frequency score. The results are presented in Table 5-1, Table 5-2 and Figure 5-1.

**Table 5-1: Drivers for using OSM and implementation strategies in house building**

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revisions to Building Regulations to support OSM</td>
<td>• Considering all aspects of off-site construction</td>
</tr>
<tr>
<td></td>
<td>• Cover all building performance</td>
</tr>
<tr>
<td></td>
<td>• Introduce new codes and standards</td>
</tr>
<tr>
<td></td>
<td>• Deliver new homes using off-site technologies</td>
</tr>
<tr>
<td></td>
<td>• Applying latest regulations and standards</td>
</tr>
<tr>
<td></td>
<td>• Achieving carbon agenda target</td>
</tr>
<tr>
<td></td>
<td>• Meeting house-supply agenda</td>
</tr>
<tr>
<td></td>
<td>• Applying latest standards and codes to support OSM</td>
</tr>
<tr>
<td></td>
<td>• Reduction in defects and improving performance</td>
</tr>
<tr>
<td></td>
<td>• Minimising overall project life cycle cost</td>
</tr>
<tr>
<td></td>
<td>• Meeting Housing Corporation Policy agenda</td>
</tr>
<tr>
<td>Government and Industry’s agenda and concerns</td>
<td>• Achieving carbon agenda target</td>
</tr>
<tr>
<td></td>
<td>• Meeting house-supply agenda</td>
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<td></td>
<td>• Applying latest standards and codes to support OSM</td>
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<tr>
<td></td>
<td>• Reduction in defects and improving performance</td>
</tr>
<tr>
<td></td>
<td>• Meeting Housing Corporation Policy agenda</td>
</tr>
<tr>
<td>Reducing on-site construction duration</td>
<td>• Minimising on-site activities</td>
</tr>
<tr>
<td></td>
<td>• Speed on installation units on-site</td>
</tr>
<tr>
<td></td>
<td>• Minimising time spent on none-construction</td>
</tr>
<tr>
<td></td>
<td>• Reduction in time due to over lapping between on-site activities and off-site manufacturing</td>
</tr>
<tr>
<td></td>
<td>• Reduction in overall project duration.</td>
</tr>
<tr>
<td>Shortage in housing supply</td>
<td>• Rate of housing supply necessitates more efficient ways of construction new homes</td>
</tr>
<tr>
<td></td>
<td>• Achieving government and industry agenda</td>
</tr>
<tr>
<td></td>
<td>• Pushing up prices of houses in certainty areas</td>
</tr>
<tr>
<td>Projected skills shortage</td>
<td>• Necessitates need for modernisation</td>
</tr>
<tr>
<td></td>
<td>• Stable, skilled and trained labour in factory environment</td>
</tr>
<tr>
<td></td>
<td>• Strategy to reduce labour on site – concerns labour cost, safety and interfaces disruption</td>
</tr>
</tbody>
</table>

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Concerning quality of new housing
- Level of required quality for facility
- Working under factory conditions gives better quality control
- Testing and proving OSM components before transported and incorporated into building

Reduction in overall project cost
- Applying whole life cost
- Cost efficiency of product or facility
- Greater business efficiency and profitability
- Long life-span of components and lower defects-related cost savings
- Operation and maintenance costs of product or facility
- Earlier income generation for clients and developers

Integration of project processes
- Technologies – e.g. IT, other industries, other countries, etc.
- Design, manufacturing and construction – working as one
- Good design co-ordination and integration
- Management and coordination of activities onsite
- Effective communication across supply chain at all levels

Improve environmental performance of building
- Using sustainable materials
- Reducing CO₂ emission of new homes
- Reduction in waste and substance dangerous on site
- Enhance re-use and re-cycle opportunities
- Reducing the amount of waste to be dumped

Reducing environmental impacts during construction
- Reduce impacts through reduction of site activities
- Minimise local disruption
- Less transport deliveries and congestion
- Reduce land impacts surrounding site
- Reduced pollution due to plant at site

Employment opportunities from building-sites
- Secure jobs and long-term working relations
- Improve conditions of workers in factory
- Reduce H&S risks under controlled work environment
- Training and awareness programmes
- Areas of responsibilities

Reduction in accidents and ill health on building sites
- Transferring much of construction programme from an open site to a controlled factory environment.
- Reduces the potential accidents and ill health by reduction and increased control of site activity.
- CDM regulations
- However, risk is not transferred to the factory or somewhere in-between factory and site.

Product and end users focus
- Quality of in-door and out-door environment of facility
- Low households’ billing
- Flexibility for future changes
- Maintenance issues
- Bring end-users’ feedback into considerations for new projects
The research has identified 13 key drivers for using Off-Site Manufacturing (OSM) in house building. A number of implementation strategies has established for each of the 13 drivers which seems to suggest that the industry clients and practitioners have recognised the benefits of implementing the system in the construction of house building projects.

Only 3 out of the 13 drivers were scored less than 50% (i.e. environmental performance of building (46%), employment opportunities (48%), and reduction of accidents and ill health (46%). This means that drivers scored above 50% have the most influence on house builders to adopt OSM in construction. However, it may be argued that with all drivers weighting above 50% level, all will have a significant influence in bringing change to house building.

![Figure 5-1: Drivers for using OSM in house building](image)

The frequency score of each driver was also established and presented in Table 5-2. It seems that the first six identified drivers have the highest impact on using OSM in house building namely ‘highly importance’. The drivers that followed were 7-10 with ‘moderately importance’ impact. This may suggest that these are most significant
drivers to focus on for the housing sector to transform to using OSM as a construction strategy.

Table 5-2: Drivers categories to use OSM in house building

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Frequency (%)</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Reducing overall project timescale</td>
<td>90</td>
<td>Highly importance</td>
</tr>
<tr>
<td>2 Shortage in housing supply</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>3 Reducing environmental impacts during construction</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>4 Concerning quality of new housing</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>5 Projected skills shortage</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>6 Integration of project processes</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>7 Reduction in overall project cost</td>
<td>69</td>
<td>Moderately importance</td>
</tr>
<tr>
<td>8 Revisions to Building Regulations to support OSM</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>9 Government and Industry’s agenda and concerns</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>10 Product and end-user focus</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>11 Employment opportunities away from building sites</td>
<td>48</td>
<td>Less importance</td>
</tr>
<tr>
<td>12 Environmental performance of buildings</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>13 Reduction in accidents and ill health</td>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>

However, the lowest scored drivers were sorted as ‘less importance’ of their impacts on the use of OSM in house building. The impact of these drivers may change from project to project, because every project has its own specific requirements, characteristics and objectives. Thus, the research concluded that none of the drivers be ignored at the evaluation stage when it comes to deciding to use OSM in house building.

5.1.3 Constraints to OSM in House Building

Whilst, the project drivers frequently seem to be the important factors in decision making process, it is the constraints that have the greater potential to affect project outcomes (Blismas et al., 2005). Pan et al., (2004) suggests that there is little understanding within the UK construction industry of the process of manufacturing components off-site which exacerbate the effect of constraints impacting against using OSM. In such circumstance, Armstrong et al., (1999) recognised that decision makers face a range of possible constraints that need to be identified and considered at the evaluation stage of decision. This led the research to further need to identify the house builders’ constraints to use OSM, using the same approach as used to identify the drivers:
Q: In your opinion, what are the key constraints that are facing the industry to the use of OSM systems in housing projects?

The research has identified 20 constraints, which the interviewees have indicated to be valid constraints to the use of OSM in house building projects. The interviewees were asked to rate (out of 100%) the impact of each constraint on the use of OSM in house building. The average rating for each constraint is shown in Figure 5-2.

92% was scored by ‘Early design freeze’ as the highest rated constraint, followed by ‘Projected skills shortages’ at (87%), then ‘Low market demand’ at (81%), and ‘Mortgage to OSM’ at (77%). The constraint, ‘Higher capital cost’ and ‘Complex interfacing between systems and tolerance issues’ were equally standing at (71%). These could be classified as the ‘high effect’ constraints. 6 others are considered medium, with 7 more considered as Low effect constraints.

Figure 5-2: Constraints for using OSM in house building
The 20 identified constraints were also suggested categorisation in terms of their impacts to use OSM in house building as shown in Table 5-3. It seems that the top 7 constraints have the highest impacts against its use in house building. This was followed by the constraints 8-13 with moderately impact on its use. However, the rest of the established constraints 14-20 seem to have less impact on the use OSM in house building.

Table 5-3: Key Constraints against the use of OSM in house building

<table>
<thead>
<tr>
<th>Constraints</th>
<th>Frequency (%)</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Early design freeze</td>
<td>92</td>
<td>Highly importance</td>
</tr>
<tr>
<td>2 Projected skills shortages</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>3 Low market demand on OSM homes</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>4 Mortgage to OSM due lack of awareness of the system</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>5 Regulations are too old to cover all off-site aspects</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>6 Complex interfacing between systems and tolerance issues</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>7 Higher capital cost</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>8 Limited UK capacity in OSM to enhance its use and efficiency</td>
<td>66</td>
<td>Moderately importance</td>
</tr>
<tr>
<td>9 Expensive with comparison to traditional methods</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>10 Site and access constraints</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>11 Lack of existing codes and standards to OSM</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>12 Design fees seen more costly</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>13 Difficult long-distance transport from/to manufacturing plants, with associated issues</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>14 Lack of understanding of OSM by local authorities</td>
<td>48</td>
<td>Less importance</td>
</tr>
<tr>
<td>15 Possible increased consequences of incidents onsite due to large units and heavy loads</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>16 No legal framework available to support OSM</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>17 Culture resistance – poor public perception of OSM</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>18 Limited expertise in the marketplace of the system</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>19 Crane requirements and associated costs</td>
<td>23</td>
<td></td>
</tr>
</tbody>
</table>

Interestingly, the constraints identified to the use of OSM in house building from practice aspect are very similar to those identified from the existing literature. Similarly, they are also reflective of the industry's traditional fragmented approach to construction.

5.1.4 Factors for Making Decision to Use OSM

Having identified the drivers and constraints, the research further used interviews to identify the factors that have a significant influence when it comes to taking the decision to use OSM in house building. In order to establish a robust set of decision factors based
on the interviewees experienced from using the system, the next question was developed:

Q: *From your experience, what are the key factors that need to be considered when considering to use OSM systems in house building projects?*

The interviews conducted provided a list of key factors that need to be considered at the evaluation stage for decision to use OSM in house building projects. The list has 122 factors that have an influence on the decision making process when considering to use OSM as a construction strategy. These factors were then categorised into 16 themes of decision factors for ease of handling and comprehension. The identified themes are time, quality, cost, predictability, interface, environmental, labour, productivity, space, safety, complexity, logistics, resources, planning and market demand.

To validate the established 16 themes of decision factors, the research consulted five carefully selected experts in order firstly to make sure that each factor is suitably placed under the right category. The panel of experts involved two academics who had a wealth experience in the UK construction industry, and three experts who are currently working in the construction industry: a project manager with 20 years’ experience, a consultant with over 27 years’ experience, and a construction practitioner who had over 25 years’ experience in house building industry.

Figure 5-3 gives an example of categorising the decision factors under the theme of quality and the theme of logistics. All factors identified from the interviews which have means or functions of quality are included under the theme of quality. These factors are:
Figure 5-3: Categorising of decision making factors to OSM
achieving high quality; level of required quality for project; reduction in defects of product or facility; quality level of end product or facility; quality control condition in factory; experience of labour force in factory environment; quality control review during manufacturing processes and onsite assembly; and high standard quality of both internal and external finishes of building elements. In addition, the factors that have means or functions of logistics are placed under the theme of logistics. The factors identified this term are: site location/community; restricted access and site size; plant and equipment’s movement on site; transport of materials and components from factory to site; congested site area; understand crane requirements; and unit size restricts flexibility. By the same way, the other factors are placed under the most suitable category. Appendix A provided 16 figures that show the categorising process of the decision factors under each of the themes.

The 16 themes or categories are henceforth regarded as the key decision factors for the use of OSM in house building. The valuation and identification of the impacts of the key decision factors on the decision to use OSM in house building required a further investigation using questionnaires both house builders and case based precedence projects review surveys.

5.2 Data Collection and Analysis: Questionnaire – House-builders’ Survey

The data obtained from the interviews on the use of OSM have identified and the established the key decision factors that have most influence on the decision to use OSM as a construction strategy for house building in the UK. This section presents a robust validation of the initial findings and quantifying the impacts of the key factors on decision to use OSM in house building by using questionnaire survey. It aims to establish key components and the current understanding of decision making and also to establish the importance and significance of the key factors on decision to use OSM as a construction strategy for house building.

5.2.1 Questionnaire Profile

The questionnaire was designed to build upon the findings obtained from the interview study on the use of OSM in house building. The questionnaire survey can be found in Appendix B. The survey aims firstly to validate the reliability of the established key
decision factors and secondly explores how decisions to use OSM were currently being made within the house building sector.

A postal questionnaire survey was targeted leading UK offsite house builders in the construction industry. The survey was sent out to a selection of 75 carefully selected members and stakeholders of Buildoffsite (BoS) organisation who involved directly in house building. The selection criterion for key participants has been detailed in section (4.5.2.2).

The response rate of the survey totalled 48%. This response rate was considered high compared with the norm of 20-30% response rate with most postal questionnaire surveys of the construction industry (Akintola and Fitzgerald, 2000). The obtained high rate of response may be resulted from two aspects. Firstly, the key participants were invited in advance if they would like to take part of the research survey and secondly the researcher is a key delegate member of the Buildoffsite’s events/workshops and thus, this was helpful to build up a good network with the key participants which helped to achieve a good response of the survey.

A total of 36 responses out of 75 postal questionnaires were received. However, only the first 30 responses were included in the data analysis in order to be equivalent to the number interviews (5.1.1). Table 5-4 summarise the responses of the questionnaire survey.

<table>
<thead>
<tr>
<th>Research Participants</th>
<th>Number</th>
<th>OSM – Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client/Developer</td>
<td>10</td>
<td>✓</td>
</tr>
<tr>
<td>Project Manager</td>
<td>4</td>
<td>✓</td>
</tr>
<tr>
<td>Main Contractor</td>
<td>8</td>
<td>✓</td>
</tr>
<tr>
<td>Specialist supplier</td>
<td>1</td>
<td>✓</td>
</tr>
<tr>
<td>Architect/Designer</td>
<td>4</td>
<td>✓</td>
</tr>
<tr>
<td>Consultant</td>
<td>3</td>
<td>✓</td>
</tr>
</tbody>
</table>

Initially, the key decision factors were validated and their individual level of importance is established. Secondly, the respondents were asked to identify the 3 overriding factors among the 16 decision factors in the list. Thirdly, the respondents were asked to indicate the best time in the project timeline is appropriate for the project team to take the
decision to use OSM as a strategy. Fourthly, they were asked also to state which of the project stakeholders is most suited to lead the decision making process. The responses and the analysis of the key issues investigated in the survey are discussed in the next sub-sections.

5.2.2 Factors for Making Decision to use OSM in House Building

In order to validate and establish the impact/importance of the established key decision factors, the following question has been developed:

Q: Which of the following key factors influence the decision to use OSM in house building projects?

Having indicated which factors apply, please score their level of importance on the decision between (1 – 5), 5 being the most important?

The question has been designed in a manner to identify the factors that have an effect on decision by ticking Yes/No of the listed factors and/or by adding other factors that have not been identified by the interviews. The indicated factors are then scored on their level of importance on the decision to use OSM in house building.

The data obtained from the survey was analysed in terms of the frequency of occurrence to measure the house builders’ most indicated factors that have influenced their decisions on the use of OSM. A frequency index ($F_i$) of each of the 16 key factors or themes is established by using the following function:

$$F_i = 100 \times \left( \frac{s}{F} \right)$$

Where: $s$ = frequency of possible weighting for each key factor

$F$ = total number of respondents

Table 5-5 shows a detail breakdown of the 30 responses. The matrix provided the total number of factors, the frequency index and percentage value of each theme. The percentage value represents the number of factors that were experienced against the total number of possible factors that could have been experienced by each participant on the use of OSM in house building projects.
| Code | Factors | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | %  |
|------|--------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| F1   | Time   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 30 | 100.00 |
| F2   | Quality| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 29 | 96.67 |
| F3   | Cost   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 26 | 86.67 |
| F4   | Predictability | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 22 | 73.33 |
| F5   | Interface Issues | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 17 | 56.67 |
| F6   | Environmental Issues | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 17 | 56.67 |
| F7   | Performance | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 19 | 63.33 |
| F8   | Labour | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 15 | 50.00 |
| F9   | Productivity | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 16 | 53.33 |
| F10  | Lack of Space | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 16 | 53.33 |
| F11  | Safety | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 12 | 40.00 |
| F12  | Project Complexity | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 10 | 33.33 |
| F13  | Logistics Issues | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 12 | 40.00 |
| F14  | Availability of Resources | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 | 26.67 |
| F15  | Planning Issues | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 6 | 20.00 |
| F16  | Market Demand | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 | 26.67 |
| SUM  | 8 | 8 | 9 | 8 | 7 | 10 | 7 | 8 | 9 | 9 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 7 | 8 | 8 | 13 | 9 | 9 | 10 | 12 | 6 | 15 | 7 | 14 | 8 | 50 |
| %    | 50 | 50 | 56.3 | 50 | 43.8 | 62.5 | 44 | 50 | 56.3 | 50 | 44 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 81 | 56 | 56 | 63 | 75 | 38 | 94 | 44 | 88 | 50 |

Table 5-5: Matrix of breakdown of each key decision factor to use OSM in house building
Figure 5-4 shows that key factors of time, quality and cost were highlighted as most influenced factors on decision to use OSM in house building, with a score of 100, 96.69 and 86.67, respectively; followed by theme of predictability at (73.33), performance at (63.33), interface issues and environmental issues at (56.67), productivity and lack of space, equally standing at (53.33), and labour issues at (50).

With reference to the rating scale used, it suggested that the factors scored 50 and above were rated as ‘most significant’ factors on decision to use OSM. The research has therefore established the 10 most important factors obtained from the survey that have potential influence on decision when considering OSM as a construction strategy to house building. However, this does not mean that the other last 6 factors are insignificant because every project has its own characteristics and unique requirements.

The established frequency indices will be used for final analysis in order to establish the importance and significance indices for each key decision factor on the use of OSM as a strategy in house building (5.4.3).
5.2.3 Overriding Factors for Making Decision to use OSM in House Building

In order to establish the factors that House Builders used as their measure/characteristic for making the decision to use OSM vs. TOS methods, a question was set to identify which of the 16 key factors would their important consider to be the overriding factors on decision making to use OSM.

Q: In your opinion, are there any overriding factors influencing decision that determine a house project using Off-Site Manufacturing (OSM) systems?

The data were analysed in terms of the frequency of occurrence and indicated as shown in Figure 5-5. It was surprisingly to note that 30 out of 30 of the participants all indicated that time and quality factors have the most influence on decision. While, 26 responses out of 30 of the participants also highlighted that time, quality and cost factors are overriding factors. Thus, the research has established that the three classic time-quality-cost management triangle are the main key factors that have the highest impact on the decision for using OSM in house building.

![Figure 5-5: Overriding decision factors to use OSM](image)

Time factor was highlighted as the most effective factor on decision to use OSM. There is an overall saving in programme time; this reduction is obtained through the overlapping of off-site manufactured process and on site building activities which would be done in sequence using traditional methods. Thus, the reduction in time
should lead to reduction in the overall cost of project include reduction in the cost of prelims associated with the major contractor’s site setup costs. Cost factor although seems still challenging issue to OSM among the house builders. The use of OSM can appear more expensive than onsite traditional methods due to lack of understanding of its use in construction process. However, if considering long term benefits of using OSM then this perception will dramatically change and be seen as a beneficial strategy for construction. In addition, achieving the highest quality was highlighted as an important factor because quality control and assurance procedures are easier to apply in the factory environment than onsite traditionally build. Working under factory conditions gives a better product control, productivity and quality of end product. This may imply that OSM can be a strategy if well implemented to deliver to the specified quality within the cost plan and the agreed construction time.

