

Factors and Drivers Effecting the Decision of Using Off-Site Manufacturing (OSM) Systems in House Building Industry

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Abstract: Much has been written on Off-site Manufacturing (OSM) in construction, particularly regarding the perceived benefits and barriers to implementation. However, there seems to be a wide misunderstanding of the state of OSM associated with the concept of decision by many of those involved in decision making process within the house building industry. This has led to a demand for guidance's on decision making process for construction project leaders particularly at early project stages. Choosing a construction method for a project will require an optimum decision strategy which involves careful understanding, measurement and evaluation of a number of decision factors that can have the most influence on successful decision action. This paper, therefore, aims to identify the key decision factors to be considered at evaluation stage when choosing to use Off-Site Manufacturing (OSM) as a construction strategy in house building projects. This will reveal the key drivers for change in the industry towards the use of OSM in house building.

Keywords: Decision making, decision strategy, off-site manufacturing (OSM).

1. Introduction

The UK construction industry faces increasing demands to build more homes, build them quicker and build them to higher standards (Goodier et al., 2010). The industry is also expected to reduce CO₂ emission and the environmental impacts of buildings, reduce overall project duration and costs, reduce defects, and eliminate accidents (NHBC House, 2009; Ross et al., 2006 and Housing Forum, 2004).

Government departments and a competitive market have driven the construction industry to review its operations and seek ways of improving its management processes and delivering of new housing (Pan et al., 2007). Traditional construction methods have struggled to meet these demands; in an effort to tackle these challenges, house builders seek alternative ways to improve their performance. It is suggested that traditional forms of construction will fail to meet future demands; Blismas and Wakefield (2007) state that OSM can contribute to addressing some of the challenges facing the construction industry. Whilst, Goodier et al., (2010) stated that offsite production systems have been promoted as a part of the solution to addressing these challenges. Further, Ogden, (2010) emphasised that the adoption of new practices and

technologies is seen as one of the key survival strategies of improving construction in the 21st century.

Gidado (2013) suggests that there is tremendous benefit in either applying production management expertise on construction sites or transferring construction activities to the production yards or plants for effective management. The potential of using offsite production to reduce cost, time, defects, health and safety risks and environmental impact and a consequent increase in predictability, whole life performance and profits on long term has been well established (Venables et al., 2004; Gibb and Pendlebury, 2005). It is further seen as a key vehicle for driving process and efficiency improvements within the house building sector (Housing Corporation, 2007). Despite this potential, Goulding et al., (2012) stated that the uptake of OSM is much lower than expected in the UK construction industry. Pan et al. (2007) have expressed a similar view that the use of OSM in the UK housing sector was very low, with most top 100 house builders rarely using OSM.

Using OSM has the potential for further use in the UK house building industry, however, literature has identified that there are many issues and questions that need to be addressed regarding the decision making process. This research agrees that the identified challenges can be met

through the implementation of offsite technologies to house building, but this potential can only be met if the decision to use OSM is better understood and properly guided. Therefore the following objectives were set in order to establish a decision selection criteria: 1) Identify key drivers for change to adopt OSM in the housing sector, 2) Review the characteristics associated with the current decision making procedure used to select OSM, 3) Identify the key factors used at the evaluation stage of decision making to selecting or considering to use OSM, 4) Establish a selection criteria to use OSM as construction strategy for housing.

2. Research Methodology

The scoping study employed mixed methods throughout this research using both qualitative and quantitative approaches for data collection that involved semi-structured interviews and case studies.

The literature review established the need of using OSM as a strategy for house building projects and a robust understanding of the concept of decision making with regard to using OSM. Interview questions were developed from issues highlighted by the literature review, in particular the need to improve decision making when it comes to OSM choice. The primary objective of the data gathering was to canvass construction practitioners' opinions and views based on their experience of decision making to use OSM systems in the construction houses.

A total of 30 interviews were carried out using semi-structured form with leading construction professionals of the housing industry particularly members of BuildoffSite (BoS) organisations. All the interviewees were senior managers and directors with responsibility for making company policy decisions. They include clients, contractors, consultants, project managers, design managers and contract/construction managers. This mix of firms and roles has allowed a range of views and opinions to be gathered in order to establish a robust data set to explore how decisions to use OSM systems were currently being made by professionals in the house building industry.

Following the literature review and interviews, the research analysed and cross checked those factors that were emerging against known outcomes via case studies. A further 15 case studies of projects using OSM systems were conducted, which provided a comprehensive set of factors and criteria used when considering to use OSM systems for house building projects. The case study approach focused on the identification of key factors and the impact of each factor on the outcome of the decision made. Each case study shared facts that had been considered during the decision making process to use OSM systems instead of onsite construction methods.