5.2.4 Critical Stage of Decision Making to use OSM

Literature revealed that decision making for using OSM should be taken at a very early stage of the project in order to maximise the benefits. To take the advantage of using OSM, the earlier the key decisions are made the greater will be to achieve project benefits (Gibb, 1999: 51). This means that the key decisions should be made ideally before project moved to detailed design or production stage. There was no specific indication in literature suggesting at which specific stage of project life-cycle is the key decision to be made. This research mapped the decision making process using the RIBA Plan of Work stages (the updated version of RIBA Plan of Work has provided in Appendix F); and the following question was developed:

Q: What stage using the RIBA Plan of Work should be the decision to use OSM systems made of house building projects?

The results turned out that 60% of the respondents have indicated that the decision to use OSM should occur during the feasibility as a hard gate stage before the project move to the next stage. About 10% of the total respondents also indicated that it is even too late at feasibility stage. 23.33% of the respondents suggested that the inception stage before the project moves forward to the next stage. The outline proposals and scheme design of RIBA stages were suggested with 10% and 6.67% respectively. However, none of the respondents indicated any of the other project stages. The results were represented in a bar chart in Figure 5-6.
5.2.5 The Decision Maker for using OSM

In order to examine who makes the decision and the level of influence key project players have in arriving of the decision to use OSM as strategy for the construction of housing projects. The following question was developed:

Q: Who among the key project players currently makes the decision to use Off-Site Manufacturing (OSM) as a strategy for the construction of housing projects?

Indicate the level of influence of the following key project phases on the decision making process?

A list of key project players was included in the question. The list has been developed from analytic process of the interviews survey that identified who involved in making the decision to use OSM and respective level of influence is outlined using the five-point Likert scale. The data obtained of 30 responses was analysed in terms of frequency of occurrence of each key players.
Figure 5-7 illustrated the key results of this survey question. The results revealed that the main contractor is identified as the key player with the greatest influence on the decision to use OSM in housing projects, with frequency index of 70, followed by the client influence standing at 63.33 and the architect influence came third with 46.67. The remaining key players have less influence on the decision to use OSM as a strategy for the construction of housing projects.

5.3 Data Collection and Analysis: Case-based precedence projects review

The established key decision factors were again subjected to further investigation using case based precedence projects review to validate and establish their impacts on decision for using OSM in house building. This section of the data collection focuses on the use of project cases, conducting real life project information and criteria used at the evaluation stage for decision.
5.3.1 Project Cases Profile

The aim of conducting case-based precedence projects review has been to establish the frequency of occurrence of the key decision factors and the impact that they had on the decision to use OSM as a construction strategy for house building.

15 projects that have used OSM systems were identified and reviewed throughout this phase of data collection. The selection criteria of these project cases have been covered (4.5.3). A description of the context of the project is given followed by a more in depth description of the factors that have been experienced; and the procedure of making decision used for each project case have been explored. There were three research techniques applied to collect data: projects’ documents, interview with project team, and direct observation where possible which all reviewed before the completion of the serve yob the key participant of each project case. A brief description produced shows project information, data sources, and participants involved in the study for each project case can be found in Appendix C.

At least 5 to 10 factors were identified from each project that have had most influence and their impact/influence level on decision during the evaluation stage to choose a construction strategy for a project has been investigated. The data obtained from the case based precedence projects review was analysed using a five point likert scale and in order to derive frequency, importance and significance indices for each key decision factor. In order to guarantee confidentially, the names of projects, companies and individuals have been omitted.

5.3.2 Factors for Decision Making to OSM

After reviewing project documents and interview key notices, the participant were asked to indicate the factors that have been considered at the evaluation stage to use OSM as a construction strategy for each project case. The participants were also asked to score the level of influence had each factor has on the decision using a five-point Likert scale.

The matrix shown in Table 5-6 has indicated the key factors that were experienced on each individual project case number and frequency of occurrence for each factor.
Table 5-6: Overview matrix of key decision factors experienced in each project case

<table>
<thead>
<tr>
<th>Code</th>
<th>Factors</th>
<th>PC 1</th>
<th>PS 2</th>
<th>PC 3</th>
<th>PC 4</th>
<th>PC 5</th>
<th>PC 6</th>
<th>PC 7</th>
<th>PC 8</th>
<th>PC 9</th>
<th>PC 10</th>
<th>PC 11</th>
<th>PC 12</th>
<th>PC 13</th>
<th>PC 14</th>
<th>PC 15</th>
<th>N0.</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Time</td>
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This provided essential information regarding the variability of significance and occurrence from project to project. From the data in the matrix, it is obvious that the house builder were considered between 5 to 10 key factors at the evaluation stage for decision to use OSM for each project case being investigated.

The frequency of occurrence was calculated using the number of factors that were experienced against the total number of possible factors that could have been experienced in each project case. The frequency of occurrence is to be used for final analysis to calculate the importance and significance indices of the factors in order to measure the impact of each factor on decision to use OSM as a strategy in housing projects.

Similarly, the following function has been used to establish the frequency index:

\[ F_i = 100 \times \left( \frac{s}{F} \right) \]

Where:
- \( s \) = frequency of possible weighting for each key factor
- \( F \) = total number of possible factors experienced in each project case

The results are also illustrated graphically in Figure 5.8.
The Figure 5-8 and Table 5-5 show that time, quality and cost were highlighted as most influenced factors on decision to use OSM in house building with the frequency indexes of 100, 80 and 73.33, respectively. Predictability, environmental issues, labour, lack of space were scored equally at 40. The factors of interface issues, performance, and productivity also were equally rated at 33.33.

The factors with a rating greater than 70 were rated as ‘most significant’ factors that can have potential influence on the decision when considering to use OSM as a construction strategy in housing projects. Those above 20 but below 70 are considered as significant. The rest of the factors seem to have less influence on decision based on project cases review. This will be needed for the development of a methodology to measure the impact of each factor on decision and the development of a decision evaluation model.

5.3.3 **Overriding Factors for Making Decision to use OSM**

The research has investigated the overriding factors among the identified 16 themes that have most influence on decision making to use OSM in house building. The participants on each project case were asked to indicate the critical factors that had most influence on decision that determined their projects using OSM as a construction strategy. The results were indicated in Figure 5-9. The data was analysed in terms of the frequency of occurrence for each factor experienced in each case project.
All the overriding factors experienced in the 15 project cases were the factors of time, quality and cost; or minimally the factors of time, quality and market demand. Thus, the factors of time, cost, quality and market demand were indicated as the factors that have the highest impact on their decisions to use OSM in house building. However, the order and impact of these overriding factors might change when combined with the findings of the questionnaire survey for the final analysis (5.4.4).

5.3.4 Critical Stage of Decision Making for Using OSM

The participants of each project were asked to indicate the stage of decision making on the RIBA Plan of Work stages. Figure 5-10 shows the overall key findings of the stage(s) at which the decision has been made in those projects.

The results indicated that there were three stages experienced for making decision to use OSM in these projects: feasibility, inception and outline proposals, their percentages of occurrence standing at 40%, 33.33% and 20%, respectively.

In addition, the participants were asked if they were satisfied with the stage at which the decision was made in each individual project case. 12 out of 15 projects (80%) were
satisfied with the stage at which the decisions have been made. However, the other 3 projects (20%) also indicated that the decision should have to be made earlier in order to save time and avoid extra costs. The decision made to use OSM was at feasibility study stage in two of the projects and at the outline proposal stage in the third project. This supports the findings drawn from the questionnaires (5.2.4) that the decision to use OSM should be made at inception stage if the project team are familiar with using OSM systems. The latest stage should be at feasibility study stage, where more key players are involved.

5.3.5 The Decision Maker for using OSM

The 15 project cases were also used to investigate who made the decision among the key project stakeholders, and their level of influence on the decision to use Off-Site Manufacturing (OSM) as a construction strategy for these projects. A list of key project players was provided and a five-point Likert scale is used to score the level of influence. The results were presented in Figure 5-11.

![Figure 5-11: Key project players and level of influence on decision to use OSM](image)

The results identified that client, main contractor, architect and project manager were highlighted as the most influential key project players on making decision to use OSM.
as a construction strategy in the project. The client is identified as the key player with the greatest influence on the decision with a frequency index score of 80, followed by the main contractor influence standing at 66.67. The architect’s influence came third with frequency index of 53.33.

5.4 The Key Findings associated with Decision Making to use OSM in House Building

The section summarises key results and findings of previous sections and sub-sections that have been obtained from interviews and questionnaires both house builders and case based precedence projects review surveys of the study to the use of OSM in house building projects.

The survey results reveal that there seems to be a wide misunderstanding among the construction practitioners of the state of OSM associated with drivers, constraints and factors to the use of OSM as a construction strategy in housing projects. This suggestion is drawn from the findings obtained from the interviewing of the house builders. This research seems to support that the uptake of OSM must be improved, and this can only be influenced by a better understanding of the key drivers, constraints and factors by the stakeholders involved in decision making process.

![Figure 5-12: Relationships between drivers, constraints and factors associated with decision to use OSM at industry and project levels](image-url)
Figure 5-12 illustrates the relationships of the key drivers, constraints and factors associated with the decision making process to use OSM at the industry and project levels. The figure provides a broad picture of the basic interrelationships of the three components where their appearance can be occurred at specific level or integrated more than one level:

- The drivers for using OSM in house building need to be defined at the industry level. The move to OSM essentially requires the drivers are defined with an entire considerations of technical, economic, environmental, organisational and social issues.

- The key decision factors are occurred at the strategic and tactical levels of project. The factors need to be evaluated and qualified in order to identify the factors that have significant influence on the decision for best project outcomes.

- The constraints occur at the project tactical and operational levels. It is clear that there is an overlapping between the factors and constraints. This requires a careful consideration at the evaluation stage for the decision to use OSM.

Making successful decisions to use OSM is the central task of decision makers in which they are drawn their inclusion based on identified drivers, constraints and factors of project. This research aimed at developing a decision evaluation model to be used in practice to guide the choice of using OSM a strategy versus traditional onsite construction methods. Figure 5-13, overleaf, maps out the relationship graphically between the drivers, constraints and factors with regard to the decision making process to use OSM as a construction strategy in the context of house building.

The Figure 5-13 highlights elements in the decision to choose between one strategy over another for the construction. The decision is driven by defining the key factors (project priorities and specific requirements) which can have most influence on the decision based upon their significance, and then considering the benefits of various options (OSM vs. TOS) against those drives. Whilst, the project drivers are usually seen to be the important issues in decision making process, it is also the constraints that can have the greater potential to influence the decision outcomes.
Therefore, this research argues that misunderstanding the key drivers and constraints of using the OSM as a strategy at the industry and project levels can affect the decision making process in which the decision is based in the first place.

5.4.1 Drivers to the use of OSM in house building

This research has established a body of evidence to suggest that if the key drivers are understood and applied, it could enhance the use of OSM in house building. It has reviewed the drivers for adopting OSM with specific reference to decision making at industry level. The findings have been established from the 30 interviews with selected practitioners of the top UK's house builders. 13 key drivers have been identified for change to adopt OSM as a strategy in the house building. The use of OSM was driven by revision to Building Regulations to support OSM, the government and industry agenda and concerns, and shortage in housing supply. It is also determined by projected skills shortage with the industry, concerning quality of new housing, and reduction in overall project cost. OSM was also seen to simplify the construction processes through
the integration of project processes, improve environmental performance of building and reducing environmental impacts during construction. It can also provide employment opportunities away from building-sites with aim of reduction in accidents and ill health on building sites. The use of OSM was also driven by focusing on product and end users requirements.

Table 5-2 presented the identified these drivers in terms of their impact on willing to use OSM in house building. There were also a number of implementation strategies suggested by the house builders which are necessary to trigger under each of the key drivers as shown in Table 5.1. Therefore, it is essential that the decision for using OSM is to be viewed from a project-wide perspective of key project drivers and a suitable strategy is developed to optimise its use in the house building. This research suggests that the identified key drivers are indeed strong enough to encourage and motivate the housing sector to invest more in the use OSM systems to overcome the constraints.

5.4.2 Constraints to the use of OSM in house building

The research has highlighted the constraints with regard to decision making process at the project-level to the use of OSM in house building. 20 constraints have been identified to the use of OSM in house building. The constraints with the most significance impact against its use in house building were established as: early design freeze, projected skills shortages, low market demand to support its use, mortgage to OSM due lack of awareness of the system, regulations are too old to cover all OSM aspects, complex interfacing between systems and tolerance issues, and higher capital cost.

The constraints identified from practice in house building confirm the findings in a number of recent studies, but they are classified or grouped differently from study to another. Similarly, they are also reflecting of the industry's traditional fragmented approach to construction. The early design freeze is a key constraint that all studies agreed about it. This means that late changes in design are not easy to accommodate and has highly cost implications of project. It is also critical point for the stage of decision making. It is also clearly that building regulations issue has been identified as key driver for using OSM (i.e. revision to building regulations to support OSM) and in the same time identified as key constraint of regulatory category. The existing building
regulations are too old to cover all OSM aspects and the industry requirements. Thus, the issue building regulations and standards needs a special care must be taken in account at the evaluation stage for decision.

5.4.3 Impact of key Decision Factors for using OSM in House Building

This work will take unstructured decision and transform them into a structured decision using knowledge, experience and previous outcomes; ultimately the research methodology aims to replace subjected with objectivity. An optimum decision strategy involves careful understanding, measurement and evaluation of a number of factors that can have the most influence on alternate decision outcomes to use OSM production as a construction strategy for house building projects. Thus, it was necessary to identify a robust set of decision factors that should be considered when chosen to use OSM in house building.

The literature revealed that qualitative research is ‘subjective’ in nature (Naoum, 1998: 40) which involves the collection and analysis of word data (Farrell, 2011: 6). This approach relies on text and image data, seeking to gain insights and understand the people’s perceptions, opinions and views of a subject (Creswell, 2009: 173). Subjectivity reflects the perspective through a person’s reality. Subjectivity cannot be verified using concrete facts and figures and yet, that is exactly what this research had done. A quantitative approach is ‘objective’ (Naoum 1998: 38) and Farrell stated that it was a systematic process where numerical data are utilized (2011: 8); Objectivity, is verifiable by facts or performing mathematical calculations.

This research has considered these concepts and aimed at developing a procedure to translate the subjective data (house builders’ opinions and reviews) into numerical data. This data is then supported with factual data based on case based precedence real projects review. In order to develop the means of the obtained numerical/objective data, the frequency, importance, and significance indices of the key decision factors were established for both OSM and TOS. A severity index matrix has been developed using these indices to measure the impact of the key factors on decision, which forms the core of the evaluation methodology of the new proposed Decision Support Model (DSM) to guide the choice and led to objective outcome on whether OSM or TOS is the best strategy for a project.
Having carried out an extensive analysis of data gathered from 30 interviews on the use of OSM, a list of factors has been identified. Thus, the research identified 122 decision factors that have an influence on decision making process when considering OSM. These factors were then categorised into 16 themes of decision factors for ease of handling and comprehension. Further, an investigation was carried out using 30 questionnaires with selection of the top practitioners within off-site industry and 15 project cases based OSM systems. This together used to identify the factors that have the potential impacts on decision outcomes to use OSM as a construction strategy for housing projects. The findings from questionnaires surveys both house builders and case based precedence projects review were combined together in order to validate and establish the impact of the robust of the 16 themes of factors on the decision to use OSM in house building.

Making a decision is a judgement and choice between possible alternatives of the matter; it is not often a choice between right and wrong. In this way, the decision based on what is likely to be the best outcome(s) based on such as probabilities, facts or other numerical data to assist the decision makers in evaluating decisions. A mathematical approach being used is the statistical method referred to as the Importance Index, Significance Index and Severity Index, adapted from Adams (Smilas, 2003; Gidado, 1993). This work therefore has established the frequency, importance and significance indexes which will be used to establish the severity index matrix of the impact of the robust set of factors on decision for using OSM in house building. The rationale behind the application of this method stems from the fact that it helps in objectivity measuring the level of importance of each factor and its effect or influence in the decision making process.

There are a number of software packages used for data analysis available which its use depends upon the researcher and the type of data. The initial data conducted throughout this research process is quantitative and qualitative in nature which requires various analysis techniques. Microsoft Office Excel was used for analysing data in this research due to several advantages of its use. Some of these advantages are simple and easy to use, familiar to the researcher, user friendly instrument, links to variety of control box equations for generating results, able to create and develop calculation formulas, and compatibility with other software packages. Microsoft Office Excel is available in every PC or laptop computers and almost free of cost. For these reasons, the Microsoft Office
Excel was in favour for analysing data and generating results throughout this research which offers similar analysis outputs to other more sophisticated software packages such as SPSS (Hinton, et al., 2004).

The frequency index ($F_i$) was derived and established using the following function:

$$F_i = 100 \times (s / F)$$

Where: $s$ = frequency of possible weighting for each factor  
$F$ = total number of possible weighting

Whilst, the importance index ($I_p$) was derived and established using the following function for each factor of the key decision factors on the use of OSM:

$$I_p = 100 \sum (a \times s)/AF$$

Where: $a$ = the weighting  
$A$ = maximum possible weighing  
$s$ = frequency of possible weighting  
$F$ = total number of possible weighing

(Source: Adams, 2003; Ashton, 2003)

Finally, the significance indexes ($S_l$) for each factor was analysed and derived by using the following equation:

$$S_l= Importance\ index\ (I_p) \times Frequency\ index\ (F_i)$$

(Source: Adams, 2003; Ashton, 2003)

Having established the importance indices and significance indices for each individual factor of the robust of key decision factors on the use of OSM in house building, a matrix has developed summarising the results.
Table 5-7: Impact of the key factors on decision for using OSM in house building

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<td>18.25</td>
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<tr>
<td>F8</td>
<td>Labour</td>
<td>15</td>
<td>6</td>
<td>21</td>
<td>47, 19, 66</td>
<td>0.293</td>
<td>46.67</td>
<td>13.69</td>
</tr>
<tr>
<td>F9</td>
<td>Productivity</td>
<td>16</td>
<td>5</td>
<td>21</td>
<td>55, 16, 71</td>
<td>0.316</td>
<td>46.67</td>
<td>14.73</td>
</tr>
<tr>
<td>F10</td>
<td>Lack of Space</td>
<td>16</td>
<td>6</td>
<td>22</td>
<td>58, 23, 81</td>
<td>0.360</td>
<td>48.89</td>
<td>17.60</td>
</tr>
<tr>
<td>F11</td>
<td>Safety</td>
<td>12</td>
<td>4</td>
<td>16</td>
<td>36, 11, 47</td>
<td>0.209</td>
<td>35.56</td>
<td>7.43</td>
</tr>
<tr>
<td>F12</td>
<td>Project Complexity</td>
<td>10</td>
<td>3</td>
<td>13</td>
<td>32, 11, 43</td>
<td>0.191</td>
<td>28.89</td>
<td>5.52</td>
</tr>
<tr>
<td>F13</td>
<td>Logistics Issues</td>
<td>12</td>
<td>3</td>
<td>15</td>
<td>33, 7, 40</td>
<td>0.178</td>
<td>33.33</td>
<td>5.93</td>
</tr>
<tr>
<td>F14</td>
<td>Availability of Resources</td>
<td>8</td>
<td>3</td>
<td>11</td>
<td>23, 6, 29</td>
<td>0.129</td>
<td>24.44</td>
<td>3.15</td>
</tr>
<tr>
<td>F15</td>
<td>Planning issues</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td>11, 4, 15</td>
<td>0.067</td>
<td>17.78</td>
<td>1.19</td>
</tr>
<tr>
<td>F16</td>
<td>Market Demand</td>
<td>8</td>
<td>3</td>
<td>11</td>
<td>27, 13, 40</td>
<td>0.178</td>
<td>24.44</td>
<td>4.35</td>
</tr>
</tbody>
</table>

Data analysis of the Key decision factors - OSM

172
Table 5-7 summarises the impact of key factors resulted from the analysis of combined findings of both questionnaires surveys house-builders and case-based precedence projects review. It concluded the importance, frequency and significance indexes of each key factor for measuring the impact of these factors on the decision to use OSM in house building projects. A severity index matrix will be developed using these indices to measure the impact of the key factors on decision, which forms the core of the evaluation methodology of the DSM on whether OSM is the best strategy for a project versus TOS. The establishment of the severity index matrix and measurement methodology are to be detailed in Chapter 7.

The research has established the factors that can have potential influence on decision when considering OSM as a construction strategy for housing projects based on the importance indices of the factors. The data were analysed in terms of importance rating of each theme of factors, namely highly important and moderately important which have potential impact on decision to use OSM as strategy for the construction of housing as shown in Table 5.8.

Table 5-8: The Importance Index of decision factors for using OSM in house building

<table>
<thead>
<tr>
<th>Code</th>
<th>Themes (Key Decision Factors)</th>
<th>Importance</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Time</td>
<td>95.60</td>
<td>Highly Important</td>
</tr>
<tr>
<td>F2</td>
<td>Quality</td>
<td>79.60</td>
<td></td>
</tr>
<tr>
<td>F3</td>
<td>Cost</td>
<td>64.00</td>
<td></td>
</tr>
<tr>
<td>F4</td>
<td>Predictability</td>
<td>44.90</td>
<td></td>
</tr>
<tr>
<td>F5</td>
<td>Interface issues</td>
<td>33.80</td>
<td></td>
</tr>
<tr>
<td>F6</td>
<td>Environment issues</td>
<td>32.40</td>
<td></td>
</tr>
<tr>
<td>F7</td>
<td>Performance</td>
<td>34.20</td>
<td>Moderately Important</td>
</tr>
<tr>
<td>F8</td>
<td>Labour</td>
<td>29.30</td>
<td></td>
</tr>
<tr>
<td>F9</td>
<td>Productivity</td>
<td>31.60</td>
<td></td>
</tr>
<tr>
<td>F10</td>
<td>Lack of space</td>
<td>36.00</td>
<td></td>
</tr>
<tr>
<td>F11</td>
<td>Safety</td>
<td>20.90</td>
<td>Low Important</td>
</tr>
<tr>
<td>F12</td>
<td>Project Complexity</td>
<td>19.10</td>
<td></td>
</tr>
<tr>
<td>F13</td>
<td>Logistics Issues</td>
<td>17.80</td>
<td></td>
</tr>
<tr>
<td>F14</td>
<td>Availability of Resources</td>
<td>12.90</td>
<td>Less Important</td>
</tr>
<tr>
<td>F15</td>
<td>Planning Issues</td>
<td>6.70</td>
<td></td>
</tr>
</tbody>
</table>

Considering the importance values for the 16 key factors, as shown in Table 5-8, the top 10 ranked factors may considerate as the most significant factors with time, quality and
cost being the top most important factors with a clear margin. The other 6 factors are relatively having low/less impact on the decision outcome. However, the order of these factors may change from project to another based upon their significance on decision outcomes, because, each project has its own characteristics and specific requirements.

5.4.4 Overriding Factors for Making Decision to use OSM

Combining the two results obtained from questionnaire surveys house builders (5.2.3) and project cases (5.3.3), both clearly agree that factors of time, quality and cost, are the most overriding factors on the decision to use OSM in housing projects. The house builders also indicated that the predictability and market demand are factors that could not be overlooked. The combined values are showed in figure 5-14.

![Figure 5-14: Overriding Factors for Decision to use OSM](image)

Making successful decision to use OSM may depend upon reliability of these overriding factors. However, these factors and their order may different from project to another, because, each project has its own characteristics and specific requirements.

5.4.5 Stage of Decision Making to use OSM

The use of OSM as a construction strategy should be agreed as early stage in the project process as possible (Gibb, 1999: 51). The research has investigated this issue using questionnaire surveys house builders (5.2.4) and project cases (5.3.4) in order to
establish the most appropriate stage in which making decision to use OSM should be carried out using the RIBA Plan of Work stages.

The results revealed that the inception and/or feasibility stages of RIBA Plan of Work were most suitable stages where decision should take place, as shown in Figure 5-14. The stage of feasibility study stage scored the highest at (53.33%), followed by the inception stage at (31.11%).

![Figure 5-15: Critical stage of making decision to use OSM](image)

Interestingly, all respondents recommended that the decision must be made before the end of the scheme design stage. Majority agreed that it should take place at the feasibility stage when viability studies are being exerted. Where the client has clearly made up his mind to progress with the project at the onset, it is recommended that the decision could even made earlier during the inception stage especially when the project team at that stage are familiar and have some experienced in using OSM systems and the project is not considered novel or complex.

**5.4.6 Decision Maker(s) and Level of Influence for using OSM**

The decision maker is a key component in decision making process, it is therefore not different when comes to choosing between alternative construction strategies to OSM production for optimum outcomes. Decision maker might think and act objectively
using assumed perfect knowledge and understanding of the possible consequences of each strategy.

This research identified who should be involved in the decision making process and the level of influence on the decision to use OSM. The combined findings of the questionnaire surveys: house builders (5.2.5) and project cases (5.3.5) are shown in Figure 5-16.

The results show that client, main contractor and architect are the key project players with greater influence on making decision to use OSM as a construction strategy with indexes as 64, 58.67 and 36.89, respectively. The main contractor is rated higher than the architect suggesting that OSM strategy is more buildability and constructability dependent then on design. The specialist contractors are also rated higher than the project manager (with 28.44 and 27.11, respectively), which further reinforces the idea that OSM strategy is dictated by buildability issues rather than design and clearly indicates that talking the decision at inception stage when that main contractor or the specialist contractors are not yet on board will not produce the optimum outcomes. It is
therefore concluded that the feasibility stage is the most ideal stage to take the decision to use OSM as construction strategy for housing projects. The results also suggest that the key decision is to be made by/between the main contractor, client and the architect. Thus, there is a need to appoint the main contractor at very early stage in order to contribute in making key decisions to use OSM in the housing sector.

5.5 Synthesis

This chapter has looked at the significance of the house builders’ views and opinions on the use of Off-Site Manufacturing (OSM) and the current practice of its use in construction with particular reference to house building, using semi-structured interviews survey in order to address the research question. The chapter has revealed key issues of the decision making process to use OSM for housing projects in four main components. Firstly, it has identified the industry level drivers for using OSM considering the government and industry targets, agenda and benchmarks. It has also provided a body of evidence to suggest that if the key drivers if are understood and applied, it can enhance the use of OSM in house building. The results revealed that technical and economic drivers are highly integrated, followed by environmental, organisational and social drivers. Secondly, the chapter has identified the project level of constraints on the use of OSM in house building. The findings revealed that there is little understanding within the UK house building sector of the system and process of OSM applications, especially, with limited resources to enhance its use in housing projects. The results on drivers and constraints to use OSM have also been highlighted in a number of recent studies of existing literature. Thirdly, the chapter has also established a robust set of 16 themes of key decision factors that have most influence on the decision to use OSM, by investigating the perception and practices of the top house builders on using OSM in construction. In order to quantify and establish the impact of the key decision factors, a further investigation was carried out using questionnaires both house builders and case based precedence projects review surveys. These methods together reveal an overall house builders’ views of the factors’ impact on the decision indicated by frequency, importance and significance indexes for each key factor. Time, quality and cost were established as the overriding factors with greatest influence on decision to use OSM. Finally, the chapter has established the stage of decision making and key project players with greater influence in making decisions to use OSM. The
research suggests that the key decision is made between the main contractor, client and the architect, and the feasibility study is the critical stage for decision to be taken. The results, collectively, provided this research with a wider context of decision making process, all of which need to be considered at the evaluation stage for making a decision to use OSM as a construction strategy for house building projects. The successful outcomes of choosing OSM as an alternative construction strategy depends on the clear identification of the key factors affecting the specific project, the constraints affecting its use, and the knowledge of the decision makers of using the system.

Having undertaken an intensive study addressing the context of decision making to use OSM in house building and key findings have been established, the next phase of the research process is to investigate the impacts of the same 16 key factors on the decision to use Traditional On-Site (TOS) as a construction strategy for house building. This is required for the development of the DSM to enable the evaluation of the alternative decision outcomes (between OSM and TOS).
CHAPTER SIX: FACTORS ASSOCIATED WITH DECISION MAKING PROCESS FOR USING TOS IN CONSTRUCTION OF HOUSING

The aim of this research has been to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between using OSM and TOS Production as a construction strategy for housing projects in the UK.
6.0 Introduction

Having identified and validated a robust set of 16 key decision factors that influence the decision to use OSM for house building projects (5.4.3), this chapter measures the impact of these factors on the same decision but on the perspective of using Traditional Onsite (TOS) as a construction strategy for house building. The aim of this chapter is to measure the importance and significance of the effect of the factors on the decision to use TOS (i.e. not to use OSM). This decision is expected to be taken at the early project stage (stages one and two of RIBA 2013 Plan of Work). The investigation used in this chapter follows the same approach in previous chapter by adopting questionnaire survey and case studies for data collection and analysis within the house building sector. The procedure for the data collection and analysis has been discussed in chapter four.

The chapter is in three sections: firstly, the findings of the questionnaires; and secondly the results and analysis of the case studies. Thirdly the outcomes of the combined findings are presented to establish the importance and significance indexes for the key decision factors associated with the use of TOS as a strategy for the construction of housing projects. The fourth section of the chapter compares the key results and incorporated with the findings discussed in chapter five for final analysis to develop severity index matrix for each of the 16 key decision factors as associated with the two alternative decision outcomes i.e.: to use OSM or to use TOS as a strategy for the construction of housing projects.

6.1 Data Collection and Analysis: Questionnaire – House-builders’ Survey

This section gives an overview of data collection and analysis of the questionnaire survey conducted on the use of TOS in house building. It aims to measure the impact of the established 16 key factors (i.e. using OSM) on the decision to use TOS as a construction strategy for housing projects.

6.1.1 Questionnaire Profile

A postal questionnaire survey was designed based on the findings obtained from OSM study which targeted house builders on the use of TOS in house building and it further explored the impact of the 16 key factors on decision to use TOS. The questionnaire survey can be found in Appendix D. The survey targeted key references of the top 75
UK construction firms’ involved directly in house building projects including clients, project managers, architects contractors and consultants. The identification and selection criteria of the participants have been discussed in chapter four (4.5.2.2).

The questionnaire survey has been designed in a manner to conduct both quantitative data and qualitative data. A total of 33 responses were conducted of the survey with response rate totalled 44%. This rate was unexpectedly high for a construction industry survey (Black et al., 2000). Only 30 responses were included in the analysis of the data that arrived first, simply to make the number to be equivalent to the number of questionnaires that have been considered previously in the data analysis of OSM study (5.2.1). Table 6-1 summaries the details of the responses of the questionnaire survey.

<table>
<thead>
<tr>
<th>Research Participants</th>
<th>Number</th>
<th>TOS – Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client/Developer</td>
<td>8</td>
<td>✓</td>
</tr>
<tr>
<td>Project Manager</td>
<td>7</td>
<td>✓</td>
</tr>
<tr>
<td>Main Contractor</td>
<td>6</td>
<td>✓</td>
</tr>
<tr>
<td>Construction Manager</td>
<td>1</td>
<td>✓</td>
</tr>
<tr>
<td>Architect/Designer</td>
<td>5</td>
<td>✓</td>
</tr>
<tr>
<td>Consultant</td>
<td>2</td>
<td>✓</td>
</tr>
<tr>
<td>Specialist supplier</td>
<td>1</td>
<td>✓</td>
</tr>
</tbody>
</table>

Initially, the 16 key decision factors were measured and their individual level of importance is established. Secondly, the respondents were asked to identify the three overriding factors among the 16 decision factors. The outcomes of the survey helped measured the impact of the 16 factors on the decision making process to use TOS as a construction strategy for housing projects. The levels of effect of these factors on the decision were scored on a five-point Likert scale to calculate the importance and significance indices. The responses and the analysis of the key issues investigated in the survey are discussed in the next sub-sections.

6.1.2 Measuring the Effect of the Decision Factors on the use of TOS

In order to measure and establish the 16 key decision factors, their individual level of importance on the decision to use TOS, the following question has been developed:

*Q: Which of the following key factors influence the decision to use Traditional Onsite (TOS) as a strategy in house building projects?*
Having indicated which factors apply, please score their level of importance on the
decision between (1 – 5), 5 being the most important?

The question has been designed into two parts. The first part was to indicate whether the
16 key factors have an effect on the decision or not by ticking Yes/No of the listed
factors and/or by adding other factors that have not been identified or experienced from
OSM study. Secondly, the indicated factors are then scored on their level of importance
on the decision to use OSM in house building projects. Figure 6-1 shows a sample of
questionnaire survey response on this question highlighted the factors that need be
considered which have different levels of impact on the decision scored on a five-point
Likert scale.

| 1.1 Please identify by ticking Yes/No, which of the following key factors influence the
decision to use of TOS in house building projects? |
| 1.2 Having indicated which factors apply – please score their level of importance on
the decision between (1 – 5), 5 being the most important. |

<table>
<thead>
<tr>
<th></th>
<th>Y</th>
<th>N</th>
<th>N/A</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>☒</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☒</td>
</tr>
<tr>
<td>Quality</td>
<td>☒</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☒</td>
</tr>
<tr>
<td>Cost</td>
<td>☒</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☒</td>
</tr>
<tr>
<td>Predictability</td>
<td>☒</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☒</td>
</tr>
<tr>
<td>Interface Issues</td>
<td>☒</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☒</td>
</tr>
<tr>
<td>Environmental Issues</td>
<td>☒</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☒</td>
</tr>
</tbody>
</table>

Figure 6-1: A sample of questionnaire response

Results revealed that none of the responses indicated any new factors. Therefore, this
has exposed that the established 16 themes of key decision factors are applicable for
evaluating decision outcomes for both strategies to use OSM or to use TOS in house
building.
Table 6-2: Matrix of breakdown of each key decision factor to use TOS – House builders

| Code | Factors             | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | N0. | Frequency |
|------|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| F1   | Time                | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 26  | 86.67 |
| F2   | Quality             | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 18  | 60.00 |
| F3   | Cost                | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 30  | 100.00|
| F4   | Predictability      | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 14  | 46.67 |
| F5   | Interface Issues    | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 10  | 33.33 |
| F6   | Environmental Issues| ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 10  | 33.33 |
| F7   | Performance         | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 12  | 40.00 |
| F8   | Labour              | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 20  | 66.67 |
| F9   | Productivity        | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 14  | 46.67 |
| F10  | Lack of Space       | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 14  | 46.67 |
| F11  | Safety              | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 16  | 53.33 |
| F12  | Project Complexity  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 16  | 53.33 |
| F13  | Logistics Issues    | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 24  | 80.00 |
| F14  | Availability of Resources | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 16  | 53.33 |
| F15  | Planning Issues     | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 6   | 20.00 |
| F16  | Market Demand       | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | ✓  | 5   | 16.67 |
| SUM  |                    | 7  | 8  | 10 | 5  | 7  | 11 | 9  | 9  | 11 | 9  | 11 | 6  | 8  | 9  | 9  | 11 | 9  | 7  | 12 | 10 | 4  | 10 | 7  | 5  | 5  | 7  | 10 | 9  | 9  | 8  | 9  |
| %    |                    | 44 | 50 | 63 | 31 | 44 | 63 | 69 | 56 | 56 | 69 | 38 | 50 | 56 | 56 | 69 | 56 | 44 | 75 | 63 | 25 | 63 | 44 | 31 | 44 | 63 | 56 | 56 | 50 | 56 | 56 | 56 | 56 | 183 |
A detailed breakdown of the 30 responses presented in Table 6-2. The matrix provided the total number of factors, the frequency index and percentage value of each theme of key factors. The percentage value represents the number of factors that were experienced against the total number of possible factors that could have been experienced by each participant on the use of TOS in house building projects. The established frequency indexes will be used for final analysis in order to establish the importance and significance indices for each key factor on the decision to use TOS as a strategy in house building (6.3.1).

Figure 6-2 presents the findings obtained from the preliminary data analysis of this question of the questionnaire survey. The results revealed that the factors of cost, time and logistics issues were highlighted as most influenced factors on decision to use TOS with a score of 100, 86.67 and 80.00, respectively. The factors that follow were labour at (66.67), quality at (60.00), and the factors of safety, project complexity and availability of resources, standing equally at (53.33). The factors of predictability, productivity and lack of space, were equally scored 46.67; followed by performance, interface issues, environmental issues planning issues and market demand factors were scored 40, 33.33, 33.33, 20.00 and 16.67, respectively.

![Figure 6-2: Level of influence of the key factors on decision to use TOS – House builders’ Survey](image)

With reference to the rating scale used, it suggested that the factors scored 50 and above were rated as ‘most significant’ factors with potential influence on the decision to use
TOS as a construction strategy for housing projects. However, this does not mean that the other factors can be ignored, because, each project has its own characteristics and especial requirements. In order to validate the impact of the key decision factors, the research conducted further case studies projects to be investigated.

6.1.3 Overriding Factors for Making Decision to use TOS in House Building

In the similar manner of the OSM questionnaire of House builders’ survey, a question was set to identify the overriding factors among the 16 key factors would their important consider to be on decision outcomes to use TOS in house building.

Q: Are there any overriding factors influencing the decision that determine a house project using Traditional Onsite (TOS) methods?

The data was analysed in terms of the frequency of occurrence and indication of each key factor as shown in Figure 6-3. The majority of the respondents indicated that the factors of cost and time have the most significant influence on decision to use TOS with score of 100 and 90, respectively; followed by the influence of logistics at (76), labour at (62) and quality at (58).

![Figure 6-3: Overriding decision factors to use TOS – House builders’ Survey](image)

The research has therefore established that cost, time, logistics, labour and quality are the overriding factors with steady decline of impact on the decision to use TOS in house building.
building projects. These findings were based on the analytic process of the questionnaire of house builders’ survey. In order to validate these outcomes, the research has conducted further case based precedence projects review to be investigated for the final analysis.

6.2 Data Collection and Analysis: Case-based precedence projects review

This section provides an outline of data collection and analysis of the case based precedence projects review. It aims to validate the impact of the established 16 factors that had on the decision to use TOS as a construction strategy in housing projects.

6.2.1 Project Cases Profile

15 projects based on TOS methods were identified and used as case based precedence review survey. This provided a comprehensive set of information and validates the effect of the 16 key factors on the decision to use TOS in house building projects. This part of the study was targeted 15 project cases in order to be equivalent to the 15 project cases have been conducted in the part of data collection of OSM study (Chapter 5). Each project case has its own characteristics and the overall aim of using a wide range of different projects is to ensure the transferability and generalisability of the results. The selection criteria of these projects have been discussed in details previously in section (4.5.3). A description of the context of the project is given followed by a more in depth description of the factors that have been experienced and being considered at the evaluation stage for decision to use TOS for each project case has been explored. It investigates also the overriding factors experienced among the 16 key factors that have the most significant impact on the decision outcomes to use TOS.

There were at least one or two members of project team participated in the study of each project case with different role in their companies. The participants were clients, developers, project managers, contractors, construction managers and architects with the responsibility of companies making decisions. There were also documents, scheme design information and observation of project provided when possible whilst carrying out each project case. A brief description produced shown that project information, data sources, and participants involved in the study for each project case can be found in
Appendix E. In order to guarantee confidentiality, the names of projects, companies and individuals have been omitted.

The data obtained from the project cases will be combined with the data have been obtained from the questionnaire of house builders’ findings in order to establish the final impact of the key factors on decision to use TOS in house building projects.

### 6.2.2 Validating the Effect of Decision Factors on Decision to use TOS

Having identified the impact of key factors obtained from the questionnaires findings, the research investigates if the indicated factors were occurred and experienced in the selected 15 project cases and their level of impact on the decision outcomes. After studying and reviewing the project documents, key project team members are identified and designed as participants to the research of case based precedence projects review. The participants were asked to indicate the factors that have been considered at the evaluation stage to use TOS as a construction strategy for each project. They were also asked to score the level of impact had each factor has on the decision to use TOS using a five-point Likert scale.