The case study approach focused on the identification of the impact of each factor on the outcome of the decision made. The outcomes were used to establish the selection criteria that can assist in the decision making to use OSM system as a strategy for construction of houses.

3. The Concept of Decision Making to OSM

Decision making is an on-going task, carried out through the construction project's life cycle. It is a process solving activity, through making a conscious choice or selecting to achieve an objective or willing outcome of a project. Decision making process is concerned with the finding

and selection of satisfactory and optimal alternatives that is the best possible solution for particular decision matter (Choo, 2006).

According to Lucey, (1997), all decisions must decide by some means to choose the outcome or outcomes which are desirable to decision maker(s) and to do so after some form of appraisal of the situation. Further, Choo (2006) stated that an alternative is considered optimal if it is greater to all other alternatives when a single, consistent set of criteria is used to compare all the available alternatives. Thus, if one is to choose a construction strategy, making a decision should be based on a number of pre-established key factors and drivers in order to choose the optimum construction strategy for a project.

This research has focussed on the decision making of choosing between two decision outcomes: 'offsite construction' versus 'onsite construction' strategy for house building projects. Industry professionals have expressed their interest in the process of Off-Site Manufacturing (OSM) systems in construction, however, due to the lack of understanding of the decision making process, some professionals have avoided using these technologies entirely (Ogden, 2010). A major reason, established by Pasquire and Gibb (2002), is that clients and practitioners are unwilling to adopt OSM because they have difficulty ascertaining the benefits that would add to their project.

Whilst there exists decision support systems and evaluation techniques, Pasquire and Gibb (2002) argued that decisions to use offsite techniques in construction are still largely based on unreliable and subjective approaches. Further, Blismas et al. (2006) also stated that the decision making process used to evaluate what extent a component or building system should be produced offsite is inadequate within the industry.

According to CIRIA (2000), the decision making process used to evaluate the application of OSM in the construction process is poorly understood. Pasquire et al (2004) stated that the decision making process is inadequate within the industry, while Blismas et al (2006) pointed out that decisions regarding the use of OSM are unclear and complex. Pasquire and Gibb (2002) confirm that the decision seems to be based on anecdotal evidence rather than rigorous data, as no formal measurement procedures or strategies are available. Pan et al (2008) argues that with increasing pressure on construction professionals to improve efficiency and to make decisions quickly, there is a lack of rational, robust and balanced decision criteria for building system selection in house building. There has been very little evidence to suggest that the existing decision making systems and tools designed in the context of OSM meet the current needs of the construction practitioners. This therefore confirms the need to develop a decision selection criteria framework or mechanism that is based on thorough knowledge and understanding of decision making methodology and its potential application to guide the selection to use OSM systems in house building projects.

4. Results of the Study

The key results in line with the research objectives identified are presented in the following sub-sections:

4.1. Drivers to Adopt OSM in the Housing Industry

The existing literature reveals a wide range of driving forces for utilising offsite technologies in different sectors of the construction industry. Some research projects such as Construction Excellence (2006) have revealed the drivers within the project context, which identified five drivers for change to using offsite technologies that have been recognised in the UK's house building industry: customer focus, quality driven agenda, committed leadership, integration of processes and teams around the product and commitment to people. Further, Jaillon and Poon (2009) expressed that one of the most potential drivers of using OSM is to address the environmental challenges in terms of energy efficiency and waste reduction. Nehmens and Mullens (2009) suggest that improving financial efficiency through economics of scale through mass customisation may be the key driver. Burgen and Surgen (2006) argue that improving the social aspects of people's lives by providing job opportunity in factory environment (which is safer), training and better working conditions is the key driver for change.

Further, Pan et al., (2005) argued that the most significant drivers for adopting offsite technologies are addressing skills shortages, delivering within agreed time and costs and achieving high quality. A study by Rose, et al. (2006) also identified five drivers for change in the context of house building, these are: shortage in housing supply, skills shortage, concerns about quality, changes to Building Regulations and environmental performance. Whilst the literature review provided existing drivers to the general implementation of OSM in the construction industry, this research has reviewed the drivers for adopting OSM with specific reference to decision making. The findings have been established from the 30 interviews with practitioners in the UK housing industry based on their on-going projects or past experience. 12 key drivers for change in the house building industry have been identified. These drivers were then categorised into 5 main categories: technical, economic, environmental, organisational and social.