Table 6-3 shows a matrix of the breakdown of the number of occurrence of each key decision factor in the project cases using TOS as a strategy. The frequency of occurrence was calculated using the number of factors that were experienced against the total number of possible factors that could have been experienced in each project case. The frequency of occurrence is to be used for final analysis to calculate the importance and significance indices of the factors in order to measure the impact of each factor on decision to use TOS as a strategy in housing projects.

Similarly, the following function has been used to establish the frequency index:

\[
F_i = 100 \times \left( \frac{s}{F} \right)
\]

*Where:*  
- \( s \) = frequency of possible weighting for each key factor  
- \( F \) = total number of possible factors experienced in each project case.

From the data in the matrix, it is apparent that in these projects, the house builders have considered between 5 to 10 the key factors at the evaluation stage for their decision to use TOS as a construction strategy.
Table 6-3: Matrix of breakdown of each key decision factor to use TOS – *Project Cases*

<table>
<thead>
<tr>
<th>Code</th>
<th>Factors</th>
<th>PC 1</th>
<th>PC 2</th>
<th>PC 3</th>
<th>PC 4</th>
<th>PC 5</th>
<th>PC 6</th>
<th>PC 7</th>
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<th>PC 11</th>
<th>PC 12</th>
<th>PC 13</th>
<th>PC 14</th>
<th>PC 15</th>
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<td>7</td>
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<td>50</td>
<td>50</td>
<td>38</td>
<td>188</td>
<td></td>
</tr>
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</table>
This provided essential information regarding the variability of significance and occurrence from project to project.

The factors identified and their impacts on decision are illustrated graphically as shown in Figure 6-3. With reference to the rating scale used, it suggested that the factors scored 50 and above were rated as ‘highly significant’ factors and 30 to 50 rated as ‘moderate significant’ on the decision to use TOS in housing projects. The results revealed that the factors of cost, time and logistics were as most indicated factors with a significant influence on the decision to use TOS, their frequency indexes standing at 100, 86.67 and 73.33, respectively. The factors that follow are quality and labour, frequency indexes equally standing at (60.00), and safety at (53.33%). Those factors rated ≥ 30 and ≤ 50 are considered as ‘medium/moderate significant’ on the decision to use TOS in housing projects. These factors are predictability, project complexity, resources, interface issues, productivity and lack of space. The other factors are considered as less significant on decision outcomes.

![Figure 6-4: Level of influence of the key factors on decision to use TOS – Project Cases](image)

However, the order and influence of the 16 key factors might change when combined with the findings obtained from the questionnaire survey for the final analysis to establish the final impact of the robust key factors on decision to use TOS.
6.2.3 Overriding Factors for Making Decision to use TOS

The participants in each project case were asked to indicate the most critical factors that would be more important or had overriding consideration on the decision that determined their projects using TOS as a construction strategy. The results were illustrated in Figure 6-5. The data was analysed in terms of the frequency of occurrence for each factor experienced in each project case.

![Figure 6-5: Overriding decision factors to use TOS – Project Cases](image)

Interestingly, the majority of the respondents on the 15 projects indicated the same factors that would be more important or considered critical on the decision to use TOS in house building. The overriding factors were cost, time, labour, logistics and quality that had the highest impact correspondingly on the decisions to use TOS in their projects. The order and impact of these overriding factors might change when combined with the findings of the questionnaire survey for the final analysis (6.3.2).

6.3 The Effect of the key Factors on the Decision to use TOS in House Building

This section gives overall results of the analytic process of combined data obtained from both questionnaires house builders and case based precedence projects review surveys for measuring the effect of the established 16 key factors on the decision to use TOS as
a construction strategy for housing projects. This is discussed in the following sub-
section in details:

6.3.1 Impact of Factors on the Decision to use TOS

The approach of combining different informant from different research sources enabled
the collection of rich data. This enhanced the validity and reliability of the decision
factors. In order to establish an optimum decision strategy, this work required to
measure the impact of the key factors on decision to use TOS as a strategy. This
sections aims to combine the key findings that have been obtained from both 30
questionnaires house builders and 15 project cases review for final analysis in order to
establish the frequency, importance and significance indices for each of the 16 decision
factors.

The frequency index ($F_i$) was derived and established using the following function:

$$F_i = 100 \cdot \sum (s / F)$$

*Where:*

- $s$ = frequency of possible weighting for each factor
- $F$ = total number of possible weighting

A five-point Likert scale was used to rank the impact of each factor on decision in order
to derive importance index and significance indices. Whilst, the importance index ($I_p$)
was derived and established using the following function:

$$I_p = 100 \sum (a \cdot s)/AF$$

*Where:*

- $a$ = the weighting
- $A$ = maximum possible weighting
- $s$ = frequency of possible weighting for each factor
- $F$ = total number of possible weighting could be experienced

Finally, the significance indices ($S_i$) for each factor were derived using the following
equation:

$$S_i = Importance\ index\ (I_p) \cdot Frequency\ index\ (F_i)$$
Table 6-4: Impact of the robust set of factors on decision for using TOS in house building

<table>
<thead>
<tr>
<th>Code</th>
<th>Indicated Factors</th>
<th>House builders</th>
<th>Project Cases</th>
<th>Total (No.)</th>
<th>Importance Index (Ip)</th>
<th>Frequency Index (Fi)</th>
<th>Significance Index (SI)</th>
</tr>
</thead>
<tbody>
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<td>F1</td>
<td>Time</td>
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<td>13</td>
<td>39</td>
<td>0.693</td>
<td>86.67</td>
<td>60.09</td>
</tr>
<tr>
<td>F2</td>
<td>Quality</td>
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<td>27</td>
<td>0.396</td>
<td>60.00</td>
<td>23.73</td>
</tr>
<tr>
<td>F3</td>
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<td>100.00</td>
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</tr>
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<td>20</td>
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<td>12.44</td>
</tr>
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Data analysis of the key decision factors - TOS

Occurrence (a x f)
Table 6-4 summarises the impact of key factors resulted from the analysis of combined findings of both questionnaires house builders and case based precedence projects review surveys. It concluded the frequency, importance and significance indices of each factor for measuring the impact of these factors on decision to use TOS. The order of the key factors in the matrix was set according to the order that have been allocated in the matrix of the impact of those factors to use OSM (Table 5-5). This was needed to simplify the handling and modelling of the key factors to use TOS in house building. A severity index matrix will be developed (6.5.2) using the frequency, importance and significance indices of these factors, which forms the core of the evaluation methodology of the Decision Support Model (DSM). The development of the severity index matrix is detailed in chapter 7.

This work has also established the impact of the key factors on the decision to use TOS based on the importance indices for each factor namely: highly important, moderately important, usually importance and less impotence. Table 6-5 shows the factors that have potential impact and less impact on decision to use TOS as strategy for the construction of housing.

Table 6-5: The impact of the decision factors on using TOS in house building

<table>
<thead>
<tr>
<th>Code</th>
<th>Themes (key decision factors)</th>
<th>Importance</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3</td>
<td>Cost</td>
<td>93.38</td>
<td>Highly Importance</td>
</tr>
<tr>
<td>F1</td>
<td>Time</td>
<td>69.30</td>
<td></td>
</tr>
<tr>
<td>F13</td>
<td>Logistics Issues</td>
<td>52.00</td>
<td></td>
</tr>
<tr>
<td>F11</td>
<td>Safety</td>
<td>41.80</td>
<td></td>
</tr>
<tr>
<td>F2</td>
<td>Quality</td>
<td>39.60</td>
<td></td>
</tr>
<tr>
<td>F8</td>
<td>Labour</td>
<td>35.10</td>
<td></td>
</tr>
<tr>
<td>F4</td>
<td>Predictability</td>
<td>28.00</td>
<td>Moderately Importance</td>
</tr>
<tr>
<td>F12</td>
<td>Project Complexity</td>
<td>27.60</td>
<td></td>
</tr>
<tr>
<td>F9</td>
<td>Productivity</td>
<td>27.10</td>
<td></td>
</tr>
<tr>
<td>F14</td>
<td>Availability of Resources</td>
<td>26.70</td>
<td></td>
</tr>
<tr>
<td>F10</td>
<td>Lack of space</td>
<td>26.20</td>
<td></td>
</tr>
<tr>
<td>F15</td>
<td>Interface Issues</td>
<td>23.60</td>
<td></td>
</tr>
<tr>
<td>F7</td>
<td>Performance</td>
<td>19.60</td>
<td></td>
</tr>
<tr>
<td>F15</td>
<td>Planning Issues</td>
<td>19.10</td>
<td></td>
</tr>
<tr>
<td>F6</td>
<td>Environment Issues</td>
<td>18.70</td>
<td></td>
</tr>
<tr>
<td>F16</td>
<td>Market Demand</td>
<td>14.70</td>
<td>Less Importance</td>
</tr>
</tbody>
</table>

193
Based on the importance values of the 16 key factors, the top 11 ranked factors may be considered as the most significant factors with cost, time, and logistics issues being the top most important factors on the decision with a clear margin. However, the other 5 factors with ‘low impact’ and ‘less impact’ may not be ignored at the evaluation stage for decision to use TOS, because, each project has its own specific requirements and priorities to achieve which is decided by the key decision makers.

6.3.2 Overriding Factors for Decision Making to use TOS

The results were drawn from combined findings of both questionnaires surveys: house builders (6.1.3) and project cases review (6.2.3) and presented in terms of the frequency of occurrence for each key factor as shown in Figure 6-4. Interestingly, both questionnaires and project case review investigations were identified the same overriding factors; however, they were slightly different in order.

![Figure 6-6: Impact of Overriding decision factors to use TOS in house building](image)

The combined values revealed that cost, time and logistics issues are the overriding factors with greater influence on the decision to use TOS as a strategy for house building projects; followed by the influence of labour and quality factors. The research suggests that the overriding factors are the key importance serve as basic requirements
for the house builders for decision outcomes. Therefore, making successful decision to use TOS may depend upon reliability of these overriding factors which need to be considered carefully at the evaluation stage.

### 6.4 Comparing the Impact of the key Factors on Decision to use OSM versus TOS in House Building

This section provides a summary of comparison analysis of the key results of Traditional On-Site (TOS) study and incorporated with the findings of Off-Site Manufacturing (OSM) study discussed in chapter 5. It aims at providing a better understanding of the impact of key factors as associated with the two alternative decision outcomes i.e.: to use OSM or to use TOS as a construction strategy for housing projects.

#### 6.4.1 The Impact of key Factors on the Decision to use TOS vs. OSM

When comparing the two results gained from OSM and TOS studies, it can be seen that there were significant differences in the impact order of the 16 key factors on decision to use TOS (Table 6-5) in contrast with the impact order of these factors conducted using OSM study (Table 5-8). The factors of cost, time and logistics have the highest impact order on the decision to use TOS, in contrast the factors that have the most significant impact order on the decision to use OSM were identified as time, quality and cost.

The quality factor is usually an importance issue and it is among the key construction management indicators; however, its impact on decision to use TOS not that high as the impact on decision to use OSM. Another factor with major difference impacts on decision outcomes was logistics issues factor of both strategies. It was identified among the highest impact factors on decision to use TOS in contrast with the use of OSM it has lower impact ‘usually important’ on decision outcomes. In addition, the market demand was identified as the factor with lowest impact on decision outcomes to use TOS, however, it located among the category with factors that their impacts rated ‘usually importance’ on decision outcomes to use OSM. This indicates that the established 16 key factors have different impacts on decision when considering to use OSM or to use
TOS as a strategy for house building, depending upon project characteristics, priorities and specific requirements.

6.4.2 The Impact of Overriding Factors on the Decision to use TOS vs. OSM

Comparing with the results of OSM study, it can be seen that the top three overriding factors with the highest impact on decision to use TOS were identified cost, time and logistics issues, while to use OSM were established as time, quality and cost.

There is a clear drop margin between the top three overriding factors and the other indicated two factors of predictability and marked demand to use OSM, while a steady decline with the impact of the fourth and fifth factors on decision to use TOS as shown in Figure 6-7.

The factor of quality was indicated among the overriding factors for both strategies but with significant difference of the impact on decision in the order of these factors. Therefore, the overriding factors have different impacts on decision whether to use OSM or TOS production. This can also demonstrate that the established key overriding factors are the key inputs which need to be considered carefully at the evaluation stage for decision on whether to use TOS or OSM production as strategy for house building projects.
6.5 Mapping the Impact of the key Decision Factors

In order to establish a mechanism for measuring the impact of the factors on decision association with decision making process to use Off-Site Manufacturing (OSM) versus Traditional On-Site (TOS), a severity indices matrix needs to be developed using these factors. The next sub-sections are addressing the establishment and development of severity indices matrix of the factors:

6.5.1 Establishing the Severity Indices of the Factors

The research has established a robust set of decision factors; the factors that should be considered and deemed appropriate when evaluating a decision on whether to use OSM or TOS as a strategy for the construction of house building projects. The proceeding chapters have concluded the key findings of the analytic process of data conducted from the OSM study and TOS study in the context of house building.

Chapter five has described the identification and categorisation of the sixteen themes of decision factors occur when considering to use OSM in the construction of housing projects using semi-structured interviews survey. These factors were then validated and established the impact of the factors on decision to use OSM as a construction strategy for housing, using both questionnaire surveys: house builders and case based precedence projects review. The importance and significance indices of the factors on decision to use OSM have been established. In addition, the current chapter has also illustrated the validation and establishment of the impact of these factors on decision to use TOS in house building. The validation and establishment of the impact of the factors were employed questionnaire surveys house builders and case based precedence projects review. The importance and significance indices of the factors on decision to use TOS have been established.

Severity indices of the impact of the factors on decision were established using the importance and significance indices of both ‘OSM’ and ‘TOS’ studies. As the importance indices were used to generate the significance indices (5.4.3 and 6.3.1); the severity indexes were calculated using only the significance indices of the factors. The difference between the significance indices of both OSM and TOS for each factor is the severity index of the impact on decision. Having established the severity indices of the
all 16 decision factors, the severity values were indicated in a Severity Index Matrix (SIM). If the value of severity index of a factor is positive (≥ 0) then decision is favour to use OSM as a strategy. However, if the value indicated negative (≤ 0) this means the decision is favour of using TOS as a strategy for a given project.

In some cases, the importance indices can be also used as a comparison tool versus the significance indices to identify the impact of a particular factor on decision. The deference between the importance indices of both OSM and TOS for each factor has been considered in the matrix. The decision maker may need to go back to check the impact and interrelationship of the severity indices of the importance of some factors on decision, if the value of severity index of a factor is equal zero (= 0) or about. Thus, if the importance index value of OSM is greater than the value of TOS then the decision should be favour of using OSM. Otherwise, the decision should be favour of using TOS if the severity index of the importance was greater than the value of OSM of a particular factor in the matrix. The Severity Index Matrix (SIM) presents in the next sub-section.

6.5.2 Presentation of the Severity Index Matrix

The Severity Index Matrix (SIM) has been developed and presented on Microsoft Excel spread sheet. It gives a summary of all information of the decision factors which derived the second data of the severity indices for each factor of the sixteen themes. This has provided an illustration of the interrelationship and impact of the importance and significance of the factors on decision on whether to use OSM or TOS production as a strategy for house building projects. The SIM is required for the development of the ultimately research aim – the Decision Support Model (DSM). It was deemed that the DSM model would be presented in simple format in order to make it applicable and acceptable by the house builders within industry.

The establishment of the severity indices was the first stage in which used in the development of the methodology of the DSM that measures the impact of the factors on decision outcomes. The severity index matrix has concluded the main data source which is needed for the comparison and evaluation process of choosing between the two strategies of construction for a given project for ease of understanding and comprehension. This provides a means of measuring the impact of the factors that need to be considered in practice based upon the characteristics of house building projects. The Severity Index Matrix (SIM) of the key factors that have most significant influence
on decision on whether to use OSM or TOS as a strategy for house building projects presented in Figure 6-8.

The SIM matrix can be found in Appendix H; at the evaluation stage of the effected factors for a project which took their severity values derived from the SIM and plotted them on the DSM for the final appraised to deliver the decision outcomes with recommended strategy to use for a given project. This stage is discussed in more detailed at stages of developing the DSM in the next section.
DECISION FACTORS OSM vs. TOS
Time
SI
OSM

Diff

Quality
Ip

TOS

OSM

Diff

SI
TOS

OSM

Diff

SI

Ip
TOS

OSM

Predictability

Cost

Diff

TOS

OSM

Diff

Ip
TOS

OSM

Diff

SI
TOS

OSM

Diff

Ip
TOS

OSM

Factors
Interface Issues

Diff

SI
TOS

OSM

Diff

Ip
TOS

OSM

Performance

Environmental Issues

Diff

SI
TOS

OSM

Diff

Ip
TOS

OSM

Diff

SI
TOS

OSM

Diff

Labour
Ip

TOS

OSM

Diff

SI
TOS

OSM

Diff

Significance
OSM

TOS

Importance
OSM

TOS

Severity Indices
SI

Ip

Ip
TOS

OSM

Diff

TOS

%
100

95.56

95.56

93.78
93.78

90

26.22

80

35.47

-29.78

79.56
-41.16

72.48

70

69.33
60.09

60

64.00

40.00

50

52.62

48.75

40

44.89

16.89

39.56

30

27.93

33.78

15.49

20

23.73

32.44

34.22

10.22

28.00
16.51
8.66

12.44

13.78

23.56
16.58

29.33
19.56

18.67

-5.78

95.56

60.09

72.48

23.73

48.75

Cost

52.62

93.78

-41.16

Predictability

27.93

12.44

15.49

Interface Issues

16.51

7.85

8.66

Environmental Issues

16.58

5.81

10.78

Performance

18.25

6.95

11.30

Labour

13.69

22.63

-8.94

Productivity

14.73

11.45

3.28

Lack of Space

17.60

11.07

6.53

Safety

7.43

22.28

-14.85

35.47

Project Complexity

5.52

13.47

-7.95

Logistics Issues

5.93

40.44

-34.52

Availability of Resources

3.15

13.04

-9.89

Planning issues

1.19

4.25

-3.06

Market Demand

4.35

2.61

1.74

22.63
-8.94

18.25

10.78

7.85

10

35.11
14.67

Time
Quality

11.30
5.81

13.69
6.95

0

Lack of Space

Productivity
SI
OSM

Diff

SI

Ip
TOS

OSM

Diff

TOS

OSM

Diff

Safety
Ip

TOS

OSM

Diff

TOS

OSM

Diff

Ip
TOS

Logistics Issues

Project Complxity

SI
OSM

Diff

Ip

SI
TOS

OSM

Diff

TOS

OSM

Diff

SI
TOS

OSM

Diff

TOS

OSM

Planning Issues

Avalability of Resources
Ip
Diff

SI
TOS

OSM

Diff

SI

Ip
TOS

OSM

Diff

TOS

OSM

Diff

Market Demand
Ip

TOS

OSM

Diff

SI
TOS

OSM

Diff

Ip
TOS

OSM

Diff

TOS

%
100

90

80

70

60

52.00

50

41.78

40

40.44

36.00
31.56

30

9.78

4.44

-20.89

26.22

-34.22

27.11
22.28
17.60
14.73

3.28

11.45

-8.44

20.89

-14.85

6.53

13.47

-34.52

69.33

26.22

39.56

40.00

Cost

64.00

93.78

-29.78

Predictability

44.89

28.00

16.89

Interface Issues

33.78

23.56

10.22

Environmental Issues

32.44

18.67

13.78

Performance

34.22

19.56

14.67

Labour

29.33

35.11

-5.78

Productivity

31.56

27.11

4.44

Lack of Space

36.00

26.22

9.78

Safety

20.89

41.78

-20.89

Project Complexity

19.11

27.56

-8.44

Logistics Issues

17.78

52.00

-34.22

Availability of Resources

12.89

26.67

-13.78

Planning issues

6.67

19.11

-12.44

Market Demand

17.78

14.67

3.11

19.11

26.67
-13.78

17.78

-7.95

11.07
7.43

13.04

5.52

5.93

0

TOS - Traditional On-Site

Diff - Difference

PI - Importance Index

17.78
-12.44

12.89

-9.89
3.15

OSM - Off-Site Manufacturing

95.56
79.56

27.56

20

10

Time
Quality

19.11

14.67

6.67
1.19

-3.06

4.25

SI - Significance Index

Figure 6-8: Comparison of the Impact of Overriding factors to use TOS vs. OSM

200

3.11

4.35

1.74

2.61

TOTAL

373.51

351.89

576.44

562.67

21.62

13.78


6.6 Synthesis

The present chapter focuses on the second part of the primary data collection and analysis. Having established and validated the 16 key factors on decision to use OSM in housing projects, this chapter has validated and measured the impact of the 16 key factors on the decision to use TOS as a strategy for house building projects. This has been achieved by analysing data obtained from questionnaires surveys 30 house builders and 15 case based precedence projects review. The results revealed that there is no any additional new factor found beyond the established 16 factors that have been identified from the OSM study. However, these factors have had different impacts on the decision from strategy to strategy. Therefore, this has enhanced the validity and reliability of the established 16 key factors that can now be used for the evaluation of the decision on whether to use OSM or TOS as a construction strategy for housing projects. The chapter has also established the frequency, importance and significance indices of the factors. The overriding factors among the key decision factors have also been established as: cost, time, logistic issues, labour and quality. A comparison of the impact of the 16 key factors and the overriding factors with the same findings to use OSM (Chapter 5) has discussed. The established 16 key factors have different impacts on the decision outcome when to use OSM from the impacts when considering to use TOS as a strategy. The top three overriding factors also have been established as: time, quality and cost with greater influence on the decision to use OSM, while to use TOS as: cost, time and logistics. Thus, it is clearly that the factors of quality and logistics are key indicators and may have the greatest influence on the decision outcome which need to be considered carefully at the evaluation stage.

Having established the impact of the 16 key factors on the decision to use TOS in house building, the final part of the chapter has provided a severity index of each factor, using their importance and significance indices of both OSM and TOS. The severity indices can be used as a means of measuring the impact of each factor on the decision to use OSM against the implication of TOS as a strategy for the construction of housing projects. The severity index matrix will be used as a tool or as part of the development of new proposed Decision Support Model (DSM), which is addressed in the next chapter having followed a classical scientific methodology.
CHAPTER SEVEN: THE DEVELOPMENT OF DECISION SUPPORT MODEL (DSM)

The aim of this research has been to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between using OSM and TOS Production as a construction strategy for housing projects in the UK.
7.0 Introduction

The primary aim of this research has been to investigate the research problems and establish a research question, in order to prove an aim and objectives to answer the question. The research question was: Why is the uptake of Off-Site Manufacturing (OSM) as a construction strategy in house building limited? Knowledge gaps were refined and a Gap in the Knowledge immerged as the single most significant factor in addressing the research question which was this research established that there was still a need for a specific decision support tool based on robust decision factors that evaluate the use of OSM against TOS production as a strategy for the construction of house building. The aim of this thesis, therefore, has been to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between Off-Site Manufacturing (OSM) or Traditional On-Site (TOS) production as a construction strategy for housing projects in the UK.

This chapter presents the development of the DSM. The results obtained from the primary and secondary data analysis discussed in the previous chapters, a Severity Index Matrix (SIM) of the key decision factors is established. An evaluation methodology of the effect of the key decision factors on the decision outcome has been developed, which forms the basis upon which the DSM is developed. The DSM model provides a reliable system that can be used in practice at the early project stage to structure the decision making process and improve the quality of information on which the decision is based. The chapter also presents the validation of the model by testing it on a number of case studies using on-going house building projects at their pre-construction stages. The chapter is made into three parts: initially, the development of the DSM model, secondly testing and validation of the model, and finally discussion of the outcomes of the testing and validation of the model.

7.1 Development of Decision Support Model (DSM)

The objective of this research has been to fill in the gap of knowledge identified in chapter one (1.2) by developing a robust decision making mechanism that can be used
in practice at the very early project stage. This section presents the basis and foundations of the development of the new proposed Decision Support Model (DSM).

7.1.1 Development of Conceptual Model of the DSM

The proposed conceptual model is made up of four major processes as outlined in Figure 7-1. The four processes were identified by this research whilst analysing range of data and information obtained from the UK house builders conducted through using interviews, questionnaires and case based precedence project review techniques for data collection.

![Decision Support Model (DSM) Process](image)

Figure 7-1: Conceptual model of the DSM

The model starts with the identification of the project factors that can have the greatest effect on final decision outcomes at strategic planning level of a project. It draws from evaluating the client's statement of need, brief development and project scheme. It involved basically the identification of project priorities based upon its characteristics and project teams’ interests. The British Standards Institution (2006) states that typically client’s requirements are offer related to the benefits sought from the project (e.g. return on investment, payback period, etc.), the functional requirements expected of the product, and the timetable for delivery of the product. In addition, there are other requirements of other project stakeholders’ interests. Including the end users that decision makers need to consider and establish precisely what these are to fully establish the project priorities needed to deliver the project. The next process involves measuring the impact of the sixteen themes of key factors on the established project priorities. The third process is the evaluation of the decision outcomes based upon a well-developed evaluation methodology. The process box four involved the development of a mechanism to compare whether to use OSM or TOS production.
strategies based on predictable outcomes against any given project within its environment.

7.1.2 Development of Template of the DSM Model

The Decision Support Model (DSM) has been designed to be used in practice to guide the choice of a construction strategy for project during the evaluation stage of decision at pre-project phase. The new proposed ‘DSM’ is house builders’ decision process model. It aims to provide a structured and transparent approach for decision making process in order to assist them in making decisions on whether to use OSM or TOS as a construction strategy based on evaluating a number of key factors that have most influence on project characteristics and specific requirements. The model is proposed for use at early pre-project phase by key project team members within their organisational context for housing projects within its environment.

The conceptual model showed in Figure 7-1 has been adopted and viewed from a project-wide perspective, specific requirements and a suitable decision making strategy to optimise its use in the context of house building. In addition to offering an improved process for decision making in the practical model, the conceptual model has been the DSM also has transformed to comprise of four main phases: Factors Selection Matrix, Evaluation Priorities Matrix and Decision Making outcomes.

The four phases drive the process for identifying an optimum decision strategy which involves careful selection, evaluation and measurement of the key factors that have most influence on decision outcomes i.e. to use OSM or to use TOS as a strategy for housing projects. In order to place the conceptual model in practical format, the research adopted the use of Microsoft Excel, Paired Wise-Comparison, Occurrence Indexes, Frequency Indexes and Quant Indexes. The developed template of the Decision Support Model (DSM) is shown in Figure 7-2, which is based upon the established 16 key decision factors and their impacts on decision outcomes. The template of the DSM is provided in a big-scale in Appendix I.
### THE DECISION SUPPORT MODEL (DSM)

#### PHASE 1: DECISION FACTORS SELECTION MATRIX

<table>
<thead>
<tr>
<th>Factor Code</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
<th>P</th>
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<tr>
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<td>12</td>
<td>15</td>
<td>8</td>
<td>3</td>
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<td>8</td>
<td>6</td>
<td>9</td>
<td>11</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Frequency (Fi)</td>
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<td>75.0</td>
<td>93.8</td>
<td>50.0</td>
<td>18.8</td>
<td>56.3</td>
<td>43.8</td>
<td>12.5</td>
<td>12.5</td>
<td>50.0</td>
<td>37.5</td>
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<td>68.8</td>
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<td>31.3</td>
<td>6.3</td>
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<td>Ranking (Ri)</td>
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<td>F3</td>
<td>F1</td>
<td>F7</td>
<td>F13</td>
<td>F5</td>
<td>F9</td>
<td>F14</td>
<td>F15</td>
<td>F8</td>
<td>F10</td>
<td>F6</td>
<td>F4</td>
<td>F11</td>
<td>F12</td>
<td>F16</td>
</tr>
</tbody>
</table>

#### PHASE 2: DECISION EVALUATION MATRIX

**TOP 10 RATED FACTORS FOR PROJECT**

<table>
<thead>
<tr>
<th>Factor Code</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severity Index</td>
<td>±</td>
<td>Quant Index</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>High Important</td>
<td>Decision based on the Top 5 factors</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F2</td>
<td>High Important</td>
<td>Decision based on the Top 6 factors</td>
<td></td>
<td></td>
<td></td>
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#### PHASE 3: EVALUATION PRIORITIES MATRIX

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#### PHASE 4: DECISION MAKING OUTCOMES

**NUMBER OF FACTORS CONSIDERED**

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<td>F1</td>
<td>F7</td>
<td>F13</td>
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<td>F6</td>
<td>F4</td>
<td>F11</td>
<td>F12</td>
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Figure 7-2: Decision Support Model (DSM)
The four phases of the DSM model are detailed in practice by showing an example of the evaluation process of decision of real housing project data to guide the choice of a construction strategy on whether to use OSM or TOS production. Figure 7-3 presents the results of the decision evaluation process of the project using the new proposed DSM model. The four phases of the DSM application model is explained as follows:

**Phase 1 - Decision Selection Matrix**

The DSM begins in phase one with the evaluation of client’s statement of need and the outcome of brief development, in order to identify project priorities and desirable outcomes for the project. The project priorities need to be set and named according to the established 16 key decision factors (labelled A to P) that need to be considered based upon their significance on the project. This phase is the only stage that the user or decision maker inputs data into the model. The user should study the project and identify the priority issues that impact on the perceived project success and place these into the established 16 key decision factors (i.e. A: Time, B: Quality, C: Cost, D: Predictability, etc.). It may be argued that these factors may have been subjectively determined at the initial stages in a projects life-cycle. For example in our Fig 1-2 considers that these factors should have been considered and written within the ‘Outline Feasibility (PPM) or Preparation & Briefing stage (RIBA). Ultimately, when the user imports their ‘subjective’ project priorities into the Decision Support Model (DSM), only now can the model enable them to fully appreciate the impact and choice of those earlier project goals, hence the essence of this research work.

Each project has specific requirements and the factors that have a significant influence on decision for projects not necessarily to have the same impact on another project. The 16 key decision factors in the model are being ‘neutral’ and equally weighted, in order not to add or put an extra influence on the choice and priorities of the factors that have importance effects of project.

This research also recognises the simplicity and exclusion of interdependency, inference or interaction of the factors, however, the research took careful consideration and effort to reduce the effect of ‘double-counting’ and believes a robust data set that helped design and develop the DSM model does not skew its use.
As shown in the Figure 7-3, the user will then evaluate these factors by using the Paired-Wise-Comparison for each two variables of the 16 themes. Each box in this matrix represents a question phrased “in this project which is more important to you as a decision maker to meet the client’s need or towards achieving the desired project outcomes?” and the user is to type in the box the code of the factor that adds greater value to the project depended upon its set priorities. This means that each single factor is to be evaluated against the other 15 factors in the decision factors selection matrix.

For instance, the factor of ‘time’ is to be evaluated versus the other 15 factors in the matrix and the user is to type in the boxes of ‘column A’ the code of the factor with perceived or measured greater value to the project. Likewise, the second factor of ‘quality’ is to be evaluated versus the other 14 factors not including ‘time’ because it has already been compared against each other in the previous process. The outcomes of this are to be typed in the boxes of ‘column B’ of the matrix. Similarly, this process is to be carried out for the rest of the factors till the end of the matrix; although, each single evaluation process will be reduced by one factor serially.
Figure 7-3: The application of the Decision Support Model (DSM)
This research has identified that the contractor, client and architect are the key decision makers among the project team with significant influence on decision and contributions to decision making process in house building. Therefore, this research resolved that this phase of the model should be conducted together by the three members as a team. Otherwise, it should be completed separately by each member, but then the lead party or in-charge/key player compiles the separate input and complete the process by using ‘simple majority’ from the three evaluations for each key factor. One important perspective is that the research has identified that the main contractor is key in decision making process; therefore, the contractor must be involved in project as early as possible. In house building, buildability is the key issue in the construction process, which means that the key player should be the contractor who has the greatest influence on the decision making process for an optimum decision outcomes.

**Phase 2 – Evaluation Priorities Matrix**

The second phase focuses on the evaluation of the project priorities as shown in Figure 7-3 which breakdown into three sub-stages to generate the occurrence, frequency and ranking indices of the 16 key decision factors. Firstly, establishing the number of times (occurrence) each factor is selected against each other using the codes typed in the Decision Factors Selection Matrix in phase one. The occurrence indices \( O_i \) are automatically generated using the following function:

\[
O_i = \sum (a \times f)
\]

*Where:*

\[a = \text{weighting} = 1 \text{ (since each factor is presently assumed to be equally weighted)}\]

\[f = \text{number of times the factor is considered superior.}\]

Table 7-1 presents the occurrence indices of the sixteen factors in the evaluation priorities matrix.
Table 7-1: Occurrence index for priorities factors of project

<table>
<thead>
<tr>
<th>Evaluation Priorities Matrix</th>
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<tbody>
<tr>
<td>Factor Code</td>
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<tr>
<td>Occurrence (Oi)</td>
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</table>

Secondly, the number of occurrence indices used to calculate frequency indices of each factor. Table 7-2 presents the frequency indices (Fi) derived automatically using the equation as follows:

\[ Fi = 100 \times \sum \left( \frac{Oi}{F} \right) \]

Where:

\( Oi \) = Occurrence index of each factor

\( F \) = total number of possible factors

Table 7-2: Frequency Index for priorities factors of project

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<tr>
<th>Evaluation Priorities Matrix</th>
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<tbody>
<tr>
<td>Factor Code</td>
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<tr>
<td>Occurrence (Oi)</td>
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<tr>
<td>Frequency (%)</td>
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</tbody>
</table>

Thirdly, the Ranking (Ri) is simply the ranking of the priorities factors based upon their relative significance which is automatically generated using the values of the frequency indices. This ranking system puts in order of significance of the factors that can have the most influence on the decision outcomes using F1 to F16 ranking scale; where F1 is given to the factor with the highest value of Ri, through to F16 being the lowest ranked factor as shown in Table 7-3.
Table 7-3: Ranking index for the priorities factors of project

| Factor Code | A  | B  | C  | D  | E  | F  | G  | H  | I  | J  | K  | L  | M  | N  | O  | P  |
|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Occurrence (Oi) | 9  | 14 | 10 | 8  | 8  | 5  | 9  | 1  | 10 | 1  | 11 | 5  | 4  | 3  | 10 | 12 |
| Frequency (%)  | 56.3 | 87.5 | 62.5 | 50.0 | 50.0 | 31.3 | 56.3 | 6.3 | 62.5 | 6.3 | 68.8 | 31.3 | 25.0 | 18.8 | 62.5 | 75.0 |
| Ranking (Ri)   | F7 | F1 | F4 | F9 | F10 | F11 | F8 | F15 | F5 | F16 | F3 | F12 | F13 | F14 | F6 | F2 |

In this example, the highest ranked factor has most influence on decision is the quality which ranked as F1, followed with the factor of market demand (F2) then the factor of safety (F3). However, lack of space factor ranked as the lowest influence on decision which ranked as F16. Having determined the most appropriate factors based upon their ranking of significance (F1 to F16) on project, the priority of these factors were established. In case there were two factors or more that have the same values, then the rating system will automatically rank these factors based on the order that was set of the established 16 key decision factors order of their significant. The detailed calculation and ranking process of these factors can be found in Appendix J.

Phase 3 – Decision Evaluation Matrix

Using the example shown in Table 7-3, the Decision Evaluation Matrix takes the top ten ranked factors after careful consideration of the overall significance of the chosen factors. This means that there seems to be relatively less important effect of the last 6 factors on the desired project outcome therefore they can arguably be discarded.

One of the key contributions of this research project was the establishment of Severity Index values and Importance Index values for each of the sixteen themes of decision factors. Using these values, the established severity index will then be recorded for each of the 10 selected factors in column four of the Decision Evaluation Matrix. The Quant index \( (Q_i) \) is calculated using the difference between the severity indices of both Off-Site Manufacturing (OSM) and Traditional On-Site (TOS) (shown in the fifth column of the matrix). The corresponding Quant index value for each factor is simply the Quant index of the previous top factor plus the severity index value of the factor (the Quant
index of first factor F1 is equal to its Severity index value). The sixth column will automatically indicate the decision to use ‘OSM’ if the corresponding Quant index \(Q_i\) value is greater than or equal zero \((\geq 0)\) i.e. +ve value. In contrast to this, the decision is to use ‘TOS’ at any factor if its corresponding value is less than zero \(<0\) or if the value is simply a negative \((-ve)\) value.

At this stage the DSM guides the choice of construction strategy (OSM vs. TOS) to point of given project, then the decision maker has the greater influence for making the final decision based on the evaluation outcomes.

**Phase 4 – Decision Making Outcomes**

Where the outcome for each factor is indicating the clear and unambiguous use of a particular OSM vs. TOS method, the decision is straightforward. Where there is both –ve and +ve Quant values against various factors, the user or decision maker has an essential role in arriving at the final decision, in that he/she will be required to use his/her experiences and knowledge on the particular project drivers to decide upon which or how many factors are to be considered. Whilst it could be argued that this final decision is subjective in nature, this research has enable even at this late stage to guide the decision maker so that this is not simply a gut feel, but, rather a quantified ‘rated’ system from which to choose from.

In the example shown in Figure 7-5, if the decision maker chose a cut-off point on the list of considered factors at any one of the following factors, the recommended decision would be to use ‘OSM’: F1, F2, F3, F7, F8, F9 and F10. However, if for instance he/she chose to consider only the top 4 or top 5 or even top 6 factors, the recommended decision would be to use ‘TOS’. In this case study project, the decision maker chose to use top 7 factors, therefore the recommended decision is to use ‘OSM’ with a Quant index value of 30.16. This means that the recommended decision will be always influenced by the number of factors to be considered since it is based upon the Quant index value of the inclusion at the final factor chosen.

It is important that if any factor that the decision maker considers as a project priority fails to appear amongst the top 10 it means that there must have been an error in the input of data at the first phase of the DSM. In such a case, the user/decision maker may
need to go back to the first phase of the model to review his/her input data, in order to make sure that the decision based on the right project priorities and willing outcomes.

As part of the final outcome of the DSM, it essential that the key decision maker(s) should establish a report that includes the reasons and their arguments of chosen number of those specific top factors which the decision has been based on. The report can be enclosed to the project scheme for further referencing and feedback for future projects.

### 7.2 Testing and Validation of the DSM

In order to test and validate the model, four live case study projects at their planning stage were analysed. These case studies were selected using the same selection criteria that were used for the original case studies during the model development stage. All available project data provided was used to carry out the DSM testing exercise for each case study. Absolute access to all case study scheme data provided a unique opportunity to evaluate the project characteristics based on desired outcomes and client’s statement of need. The application of the DSM model was absolutely operated by one of project team participants of each case study to complete the exercise. The participants were project managers, clients, main contractors and architects who were involved in decision making for selecting a construction strategy for their housing projects. This also gave the opportunity to assess the friendliness of the user-interface of the model.

Each of the test case studies is discussed as follows:

#### 7.2.1 Case Study A: AS-Project

The case study referred to as AS-P was a new housing development and comprises 51 residential units (one, two and three bedrooms apartments). The project located in an extremely busy city centre with restricted site layout due to listed adjacent building from one side and heritage/historic elements attached to another building from another side. There is also underground train line crossing under one angle of the building site. The testing was carried out during project planning stage. The client and project manager were the participants who were involved in the testing process of the model in this case study. Based on the project scheme, the project manager stated that the main project priorities and objectives to achieve are as follows:
- Ensuring the project completion is certain due to highly market demand in the area.
- Quality of internal and external finishes to be met.
- Total cost within +/- 10 percent of initial budget set of the project.

These requirements indicated that factors of time and predictability of quality and cost along with market demand were the key issues that can have a greater influence on decision. The project team stated also that factors of safety of labour and environmental issues must be considered governed by the industry regulations and CDM. The issue of labour and the lack of space are concerns for the contractor more than the client; however, it is important and should be considered for overall project outcomes. In addition, due to restricted site layout and project location, the factors of planning and logistic issues took in account as well. All these factors were therefore considered carefully during the evaluation stage of the model of identifying the factors with the most effect on decision outcomes on whether to use OSM or TOS production.

Based on the evaluation process of the DSM model, the decision arrived at is to use ‘OSM’ production as a construction strategy for this project. This was based on deliberation and the inclusion of the top 8 factors. These factors were time, quality, cost, predictability, market demand, project complexity, planning issues and safety. This case study provided overwhelming evidence to suggest the recommendation to use OSM. The information and results of the evaluation process of the DSM model illustrated in Figure 7-4.
## PHASE 1: DECISION FACTORS SELECTION MATRIX

<table>
<thead>
<tr>
<th>Factor Code</th>
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<th>C</th>
<th>D</th>
<th>E</th>
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### PHASE 2: EVALUATION PRIORITIES MATRIX

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- B: 13
- C: 12
- D: 11
- E: 3
- F: 4
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#### Frequency of Each Factor
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- C: 75.0
- D: 68.8
- E: 18.8
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#### Top 10 Rated Factors for Project

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### PHASE 3: DECISION EVALUATION MATRIX

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### PHASE 4: DECISION MAKING OUTCOMES

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</table>

### REPORT:

**Figure 7-4: Testing and analysis of the case study AS-Project**
7.2.2 Case Study B: MR-Project

The MR-P was a residential development and comprises 48 units one, two and three bedroom flats. This project is in central city location with very restricted site layout. The site is facing onto a busy street from one side and adjacent to mixed use buildings (retail and offices) at both sides. In addition, two blocks residential use was adjacent to the site from the back side. There were two major issues of concerns to the project team. First concern was traffic management issues (e.g. delivery) and second concern was site crane issues (e.g. swing distance/range) during the construction phase of the project.

The testing of the model took place at the planning stage of this case study. There was the contractor and project manager involved in testing process of the model in this case study. All available project data was used to carry out the DSM testing exercise and to identify the key desirable objectives of the project team to achieve. These objectives are identified as the following:

- Achieving predictability of quality level.
- Early occupation and return on investment.
- Overall project cost is certainty.
- Meeting planning conditions and neighborhood issues.
- Meeting CDM requirements.

These requirements can indicated that the factors of quality, early occupation due to market demand, cost, planning issues and safety of labour and public were the top priorities to be through this project. Thus, these factors should play key role at the evaluation of identifying the most effected factors on decision outcome when inserting data into the DSM model.

The assessment of whether to use OSM or TOS as a construction strategy, the DSM indicated the use of ‘TOS’ production was recommended based on the inclusion of the top 6 factors. The factors that the project team considered as top priorities which have most influence on the project outcomes. These factors were quality, market demand, cost, productivity, safety and planning issues which confirmed to use TOS as a construction strategy for this project. The information and decision outcome of the evaluation process of the DSM model are shown in Figure 7-5.
### THE DECISION SUPPORT MODEL (DSM)

**Phase 1: Decision Factors Selection Matrix**

<table>
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<tr>
<th>Factor Code</th>
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<td>F4</td>
<td>F16</td>
<td>F5</td>
<td>F12</td>
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</table>

**Phase 2: Evaluation Priorities Matrix**

- **A. Time**
- **B. Quality**
- **C. Cost**
- **D. Predictability**
- **E. Interface Issues**
- **F. Environmental Issues**
- **G. Performance**
- **H. Labour**
- **I. Lack of Space**
- **J. Project Complexity**
- **K. Logistics Issues**
- **L. Project Complexity**
- **M. Logistics Issues**
- **N. Availability of Resources**
- **O. Planning Issues**
- **P. Market Demand**

**Phase 2: Decision Evaluation Matrix**

<table>
<thead>
<tr>
<th>TOP 10 RATED FACTORS FOR PROJECT</th>
<th>Severity Index</th>
<th>± Quant Index</th>
<th>DECISION</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1. Quality</td>
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<td>+ve (OSM)</td>
<td>Decision based on the Top 5 factors</td>
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<tr>
<td>F2. Market Demand</td>
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<td>TOS</td>
</tr>
<tr>
<td>F3. Cost</td>
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<td>-ve (TOS)</td>
<td>Decision based on the Top 8 factors</td>
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<td>F4. Productivity</td>
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<td>F6. Planning Issues</td>
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<td>F7. Environmental Issues</td>
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<td>F8. Performance</td>
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<td>F10. Interface Issues</td>
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<td>+ve (OSM)</td>
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**Phase 4: Decision Making Outcomes**

- **Number of Factors Considered**: Top 6 factors
- **Recommended Construction Strategy**: Traditional On-Site (TOS)
- **Date**: 22/05/2013
- **Decision Maker/ User**: Contractor

---

Figure 7-5: Testing and analysis of the case study MR-Project
7.2.3 Case Study C: FR-Project

The third case study FR-P was housing development containing 13 units of three and four bedroom homes. The project is located close to central location in an open area adjacent to a park which can be used as additional storage space during the construction. The main contractor and architect were the participants of this project. The DSM model was operated by them till the end of deriving the decision outcome on whether to use OSM or TOS. The testing took place during the planning stage of the project. There were a number of issues identified that the project team was aiming to achieve through this project. These are listed as follows:

- New developed area and demand quite high.
- Minimizing overall project duration.
- Meeting planning authorities’ requirements.
- Reducing multi-trade interface issues due to restricted work area.

There requirements highlighted that market demand, time, planning issues and interface issues were the overriding factors for the project that need to be considered carefully versus the other factors into the matrix of the first phase of the DSM model. The project team participants were involved into assessing each single factor versus the other factors (paired-wise comparison) before inserting the code of the factors into the matrix of the model. This process was in order to identify the most significance factors for the project outcomes. In this particular case study, the DSM model indicated to recommend ‘OSM’ as construction strategy based on deliberation and the inclusion of the top 10 factors. The project specific requirements identified above can be met in the top 6 factors and the decision also indicated to use OSM. However, predictability of quality and cost are essential of a construction project, therefore, the project team agreed to consider all the top 10 factors in which the DSM was also indicated to use OSM as a construction strategy. Even though, the DSM model indicated to use TOS at the inclusion of factors F7, F8 and F9. As mentioned earlier (7.3.2), the decision maker has absolutely the full control over the decision by choosing how many factors of the top 10 that would be most critical and add value to overall project outcomes. Figure 7-6 presents the information and results of the DSM model of the evaluation process of the decision outcome.
Figure 7-6: Testing and analysis of the case study FR-Project
7.2.4 Case Study D: CH-Project

The fourth case study CH-P was a housing development project of four blocks of total 124 units mixed of one, two and three bedroom apartments. The development is located in quiet part of city location with less restricted site. There is an open air car parking adjacent to the site which can be used part of it as temporary site offices and addition storage area during the construction operation. The participants of the project team were the client, project manager and architect who involved in the testing process of this case study. From the reviewing process of the project brief, statement of needs and scheme design, the project team identified a number of key project requirements. These are as follows:

- Concerns the quality of end project.
- Ensuring project overall cost is certainty.
- Safety of workers construction onsite.
- Minimising environmental impacts of surrounding area.

These requirements seem to be most desirable issues for the project team were seeking to achieve of the project. Thus, time, quality, cost, safety and environment issues were the factors that have most effect on decision of the evaluation process of the DSM. all the team members were involved into assessing each single factor versus the other factors (which is more important for project) before inserting its code into the matrix of the first stage of the model.

Based on the evaluation process of the DSM model, the decision indicated to use ‘OSM’ as a construction strategy for the project. This is based on deliberation and the inclusion of all to the top 10 factors that considered and have most influence impact on decision outcome on whether to use OSM or TOS production. These factors were safety, time, quality, cost, interface issues, environmental issues, productivity, labour, performance and predictability. The project team confirmed to consider the recommended strategy ‘OSM’ for the construction this project. The information and decision outcomes of the evaluation process of DSM model are shown in Figure 7-7.
### THE DECISION SUPPORT MODEL (DEM)

#### PHASE 2: DECISION EVALUATION MATRIX

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<th>TOP 10 RATED FACTORS FOR PROJECT</th>
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<th>DECISION</th>
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Decision based on the Top 5 factors.

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(Occurrence of Each Factor Code in the Matrix)

(Frequency [%] of Each Factor)

(F1 to F16, Where F1 being the Highest Rate & F16 the Lowest Rate)

#### PHASE 4: DECISION MAKING OUTCOMES

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<td>01/08/2013</td>
</tr>
<tr>
<td>DECISION MAKER / USER</td>
<td>CONTRACTOR</td>
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### REPORT:

Figure 7-7: Testing and analysis of the case study CH-Project
7.3 Discussion of the Decision Support Model (DSM)

This section provides the testing outcomes of the validation of the DSM and the house builders’ feedback obtained whilst conducting the test process on the four case studies. The data validated included the current decision making procedures, reviewing the DSM and the decision outcomes.

7.3.1 Participants for the Validation Process

To validate of the DSM by using current decision makers in the house building industry, four housing companies and housing associations were used in this research phase. All four companies had used both OSM and TOS production in their projects. One case study from each company was selected which were available at the time of the validation stage. Each project case was also subjected to meet the criteria of case study selection which was set in the research methodology chapter (4.4.3.2 & 4.6.2). All the participants or representatives of the four case studies were senior managers including clients, project managers, main contractors and architects who were involved in decision making for selecting a construction strategy for their housing projects.

7.3.2 Current Decision Making Approach

The procedures of validation were carried out using interviews and project document analysis. First of all, the four companies had used both strategies (OSM and TOS) within their companies’ projects in the last 5 years. Secondly, all of them mainly relied upon heuristic decision-making, cost compression, drawing on individual experience and intuition, informal team discussion, relaying on past project data and feedback, and sometimes gut feel.

In this sense, one of major clients indicated that usually decisions made based on cost implication using comparison methods with repeated or similar projects. Another reason was indicated is that decisions made sometimes based upon the availability of resources. For instance, two clients indicated that currently working with seven major contractors and they are more familiar with TOS methods, therefore, as clients or developers cannot risk to use other methods. Even though, both clients are keen to use OSM as a strategy in their project rather than only use OSM products particularly pods for wet areas and services rooms in housing projects. In addition, architect of one of the case studies was very dedicated and optimistic to use OSM as construction strategy for the project. His
decision to use OSM is that there are number of on-going housing projects using variety of offsite systems in the area of our project. Again the decision was made based upon subjective evidence rather than evaluation of adequate project data. Each project must have had its own characteristics and it is not necessary to be common on other projects.

However, none of the four companies had used any formal decision support systems that can provide them some assistance to guide the choice between alternative production strategies. Three of them indicated that in such big or complicated projects, they seek further support from external management consultants to help with making decisions. Thus, there remains a lack of knowledge regarding to decision making process of choosing a construction strategy between OSM and TOS production within the industry at least among those practitioners being involved in the validation process. The house builders are therefore still making their decisions based on subjective evidence and reputations rather than practical reasons and data for current project. This is due to lack of reliable guidance and decision support systems available and used within the industry.

These findings seems to agree with the findings of existing literature regarding the decision making process used within the industry particularly in house building. It acknowledges that decision making process used to evaluate the use of OSM as a strategy within the construction industry is poorly understood is based on subjective evidence rather than reliable industry data (Blismas and Wakefield, 2009). There is no clear evaluation methodology to enhance its use in house building (Meling and Sandberg, 2009), is inadequate and complex (Ozorbon, 2013). There is also a lack of understanding how to compare offsite production appropriately with traditional construction methods (Pan et al., 2012b). This is due to lack of trust in the evaluation methods to choose a construction strategy between alternative construction methods (Pan et al., 2012a). Several decision support systems and evaluation techniques have been used in the UK construction industry, however, it appears that only few are being used and their use is often questioned by construction professionals. This led to lack of confidence of the existing decision support systems and their measurement methodology among housing practitioners for evaluating the use of OSM as alternative construction method for house building. Consequently, the use of OSM remains limited and lower than anticipated in the UK house building (Buildoffsite, 2012; Rahman,
2014; Zhai, et al., 2014). Therefore, this has emphasise the demand within the industry for a systematic and affective evaluation tool for selection of a construction strategy to use OSM as alternative construction to TOS for house building.

7.3.3 House Builders Review and Characteristics of the DSM

Overall feedback provided by the house builders concluded that the model works well and found to be simple to use and user-friendly. It also minimises the time and the quantity of data required by the user to complete the exercise of the evaluation and recommended decision outcome. Although, the question surrounding the availability of the DSM model within the industry is that: What is the difference between the existing models and the new proposed model? What are the potential benefits of using this model? How can this benefit the housing sector? To address these questions, a summary provided in the discussion points as follows:

- The DSM has been developed based upon house builders’ data and established robust set of decision factors that need to be considered and appropriate for evaluating decisions of using OSM or TOS production as a construction strategy. This means that the DSM is not applicable for making decisions between other types or systems of construction.

- The DSM model can be used in practice to structure the decision making process, improve the quality of information on which the decision is based, and provide the opportunity to assist practitioners in making decisions based on appropriate and adequate data within the project environment.

- The DSM identified the project priorities based upon its characteristics that need to be considered in order of significance on decision outcomes to make the choice between OSM and TOS production. It provides a reliable means of measuring the impact of the priority factors on whether to use OSM versus TOS production. The process quantified the outcomes of the evaluation process of project characteristics based on the established key factors. A methodology has been developed to measure and evaluate the top effected factors, which forms the core of the DSM.

- One of major feature of the model is that the decision maker retains overall control of the decision making process based on the critical priorities for a given project.
This feature has been uniquely embedded with developed DSM approach. The existing systems and models usually take over full control for making the final choice between possible options.

- Whilst the DSM has deliberately relegated the financial benefits or implications of choosing between OSM versus TOS; it acknowledges Latham, (1994); Egan, (1998); Construction Excellence, (2006); Government Construction Strategy, (2011); and recently Gibb and Waterman, (2013), which have all highlighted the need for the reduction of cost of construction. This research although has not use the cost as measurement tool because it is not easy to get answer related to project cost questions in the first place and if so unlikely to be right figures. It is easily to find out more information and right figures about other project aspects for instance time, waste, materials, logistics, etc. This research has established with robust source data and information that OSM reduces materials waste, it reduces time of construction, and it reduces labour activities on construction site and therefore production onsite. It also identifies the benefits that OSM can provide regarding quality and consistency of construction. This research further suggests that many of these issues could lead to a reduction in the overall cost of construction; however, this reduction is subject to individual stakeholders involved in each unique project.

The new proposed model needs to be user friendly interface. Thus, the DSM was simply developed using Microsoft Excel Programme package. This programme was chosen for the following reasons and characteristics:

- Availability and free package in most public and private computers.
- Easy and well knowing to use among the industry practitioners.
- Ability of use different formulas and build up new equations suite the purpose.
- Save time and ability to calculate enormous data and information in a few seconds from different spread sheets data.
- Very adequate results and it has been used in many different applications addressing decision making issues within the construction industry.
- Capability to use it with other compatible computer programmes if necessary.
7.3.4 Limitations of the DSM

As the new proposed model has a number of advantages and features of its use and operation, also it may raise limitations of its application in a wider industry context. This section discusses the limitations of the application of the DSM model.

- The new proposed DSM has been designed for making a decision on whether to use OSM or to use TOS as a strategy and it is mainly applicable to housing sector and may or may not necessarily be applicable to other sectors within the construction industry. This is because the context of the study was scoped only to house building and the model was developed using data and information gathered from the house builders.

- The DSM has been developed based on UK house building within the construction industry, this means that the framework may be applicable elsewhere but the weighting of the key factors not necessarily to be applicable in other countries. It suggested that every country has its own construction industry culture and characteristics include: different building regulations and standards from the ones used in the UK to meet and different requirements and targets from the UK to be achieved to satisfy their government, industry and people’s specific need.

7.4 Conclusion - Decision Support Model (DSM)

The purpose of this chapter was to present the development process and the validation of the Decision Support Model (DSM) and ultimately provide a mechanism to help address the research question. This model was developed using the culmination of an extensive literature review, primary data gathering and collected from interviews, questionnaires and the review of projects case-based precedence in the construction industry with particular reference to house building. This model now provides a formal method to be used by making decision to choose between OSM and TOS production within the industry, this work was developed the DSM through two main aspects. Firstly, the work has established a robust set of sixteen key decision factors that need to be considered and established of their respective Severity Indices Matrix (SIM). The SIM maps the importance and the significance or the impact of these factors on decision to use OSM and TOS production on successful delivery of the house building-
type projects. Secondly, the work has developed a methodology to measure and rank the factors according to their significance on decision. The DSM for making decision on whether to use OSM or TOS production as a strategy is made up of major four phases. These are the phases of identifying project factors to measure, evaluating of project priorities, decision evaluation and making the decision. The DSM functions by taking factors that have most influence on the project, and then measure and rank each of these factors by regarding their significance on the decision whether to use OSM against TOS production as a construction strategy. The project decision outcome is quantified based upon the evaluation and inclusion of top priority factors for project.

Four case studies were analysed in order to validate the model and test its applicability in practice. The testing has been carried out on real life construction housing projects that are of different scales and different project conditions. The key aim was to identify whether there were any problems concerning the workings of the model. Each case study had different project priorities on which the decision was based and the results provided overwhelming evidence to suggest that the model is able to produce a clear recommendation on whether to use OSM or TOS production as construction strategy for any housing project.

The chapter has also discussed the overall view of the house builders involved in the validation of the DSM model. It was concluded that the model works well and found to be simple to use and user-friendly and it minimises the time and the quantity of data required by the user to complete the exercise of the evaluation. The DSM model therefore can be used in practice to structure the decision making process, and improve the quality of information on which the decision is based. It provides the opportunity to assist the construction practitioners in making decisions based on appropriate and adequate data within the project environment. Obtaining the right construction strategy impacts greatly on the probability of achieving project success and best fits with the project goals. The next chapter presents the conclusions and recommendations for future work that is vital for improving decision making process and the application of DSM in house building projects.
CHAPTER EIGHT: CONCLUSION

8.0 Introduction

This research has established that the use of Off-Site Manufacturing (OSM) has the potential to address some of the key Government and industry demands for the construction industry (1.1) to improve. The use of Off-Site Manufacturing in house building is limited due to a poor understanding of the decision making process to use an alternative construction strategy from Traditional On-Site (TOS) methods. This chapter concludes the research work addressing the research problem, knowledge gaps and research question in this thesis aim. It highlights the key findings and outcomes throughout the research stages obtained following the development and testing of the new developed Decision Support Model (DSM). It highlights the implications of the study from a theoretical and practical aspect, while examining the limitations of the study. The contributions the study makes to body of knowledge and publications have been cited. Recommendations for future work defined in this research also have been established in the chapter. The main research aim and contribution to knowledge of the study has been the development of the DSM with its associated methodology to measure the impact of key factors on decision whether to use Off-Site Manufacturing (OSM) or Traditional On-Site (TOS) for a project which forms the core of the DSM. The primary objective of the DSM model has been to provide a reliable system that could be used in practise at the early project stage to structure the decision making process and improve the quality of information on which the decision has been based upon.

8.1 Addressing the Research Question

The primary research question has been: Why the uptake of using Off-Site Manufacturing (OSM) systems in house building is limited? The research emphasised that the use of OSM systems in construction of housing could significantly help to deal with the current challenges facing the industry, but uptake is weak due to poor understanding of the decision making process and the lack of a standardised methodology involved to optimise its use.
The successful completion of Decision Support Model (DSM) that incorporated the research findings obtained from both secondary and primary studies has provided the housing industry with a robust practical model that can assist practitioners in making the decision to use OSM versus TOS as a strategy in house building projects. The model has provided a reliable guide and also transforms the decision to use OSM from ‘subjectivity’ bases to more ‘practical and objectivity’ judgements for any given project within its environment. It has been developed based on an optimum approach which involved careful understanding, measurement and evaluation of a number of practical decision factors that can have the most influence on the alternative decision outcomes.

Considering the potential of using OSM in construction, the DSM will enhance and optimise the use of OSM systems in place of TOS methods in house building projects. This potential will be realised in the UK’s construction industry when its use become widespread across the house building sector.

8.2 Work Accomplished

The importance of this research is that the use of OSM in house building projects has the potential to contribute to some of the key challenges facing the UK’s construction industry. These challenges include: reduce CO₂ emission, reduce environmental impacts, reduce overall project duration, improve the rate of housing supply, reduce defects in new housing, reduce accidents on construction sites, minimise overall project costs, and improve building performance.

These concerns are often associated with Traditional Onsite (TOS) methods; this research has confirmed the concerns that TOS methods have struggled to meet these demands with the current understanding of its management processes. There is therefore an increasing pressure on the industry’s practitioners to improve efficiency and processes of making decisions to address some of these challenges facing the construction industry. This has driven the industry to review its operations and seek other ways of improving its management process by adopting more innovative and manufacturing technologies particularly in constructing homes. This research concurs with others suggesting that the use of OSM systems could contribute to achieving
government and industry targets. However, in order to achieve the seeking improvements, the decision for using OSM systems needs to be better understood.

At a very initial research stage, the research problem has been identified to stem out from the findings and the decision making process for using Off-Site Manufacturing (OSM) as a strategy in construction. It set the tone about the emphasis and relevance of the use of OSM systems in construction. However, one major issue and key challenge facing the industry’s practitioners was the subjectivity associated with the decision making process to use Off-Site Manufacturing (OSM) or Traditional On-Site (TOS) forms of construction in house building. A conference paper has been published with the key findings of the initial study (Elnaas et al., 2009).

The research project went on to reveal the potential of using Off-Site Manufacturing (OSM) in construction, with particular reference to house building. The manufactured technologies in factory environment have been established as a significant contributor to the continuous improvement of the construction of housing. The application of OSM systems in housing projects can be used as part of a strategy to speed up onsite activities, reduce labour onsite with its attendant costs, reduce the concern with skills shortages, improve the quality of new homes, and reduce environmental impacts on construction sites.

Another key finding of the research project was that the current use of OSM systems remains lower than anticipated in house building due to key challenges that are facing the construction industry particularly in house building. These challenges were identified (1.1.1) to include increasing the demand and supply rate of new housing; capacity of house builders and suppliers; projected skills shortages within the construction; Government and industry policy context of using offsite technologies in construction; and lack of understanding the decision making process to use OSM in the context of house building by many of those involved in the construction process. Other challenges results from the variability of OSM systems, lack of sufficient information, and inadequate decision support systems in place to assist the practitioners in making decision to select the most appropriate construction strategy between using OSM or TOS for house building projects.
This research had to investigate the adequacy of the current decision support systems used in the construction industry to evaluate the use of OSM in house building. There are a number of different existing modelling techniques, ranging from simulation type models through to qualitative and conceptual models. Each of these models has a range of applications in the construction industry; unfortunately they are not fully appreciated by the industry’s practitioners to assist them in making decision to use OSM in house building. Another shortcoming is that all existing decision support systems are not based on a robust decision making methodology and are based on subjectivity or gut feel of the decision maker. This challenge becomes more evident from interviews survey carried out with practitioners within the housing sector. They all agreed to support that there were no reliable mechanism or robust decision making system designed to meet their needs for assessing whether to use OSM over TOS production to enhance their house building projects. This results in many house builders simply using traditional construction of their projects just for familiarity reasons and not as a result of any reliable evaluation process or assessing between alternative strategies for construction.

To sum up, there is potential to use OSM in house building projects and opportunities to address some of the key challenges facing the UK construction industry, however, the uptake is weak in house building due to poor understanding of decision making process and methodology to optimise its use. In order to achieve its potential in house building, the decision to use OSM needs to be better understood. This gap in knowledge was driven by the industry’s benchmarks, government agenda, and levels of sophistications and limitation of the existing decision support models and systems used in the house building industry. This provides sufficient evidence to support the need for a better understanding of decision making process and to develop a new decision evaluation model or system to assist construction practitioners to make decisions between alternative construction strategies (e.g. to use OSM or to use TOS) for house building projects.

The Decision Support Model (DSM) could help housing practitioners make decisions on whether to use OSM or TOS based upon the most appropriate construction method, based on specific project criteria.
Furthermore, there are six publications have been derived from this study to date including conferences and journal papers as shown in Appendix K. These publications have helped the knowledge contributions of this research to be distributed across the industry and academic domain.

8.3 Review of the Research Aim, Objectives and Methodology

In order to address the gap in knowledge and research questions associated with the current use of OSM in house building, the aim of this research has been to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between using Off-Site Manufacturing (OSM) and Traditional Onsite (TOS) production as a construction strategy for house building projects in the UK. The DSM is expected to provide a structured decision making process and integrate subjective judgements that are critical for making the right decision between alternative construction strategies. The research achieves its aim by completing the five objectives set out in the introduction chapter (1.4). The methodology was chosen to determine the research data and information required for achieving the aim and its objectives. The objectives have been undertaken using various research methods appropriate for each objective to collect the required data. Mixed research methods were employed for primary data collection and analysis using both qualitative and quantitative approaches guided by an extensive literature review. With reference to the outline of the objectives provided in section (1.6), as summary of how these objectives were met is discussed as follows:

The first objective was to investigate the issues, characteristics, terms and considerations of using Off-Site Manufacturing (OSM) systems in the construction industry. To achieve this objective an extensive literature review was employed to review the current knowledge and practices identified in previous research regarding OSM systems used in the construction industry. Firstly, the research reviewed definitions for the term OSM and its classifications in order to establish an adoptable definition of the term OSM (2.1). Secondly, background of the applications of OSM systems in construction and other industries and countries has been provided (2.2). Thirdly, the research identified the advantages and disadvantages of using OSM systems in house building (2.3). It further reveals the current state of using OSM in construction with particular reference to house building and identified the drivers and
constraints to using OSM (2.4). This preparatory work was required to enable a formed
the foundation upon which the study of the decision and decision making process to use
OSM in construction could be undertaken. It also enabled the identification of the
potential of using OSM systems in construction with particular reference to house
building.

The second objective was to identify and review existing decision making systems used
in the UK construction industry. Initially, this objective was achieved through an in
depth literature review of the concept of decision and decision making in general terms
(3.1 and 3.2), followed by in-depth-review of making decisions to use in construction
(3.3). The research has demonstrated the need for a better understanding of the decision
making process to arrive at a decision to use OSM as a construction strategy. Secondly,
the study investigated the existing decision support systems and models currently used
in the construction industry that helps practitioners in taking the decision to use OSM
systems in construction. Thirdly, an in-depth investigation of sophistication and
usability of the various decision techniques and evaluation methodologies has been
carried out regard to making decisions to use OSM (3.4). The research has identified a
need for a new tool to help measure and evaluate decision to use OSM as a strategy for
housing projects. This stage helped to identify the gap in current knowledge of existing
decision evaluation systems and models.

The third objective of the research was to identify the process, drivers, factors,
problems and constraints associated with current decision making methods and
procedures used in the determination of using Off-Site Manufacturing (OSM) in the UK
house building. A combination of literature review and interviews survey was used to
achieve this objective. It provides full understanding of the current decision making
process to use OSM in house building. Firstly, the research revealed the key drivers and
constraints to OSM; followed by the identification of key factors affecting the decision
making that need to be considered at early project stage for using OSM as strategy in
construction. Secondly, the research established a robust set of 16 themes of key factors
that have the most influence on the decision to use OSM in house building.

Achieving this objective has provided a clear picture of the current practices of
construction practitioners with a specific reference to decision making process to use
OSM in the context of house building. The application of OSM in house building can be
used as part of a strategy to speed up onsite activities with associated costs and provide a high quality end product. Time, cost and quality were established as the overriding factors that have the highest impact on the decision to use OSM in housing projects.

The fourth objective was to establish the components and measure the impact of the key factors used at the project evaluation stage for effective decision to use Off-Site Manufacturing (OSM) as a construction strategy for house building projects. Whilst the 16 (themes) key decision factors have been identified, the study carried out a further investigation to quantify the impact of these factors using questionnaires both house builders and case based precedence projects review surveys. Firstly, the research investigated the perception and practices of the top house builders in using OSM. A robust quantifying of the impacts of the key factors on the decision to use OSM in house building has been developed (5.2). Secondly, case based precedence review were used to validate the findings using selected housing projects (5.3). These two activities produced a ranking of the importance among the 16 key factors and established the impact of combined data for each individual factor on decision to use OSM. The most critical overriding factors and the ideal stage for taking the decision established, and also the key decision makers that need to be involved in the decision making process (5.4.3). It is important to note that the order and impact of the key factors may change from one project to another, because, each project has its own characteristics and specific requirements.

The fifth objective was to measure the impacts of the key factors on decision to use Traditional On-Site (TOS) as a construction strategy for house building projects. Similarly, the impact of the established 16 key factors on the decision to use TOS as a construction strategy for housing projects has been investigated through the combination of questionnaires both house builders (6.1) and case based precedence projects review (6.2) surveys. By combining the two obtained data, the impact for each individual factor on decision to use TOS has been established (6.3). The findings were compared with the impact of the 16 key factors on the decision to use OSM (6.4), the severity indices of the impact for each individual factor on the decision has been established (6.5).

The final objective was to develop and test the theoretical decision model for choosing between Off-Site Manufacturing (OSM) and Traditional On-Site (TOS) as a
construction strategy for house building projects. The research has provided a conceptual model made up of four major processes, as shown in Figure 7-1, which was derived from the literature search and the analysis of the data and information obtained from the interviews, questionnaires, and project cases review. The conceptual model has been transferred into a practical application model (Figure 7-2) that can be applied in practice to achieve the overall research aim (i.e., to develop a Decision Support Model (DSM) that can be used in practice to guide the choice between OSM and TOS production as a construction strategy for housing projects in the UK).

To sum up, the initial objectives of the research set out in the introductory chapter (1.4) has been achieved successfully throughout the outlined research methodology. Completion of the research objectives marked practical contributions that are needed to incorporate to the achievement of the research aim and the development of a DSM that can be used in practice.

8.4 Contributions of the Study

Since there is currently no formal method or decision support system used for making decisions on whether to use Off-Site Manufacturing (OSM) or Traditional On-Site (TOS) for house building, this research developed a new decision support model to fill the gap. In doing this, a significant and original contribution to knowledge has been made. The developed and tested new proposed Decision Support Model (DSM) would enable to assist and guide the housing practitioners in making decisions on whether to use OSM or TOS as a construction strategy for house building projects in the UK.

This research has made a significant contribution in three aspects to current knowledge: Firstly, this research project has established a robust set of 16 key decision factors that need to be considered at the evaluation stage and their impacts on the decision whether to use OSM or TOS production as a strategy in house building. Secondly, the research has developed a Severity Index Matrix (SIM) that maps up the impact of each key factor on the decision outcomes (6.5). Thirdly, the research has developed a measurement and evaluation methodology that forms the core of the model. By incorporating the measurement system into the evaluation model, the template of the DSM has been developed (7.1.2).
The DSM functions by taking the key factors that need to be considered and have most influence on the project, and then measure and rank each of those factors based upon their significance and project specific requirements; followed by an evaluation of the potential of their impact on the decision outcomes using their severity index values. The project decision outcome is quantified based upon the evaluation and inclusion of top priority factors being considered for project.

Other contributions of the study include the fact that the research has established the ideal project stage of decision making and the key project players with greater influence on the decision process and outcomes in house building (5.4.5 and 5.4.6). The research resolved that the DSM should be operated and conducted together by the main contractor, client and the architect; and the feasibility study is the critical stage for decision to be taken in order to maximise the benefit of project outcomes.

The significance of the contribution to knowledge is in the awareness and the increase in confidence in the use of OSM for house building which will consequently improve the uptake and result in reduction in CO₂ emission, project duration, defects, environmental impacts, and accidents. It may improve house supply, improve building performance and address some of the Government’s and industry’s targets.

To sum up, the DSM satisfies a clear need identified in both the literature and throughout the interviews process for a way to make decision to use OSM or TOS (i.e. None OSM systems) as a construction strategy in house building projects.

8.5 Practical Implication of the Study

This section provides a brief discussion of the implementation of Decision Support Model (DSM) and its practical implication. The new proposed DSM is house builders’ decision process model aimed to provide a structured mechanism to help think through decision process and support subjective judgements that are critical for making the right decision between possible alternative strategies.

The developed DSM enables this to be realised at the same time ensuring the output of the model clearly ascertain the benefits to be added. It is deliberately made clear and uncomplicated (Meling and Sandberg, 2009; Ozorbon, 2013), and based on reliable data
(Blismas and Wakefield, 2009). It also based on rational, robust and balanced decision criteria (Pan et al., 2008b), and based on an evaluation methodology to choose a construction strategy between alternative construction methods (Pan et al., 2012a). The DSM provides a reliable system that can be used in practice to guide the choice at the early project stage, to structure decision making process and improve the quality of information required on which the decision is based. Thus, it provides the end users with a user friendly interface to assist them in making decision on whether to use OSM or TOS as a construction strategy in house building based on adequate data against any given project within its environment.

The DSM has provided an optimum decision strategy which involves careful selection, measurement and evaluation of the key factors that have most influence on the decision outcomes i.e. use OSM or use TOS as a strategy. To be effective, the DSM must be used in the way in which it is intended, as a system to evaluate and guide the choice of decision outcomes i.e. to use OSM or to use TOS at pre-project phase for house building projects.

8.6 Limitations of the Study

This section outlines a number of important limitations of the study that need to be considered.

- The study may raise limitations of its application in a wider industry context. The research has been designed to guide the choice and evaluate the decision on whether to use OSM or to use TOS as a construction strategy. The research is not specifically integrated or designed to evaluate the decision to choose a specific building system be it an OSM or TOS type.

- The established key decision factors and their impacts on the decision outcomes have been identified from the UK house building sector, thus, they are not necessarily to be applicable to evaluate decisions out of this extent such as in other sectors within the UK construction industry, other UK’s industries or other countries. As each sector, industry or country has its own specific nature, characteristics and requirements.
• The DSM has been developed based on UK house building context; this means that the framework may not be applicable elsewhere to evaluate decisions in other sectors within the UK construction industry.

These limitations need to be acknowledged for the implementation of this study and for carrying on further research.

8.7 Conclusion

The difficulty of making decisions is one of the biggest barriers facing the house builders especially when it comes to choose between alternative construction strategies (i.e. to use OSM or to use TOS) at an early stage in the project; often due to the variability of risks and uncertainty associated within each stage of project life cycle. The final decision required that is a key which suits all the parties involved in the construction process of a project. This may depend upon the identification of client’s need, project specific requirements, and its stakeholder’s interests, and understanding of required information and process for making such key decisions. The availability of the right decision support system is a key that can be used to assist the construction practitioners in making decision between alternative strategies.

Despite this evidence, no formal decision support system currently exists by which the decision to choose between OSM and TOS production can be assessed within the industry. In the early project stage also there is not usually enough quantitative data and information of project, thus, decisions are taken based heavily on subjectivity and gut feel of the decision maker. Other key issues with significant influence on the decision are knowledge of the decision maker with the system, and timing of decision to be taken. This work has aimed at developing such a mechanism of decision making process to replace subjectivity with objectivity basis of making decision to use OSM in housing projects. Thus, the aim of this research has been to develop a Decision Support Model (DSM) to be used in practice to guide the choice on whether to use OSM or TOS as a construction strategy, which has been achieved within identified limitations. It has been achieved through successful completion of the research objectives identified. Significant contribution to knowledge has been made in the area of understanding decision making process and knowledge of decision support systems.
The DSM has been developed incorporated the research findings that provides the housing industry with a robust practical model through that can be used to assist the practitioners in making decision to use OSM or to use TOS as a construction strategy in housing projects. The initial model has been developed using Microsoft Excel software base into its own standalone software package carrying an evaluation and appraisal process into its phases. It provides a clear structure for decision making process and improves the quality of information required on which the decision is based. A critical success factor for the developed DSM is its user friendliness and simplicity.

The DSM has been validated and tested within the industry using four life housing projects at their pre-project phase with different project characteristics, locations and site conditions. The process has provided overwhelming evidence to demonstrate that the model is able to produce a clear recommendation on whether to use OSM or TOS as a construction strategy for any housing project in the UK. It was concluded that the model works well and found to be simple to use and minimises the time and the quantity of data required by the user to complete the decision evaluation exercise.

8.8 Recommendations for Future Work

Like all research projects, further research is needed in the field of the decision making process to use Off-Site Manufacturing (OSM) systems in house building industry in order to build on the findings of this study. It is recommended that further research be undertaken in the following areas:

- The move to OSM essentially requires an entire strategy of integration and coordination of project, inception, design, manufacturing and construction processes, in order to improve quality and delivery of new homes. The current version of the Decision Support Model (DSM) has been designed to guide the choice in practice of a construction strategy between Off-Site Manufacturing (OSM) and Traditional On-Site (TOS) production for house building. It is recommended that the DSM model could be developed further to incorporate other decision evaluation models or integrated with further research work that focus on making a choice of appropriate building system after the choice between OSM or TOS as a construction strategy.
• The current version of DSM has been developed using Microsoft Excel spreadsheet software carry out the evaluation and appraisal; however, a standalone software package (i.e. IT base) could be developed for use by practitioners.

• The research has investigated the effect of the drivers and constraints to OSM, but gave more emphasis on the effect of the factors on the use of OSM because, as shown in Fig 5.12, the focus is on the project strategic/tactical level. This research has made the assumption and integrates the effect of the three components on the basis of fill intersection of the levels that there is a separation between the various levels, as a furtherance of the research work. Therefore, it would be desirable to remove the assumption to appropriately include directly the impact of the drivers and constraints into the current model. This could enable fill the integration of the industry and project levels into the decision outcomes.

• The DSM model is based on the assumption that the 16 critical factors are independent of one another. The issue of intersection and complexity may impact on the effect of the factors on the decision. The DSM also did not reveal a measure of the risk consequences of the decision outcome. This research has focused on the decision making process that led to arriving at decision outcome on whether to use OSM or TOS production rather that evaluating the decision outcome itself – Scope of the work (1.5). Therefore, it is desirable that these issues are also recommended as a furtherance of the research work.
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APPENDICES

Appendix A: Breakdown of the Key Decision Factors

Appendix B: OSM Questionnaire Survey

Appendix C: Description of Case based Precedence Projects Review – OSM

Appendix D: TOS Questionnaire Survey

Appendix E: Description of Case based Precedence Projects Review – TOS

Appendix F: RIBA Plan of Work 2013

Appendix G: Process Protocol Mapping (PPM)

Appendix H: Severity Index Matrix (SIM)

Appendix I: Decision Support Model (DSM) Template

Appendix J: Ranking System of the Top 10 Decision Factors of the DSM

Appendix K: List of Publications derived from this Research
Appendix A: Breakdown of the Key Decision Factors
Key Decision Factor F1: *Time*

- Minimising on-site operation
- Minimising the overall project time
- Short overall project timescale
- Fast-track of construction process
- Minimising overall project time
- Certainly of project completion date
- Client/user benefits from early handover
- Minimising time spent on non-construction and manufacturing processes
- Ensuring a firm project completion date
- Ensuring project completion date is certain
- Rapid construction programme
- Ensuring completion on schedule
- Speed of installation

Key Decision Factor F2: *Quality*

- Achieving high quality
- Level of required quality for project
- Reduction in defects of product or facility
- Quality level of end product or facility
- Quality control condition in factory
- Experience of labour force in factory environment
- Quality control review during manufacturing processes and site assembly
- High standard quality of both internal and external finishes of building
Key Decision Factor F3: Cost

Increased predictability of project outcomes

Very predictable quality finishes

Achieving predictability of performance

Achieving predictability of quality

Achieving performance predictability throughout life-cycle

Predictability of minimising maintenance solution

Key Decision Factor F4: Predictability
Key Decision Factor F5: *Interface Issues*

- Minimising disruption between trades
- Minimising number of trades involved
- Reduce multi-trade interface in restricted work areas
- Provided fewer trades and interfaces on-site in the same time
- Improved organisation of on-site operations
- Improved management and coordination of people on-site

Key Decision Factor F6: *Environmental Issues*

- Control of waste by transfer work to controlled factory environment
- Reducing environmental impact during construction
- Reduction of environmental impact through reduction of site activities
- Minimise disruption to existing on-going activities
- Reducing neighbourhood disruption and noise
- Reduce work within an operation facility
- Improve indoor environment issues (lighting, size, height, ventilation)
- Reduce traffic movement to/from site cause less neighbourhood pollution and congestion
- Less site accommodation requires less heating/lighting during construction
- Increased recycle and reuse of the units and modules
- Reducing the amount of waste to be dumped
Key Decision Factor F7: Performance

- Improve performance of process ‘on and off’ site
- Improve performance of environmental control systems on and off site
- Improve level of time performance due to integration of processes
- Maximising environmental performance throughout the life-cycle

Key Decision Factor F8: Labour

- Availability of key trades for project
- Limited availability of skilled on-site labour
- Lack of experienced local workforce and skills
- Factory-based jobs with greater long-term security for the individual worker
- Expensive labour at site location
- Limited but specialised skills for off-site work

Key Decision Factor F9: Productivity

- Improve overall project productivity
- Increase productivity of project activities scale
- Increase productivity of labours
- Control over supply chain
- Greater efficiency in construction target and fit out process
Key Decision Factor F10: *Lack of Space*

- Restricted site layout and space, with potential weight limits
- Restricted site layout and space (low-height structure)
- Site restrictions by external parties
- Restricted site layout and storage space
- Site condition and land use
- Traffic management on site

Key Decision Factor F11: *Safety*

- Reducing health and safety risks
- Better factory control of dangerous substance
- Reduce accidents on-site
- Minimising number of site personnel transport, security, remote site
- Reduce vertical and horizontal transportation
- Jobs opportunities away from construction sites to safe conditions in factory environment
- Limited waste, plant and exposure to accidents

Key Decision Factor F12: *Project Complexity*

- Complex design and high technology requirements
- Overlapping activities of project phases
- Difficult project coordination of technical installation
- Difficulty of the building process or un-usual process involved in project
- Size and type of project
- Degree of quality level due to complexity of design
- Risk reduction due to complexity of project
Key Decision Factor F13: *Logistics Issues*

- Site location/community
- Restricted access and site size
- Plant and equipments movement on site
- Transport of materials and components from factory to site
- Congested site area
- Understand crane requirements
- Unit size restricts flexibility

Key Decision Factor F14: *Availability of Resources*

- Distance of raw material source - economic
- Availability of manufacturing plants within economical transport distance
- Availability of facilities within economical transport distance
- Availability of production information, skilled workforce and experienced team
- Availability of standards and legal framework to cover all the aspects
- Skills and experience of off-site within the project team
Key Decision Factor F15: Planning Issues

- Building regulations/legal framework requirements
- Legal framework requirements
- Government and industry targets
- Industry benchmarks and improvement targets
- Planning conditions and neighbourhood issues
- Permission issues
- Existing and adjacent buildings/facilities issues
- Condition and restriction issues of site area
- Local authorities requirements
- Special interest groups and stakeholders requirements

Key Decision Factor F16: Market Demand

- Current market condition
- Competitive market
- Opportunity for high levels of repeatability on this or future projects
- Affordable housing needs and cost reduction
- Provide wider range of design (customer choice)
- Flexibility of adaptability (future changes)
- Satisfaction the demand of housing
Appendix B: OSM Questionnaire Survey

The Decision to Use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK

Ref: Off-Site Manufacturing (OSM) – Questionnaire Survey

Dear Sir/ Madam,

I am a PhD Research student at the University of Brighton, the School of Environment and Technology. I am currently undertaking a research project titled ‘The Decision to use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK’ with the following aim:

To develop a Decision Evaluation Model (OSM) that can be used in practice to guide the choice between using Off-Site Manufacturing (OSM) and Traditional On-Site (TOS) production as a construction strategy for house building projects in the UK.

To achieve this global research aim, a questionnaire is designed and attached in order to get inputs from construction practitioners such as yourself on the survey. The questionnaire builds upon the initial findings obtained from an interview survey with selected practitioners in the house building industry. It aims firstly to establish the impact of the decision factors and secondly explores how the decision to use OSM is currently being made within the house building sector.

I would be extremely grateful if you could complete and return the attached questionnaire to me by email or post to the address provided below. The information provided will be treated with strict confidentiality and will be used solely for academic purposes.

In anticipation, thank you for your support and participation.

Yours sincerely,

Elhisain Elnaas
PhD Research Student
School of Environment and Technology
University of Brighton, Cockcroft Building, Moulsecoomb, Lewes Road
Brighton, BN2 4GJ
East Sussex, UK
E: E.Elnaas@brighton.ac.uk
T: 01273 642284   F: 01273 642285
The Decision to Use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK

Ref: OFF-Site Manufacturing (OSM) Questionnaire Survey

The aim of this questionnaire:
To establish the impact of the key decision factors that need to be considered to use Off-Site Manufacturing (OSM) as a construction strategy for house building projects. The questionnaire also explores how decision to use OSM is currently being made within house building industry and key components have influence on decision making process.

Please answer the following questions

Part One – Personal and Organisation Details

1. Name of Respondent:
2. Firm/Company:
3. Location:
4. Position / Role:

Please tick
(You can tick more than one)

Which best describes your profession:

<table>
<thead>
<tr>
<th>Client</th>
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<tr>
<td>Contractor</td>
<td>Quantity Surveyor</td>
</tr>
<tr>
<td>Consultant</td>
<td>Project Manager</td>
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<tr>
<td>Manufacturer</td>
<td>Supplier</td>
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<tr>
<td>Other, please specify</td>
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</table>
## Part Two – Off-Site Manufacturing (OSM) Survey

**Question 1:**

1.1 Please identify by ticking Yes/No, which of the following key factors influence the decision to use of OSM systems in house building projects.

1.2 Having indicated which factors apply – please rate their level of importance between (1 – 5), 5 being the most important factor.

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</table>

Please tick & rating
On scale of 1-5
The Decision to Use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK

Question 2:
In your opinion, are there any overriding factors influencing decision that determine a house project using Off-Site Manufacturing (OSM) systems?

* 
* 
* 
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Question 3:
What stage using the RIBA Plan of Work should be the decision to use Off-Site Manufacturing (OSM) as a construction strategy made of housing projects?

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<td>K Operations</td>
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<td>L Completion</td>
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</table>
The Decision to Use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK

**Question 4:**

4.1 Please identify by ticking Yes/No, who among the key project players currently makes the decision to use Off-Site Manufacturing (OSM) as a strategy for the construction of housing projects.

4.2 Having indicated which key players act – please rate their level of influence on decision making process on scale (1 – 5), 5 being most effected/influenced player (decision maker).

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**Question 5:**

What key lessons you have learned concerning the decision making process to use Off-Site versus On-Site construction methods in house building projects?

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The Decision to Use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK

Question 6:

| If you have any other comments/suggestions that might provide a better understanding for the decision making process to the use of Off-site versus On-site construction methods for house building industry, please include them here... |

Thank you for taking the time to complete this questionnaire and contribution

Elhisain Elnaas  
PhD Research Student  
School of Environment and Technology  
University of Brighton  
Cockcroft Building  
Moulsecoomb, Lewes Road  
Brighton, BN2 4GJ  
East Sussex, UK.  
E: E.Elnaas@brighton.ac.uk  
T: 01273 642284  
F: 01273 642285
## Appendix C: Description of Case based Precedence Projects Review – OSM

<table>
<thead>
<tr>
<th>Ref.</th>
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<td>Apartments for student and key workers – Volumetric system (125 units)</td>
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<td>PC 10</td>
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<td>a mixture of one, two and three bedrooms apartments – used timber panellised and volumetric bathroom pods systems (50 units)</td>
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<td>Residential development for key worker and student – using fully modular (160 units)</td>
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<td>PC 15</td>
<td>A mixed apartment types – based on panels and modular systems – (160 units)</td>
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</table>
Appendix D: TOS Questionnaire Survey

The Decision to Use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK

Ref: Traditional On-Site (TOS) – Questionnaire Survey

Dear Sir/ Madam,

I am a PhD Research student at the University of Brighton, the School of Environment and Technology. I am currently undertaking a research project titled ‘The Decision to use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK’ with the following aim:

To develop a Decision Evaluation Model (OSM) that can be used in practice to guide the choice between using Off-Site Manufacturing (OSM) and Traditional On-Site (TOS) production as a construction strategy for house building projects in the UK.

To achieve this global research aim, a questionnaire is designed and attached in order to get inputs from construction practitioners such as your-self on the survey. The questionnaire builds upon the initial findings obtained from an interview survey with selected practitioners in the house building industry. It aims firstly to establish the impact of the decision factors on the decision to use TOS as a construction strategy for the house building projects.

I would be extremely grateful if you could complete and return the attached questionnaire to me by email or post to the address provided below. The information provided will be treated with strict confidentiality and will be used solely for academic purposes.

In anticipation, thank you for your support and participation.

Yours sincerely,

Elhisain Elnaas
PhD Research Student
School of Environment and Technology
University of Brighton, Cockcroft Building,
Moulsecoomb, Lewes Road
Brighton, BN2 4GJ
East Sussex, UK
E: E.Elnaas@brighton.ac.uk
T: 01273 642284   F: 01273 642285
The Decision to Use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK

Ref: Traditional On-Site (TOS) Questionnaire Survey

The aim of this questionnaire:
Having identified the 16 key decision factors that have most influence on the decision to use Off-Site Manufacturing (OSM); this questionnaire aims to establish the impact of these factors on decision to use Traditional On-Site (TOS) as a construction strategy for house building projects.

Please answer the following questions

**Part One – Personal and Organisation Details**

1. Name of Respondent:
2. Firm:
3. Location:
4. Position / Role:

Which best describes your profession:

<table>
<thead>
<tr>
<th>Which best describes your profession:</th>
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<tbody>
<tr>
<td>Client</td>
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<td>Consultant</td>
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<td>Manufacturer</td>
<td>Supplier</td>
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<td>Other, please specify</td>
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Please tick (You can tick more than one)
Part Two – Traditional On-Site (TOS) Survey:

Question 1:

1.1 Please identify by ticking Yes/No, which of the following key factors influence the decision to use Traditional On-Site (TOS) as a strategy in house building projects.

1.2 Having indicated which factors apply – please score their level of importance between (1 – 5), 5 being the most important.

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Other factors may you like to include; please specify below

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</table>
The Decision to Use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK

Question 2:
Are there any overriding factors that determine a house project must/should be done using Traditional On-Site (TOS) methods?

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Question 3:
What key lessons you have learned concerning the decision making process to use Tradition On-Site (TOS) methods in house building projects?

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</table>
The Decision to Use Off-Site Manufacturing (OSM) Systems for House Building Projects in the UK

Question 4:

Please write down

If you have any other comments/suggestions that might provide a better understanding of the decision making process regarding the use of Traditional On-Site (TOS) versus Off-Site Manufacturing (OSM) for house building Projects, please include them here....

Thank you for taking the time to complete this questionnaire and contribution

Elhsein Elnaas
Postgraduate Researcher (PhD); MSc; BSc; Dip-Eng.
School of Environment and Technology
University of Brighton
Cockcroft Building
Moulsecoomb, Lewes Road
Brighton, BN2 4GJ,
East Sussex, UK
E: E.Elnaas@brighton.ac.uk
T: 01273 642284
F: 01273 642285
### Appendix E: Description of Case based Precedence Projects Review – TOS

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Project Description</th>
<th>Data Sources</th>
<th>Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC 1</td>
<td>Housing development of mixed types of one, two, three and four bedrooms flats (120 units)</td>
<td>✓  ✓</td>
<td>Project Manager</td>
</tr>
<tr>
<td>PC 2</td>
<td>Social housing development of one, two and three bedrooms flats (66 units)</td>
<td>✓  ✓</td>
<td>Main Contractor</td>
</tr>
<tr>
<td>PC 3</td>
<td>apartments development for key workers (63 units)</td>
<td>✓  ✓</td>
<td>Project Manager</td>
</tr>
<tr>
<td>PC 4</td>
<td>Housing project of one and two bedrooms flats (43 units)</td>
<td>✓  ✓</td>
<td>Project Manager &amp; Architect</td>
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<tr>
<td>PC 5</td>
<td>Mixed residential development one, two and three bedrooms flats (50 units)</td>
<td>✓  ✓  ✓</td>
<td>Project Manager – Contractor</td>
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<td>PC 6</td>
<td>Residential development of one, two and three bedrooms flats (60 units)</td>
<td>✓  ✓  ✓</td>
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<td>PC 7</td>
<td>Housing development of 1 and 2 bedrooms apartments and terraced houses (53 units)</td>
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<tr>
<td>PC 8</td>
<td>Residential development of studio, one and two bedrooms flats (64 units)</td>
<td>✓  ✓</td>
<td>Main Contractor</td>
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<tr>
<td>PC 9</td>
<td>Apartments of studio, one and two bedrooms development (72 units)</td>
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<td>Client &amp; Project Manager</td>
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<td>PC 10</td>
<td>Housing development of four bedrooms homes (18 units)</td>
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<td>Project Manager</td>
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<tr>
<td>PC 11</td>
<td>A mixture development of one, two and three bedrooms apartments (80 units)</td>
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<td>PC 12</td>
<td>Residential development of two and three bedrooms flats (112 units)</td>
<td>✓  ✓</td>
<td>Client &amp; Project Manager</td>
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<tr>
<td>PC 13</td>
<td>housing development of one, two and three bedrooms apartments (56 units)</td>
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<td>Project Manager</td>
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<tr>
<td>PC 14</td>
<td>Residential housing development for key workers (120 units)</td>
<td>✓  ✓</td>
<td>Architect</td>
</tr>
<tr>
<td>PC 15</td>
<td>Housing units development of three bedrooms homes (27 units)</td>
<td>✓  ✓</td>
<td>Project Manager</td>
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</table>
Appendix F: RIBA Plan of Work 2013

<table>
<thead>
<tr>
<th>Stage</th>
<th>Tasks</th>
<th>Core Objectives</th>
<th>Appendices</th>
<th>Suggested Key Support Tasks</th>
<th>Information Exchanges</th>
<th>UK Government Information Exchanges</th>
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<tbody>
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<td>0</td>
<td>None</td>
<td>Identify client's business case and strategic brief.</td>
<td>None</td>
<td>Prepare Stage 0 Report Table</td>
<td>Relevant information</td>
<td>Not required</td>
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<tr>
<td>1</td>
<td>Identify client's business case and strategic brief.</td>
<td>Prepare Project Brief and basis for work.</td>
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<td>Prepare Stage 0 Report Table</td>
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<td>Prepare Project Brief and basis for work.</td>
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<td>Prepare Stage 0 Report Table</td>
<td>Relevant information</td>
<td>Required</td>
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<td>Prepare Project Brief and basis for work.</td>
<td>None</td>
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<td>Prepare Project Brief and basis for work.</td>
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<td>Prepare Stage 0 Report Table</td>
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The RIBA Plan of Work 2013 provides a framework for the briefing, design, construction, and maintenance of buildings. It is a guidance document for architects and clients to understand the key stages of a building project and the tasks involved.
Appendix G: Process Protocol Mapping (PPM)
## Appendix H: Severity Index Matrix (SIM)

### Decision Factors: OSM vs. TOS

<table>
<thead>
<tr>
<th>Time</th>
<th>Quality</th>
<th>Cost</th>
<th>Predictability</th>
<th>Interface Issues</th>
<th>Environmental Issues</th>
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<tbody>
<tr>
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### Factors
- Time
- Quality
- Cost
- Predictability
- Interface Issues
- Environmental Issues
- Performance
- Labour

### Comparison Matrix

<table>
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<tr>
<th>Factors</th>
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<th>Quality</th>
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</table>

### Total

- TOTAL
-SI - Significance Index
-TOS - Traditional On-Site
-OSM - Off-Site Manufacturing
-Diff - Difference
-PI - Importance Index

295
### Appendix I: Decision Support Model (DSM) Template

#### THE DECISION SUPPORT MODEL (DSM)

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<th>CLIENT</th>
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#### Factor Code

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<th>M</th>
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#### Phase 1: Decision Factors Selection Matrix

- A. Time
- B. Quality
- C. Cost
- D. Predictability
- E. Interface Issues
- F. Environmental Issues
- G. Performance
- H. Labour
- I. Productivity
- J. Lack of Space
- K. Safety
- L. Project Complexity
- M. Logistics Issues
- N. Availability of Resources
- O. Planning Issues
- P. Market Demand

#### Phase 2: Decision Evaluation Matrix

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<th>Quant Index</th>
<th>DECISION</th>
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#### Phase 3: Evaluation Priorities Matrix

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(Occurrence of Each Factor)
(Frequency (% of Each Factor)
(F1 to F16, Where F1 being the Highest Rate & F16 the Lowest Rate)

#### Phase 4: Decision Making Outcomes

- RECOMMENDED CONSTRUCTION STRATEGY
- DATE
- DECISION MAKER / USER

#### Report:

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### Appendix J: Ranking System of the Top 10 Decision Factors of the DSM

#### THE DECISION SUPPOT MODEL (DSM)

**Phase 1: Decision Factors Selection Matrix**

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<tr>
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<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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**Phase 2: Evaluation Priorities Matrix**

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**Phase 3: Decision Evaluation Matrix**

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**Phase 4: Decision Making Outcomes**

- **Top 6 Factors**
  - Market Demand
  - Availability of Resources
  - Logistics Issues
  - Market Indicators
  - Planning Issues
  - Safety

- **Top 8 Factors**
  - Environmental Issues
  - Planning Issues
  - Market Demand
  - Individuity
  - Interface Issues
  - Logistics Issues
  - Availability of Resources
  - Safety

- **Top 9 Factors**
  - Environmental Issues
  - Planning Issues
  - Market Demand
  - Individuity
  - Interface Issues
  - Logistics Issues
  - Availability of Resources
  - Safety
  - Cost

**Top 10 Rated Factors for Project**

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**Report**

- **Recommendation from Expert A**
  - Rank: 31
  - Score: 9.12
  - Recommendation: Improve the quality of the project.

- **Recommendation from Expert B**
  - Rank: 20
  - Score: 8.64
  - Recommendation: Enhance the safety measures.

- **Recommendation from Expert C**
  - Rank: 28
  - Score: 8.31
  - Recommendation: Optimize the logistics issues.

- **Recommendation from Expert D**
  - Rank: 26
  - Score: 8.07
  - Recommendation: Streamline the market demand.

- **Recommendation from Expert E**
  - Rank: 24
  - Score: 7.84
  - Recommendation: Increase the productivity.

- **Recommendation from Expert F**
  - Rank: 22
  - Score: 7.61
  - Recommendation: Enhance the market indicators.

- **Recommendation from Expert G**
  - Rank: 21
  - Score: 7.48
  - Recommendation: Improve the planning issues.

- **Recommendation from Expert H**
  - Rank: 19
  - Score: 7.25
  - Recommendation: Strengthen the safety measures.

- **Recommendation from Expert I**
  - Rank: 17
  - Score: 7.02
  - Recommendation: Optimize the logistics issues.

- **Recommendation from Expert J**
  - Rank: 15
  - Score: 6.79
  - Recommendation: Streamline the market demand.

- **Recommendation from Expert K**
  - Rank: 13
  - Score: 6.56
  - Recommendation: Enhance the safety measures.

- **Recommendation from Expert L**
  - Rank: 11
  - Score: 6.33
  - Recommendation: Optimize the market indicators.

- **Recommendation from Expert M**
  - Rank: 9
  - Score: 6.10
  - Recommendation: Streamline the market demand.

- **Recommendation from Expert O**
  - Rank: 7
  - Score: 5.87
  - Recommendation: Enhance the safety measures.

- **Recommendation from Expert P**
  - Rank: 5
  - Score: 5.64
  - Recommendation: Optimize the market indicators.

- **Recommendation from Expert Q**
  - Rank: 3
  - Score: 5.41
  - Recommendation: Streamline the market demand.

- **Recommendation from Expert R**
  - Rank: 1
  - Score: 5.18
  - Recommendation: Enhance the safety measures.
Appendix K: List of Publications derived from this Research