As shown in Table 1, using simple averages of the responses from the interviewees, the 5 categories were ranked in order of importance. The results show technical,

economic, environmental, organizational and social scoring 82%, 73%, 67%, 61% and 51%, respectively. Technical is the top category, which includes shortage in housing supply, projected skills shortage and concerning quality of new build homes. House builders believe that the use of OSM systems can improve the rate of delivery of houses to meet demand/target and quality of new housing. They also indicated that industry's skill shortage can be addressed by using OSM system because most of the work takes place in the factory environment. Although, OSM in itself may not reduce the amount of labour; instead it changes the location of work and the workforce from site to factory, which enables the use of the available labour more effectively and efficiently in a more controllable environment.

With all five categories recording a weighting above 50%, it may be argued that all categories will have a significant influence in bringing change to the house building industry. One possible reason for this may be that practitioners and clients have recognised the benefits of implementing the system in the construction of houses and therefore expressed the need to fully drive the required change enthusiastically.

4.2. Constraints to OSM Implementation

Pan et al (2004) suggests that there is little understanding within the UK construction industry of the process of manufacturing components offsite which exacerbate the effect of constraints impacting against using OSM. In such circumstance, Armstrong et al., (1999) established that decision makers face a range of possible constraints that may include a lack of alternatives, no clear criteria, time and cost constraints; imperfections of the decision makers' perceptions; or incompatibility between attitudes.

Furthermore, Pan et al., (2008) stated that other factors that further increase the effect of the constraints include increasing alternatives to choose from, more uncertainties about future requirements and the need to make quick decision. While Blismas and Wakefield (2007) argued that the most significant constraint to the use of OSM in the construction is its associated costs.

Table 1. Key drivers for using OSM in house building

Categories	Drivers	Percentages (%)	
Technical	Shortage in housing supply	87	
	Projected skills shortage	76	82
	Concerning quality of new housing	83	
Economic	Reduction in overall project cost	69	73
	Integration of project processes	76	
Environmental	Environmental performance of buildings	46	67
	Reducing environmental impacts during construction	86	
Organizational	Revisions to Building Regulations to support OSM	64	61
	Government and Industry's agenda and concerns	58	
Social	Employment opportunities away from building sites	48	
	Reduction in accidents and ill health	46	51
	Product and end-user focus	58	

Table 2. Key constraints to use OSM in house building

Categories	Constraints	Percentages (%)	
System	Culture resistance – poor public perception of OSM	39	61
	Lack of understanding of OSM by local authorities	48	
	Low market demand on OSM homes	81	
	Mortgage to OSM due lack of awareness of the system	77	
Process	Early design freeze	92	70
	Complex interfacing between systems and tolerance issues	71	
	Possible increased consequences of incidents onsite due to large units and heavy loads	48	
Regulatory	Regulations are too old to cover all offsite aspects	73	59
	Lack of existing codes and standards to OSM	62	
	No legal framework available to support OSM	42	
Logistics	Site and access constraints	63	48
	Crane requirements and associated costs	24	
	Difficult long-distance transport from/to manufacturing plants, with associated issues	57	
Resources	Skills shortages	87	64
	Limited UK capacity in OSM to enhance its use and efficiency	66	
	Limited expertise in the marketplace of the system	39	
Cost Implication	Expensive available skills	23	54
	Higher capital cost	71	
	Expensive with comparison to traditional methods	64	
	Design fees seen more costly	58	

Although this research has provided 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 industry, it also identified 20 most significant constraints to the use of OSM. These constraints have been categorised into 6 main categories and tabulated as shown in Table 2.

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

4.3. Decision Factors Influencing the Adoption of OSM in House Building

Having identified the drivers and constraints, the research further used interviews and case studies to identify a robust set of decision factors that need to be considered. These factors have been measured and ranked in order of significance, depending upon the project specific requirements.

The research produced a list of 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.

The data obtained from both interviews and case studies were analysed using a five point likert scale. In order to establish a ranking for each of the 16 categories

(themes), the frequency index and importance index have been established. The results are shown in Table 3. The frequency index (F_i) was established using the following function:

$$F_i = 100 * \sum (f / F)$$

Whilst, the importance index (I_p) was established using the following function:

$$I_p = 100 \sum (a * f) / AF$$

Where:

a = the weighting

A = maximum possible weighing

f = frequency of possible weighting

F = total number of respondents

The research has confirmed that the decision factors associated with time, quality and cost have highest impact on the decision for using OSM in the house building industry. They score an importance index of 97%, 76% and 60% respectively. The rating for time is far and above all other factors. There is an overall saving in programme time; this reduction is obtained through the overlapping of offsite and onsite activities which would normally be done in a serial sequence using traditional methods. Thus, the reduction in project time should lead to reduction in the overall cost of project. However, due to the reduced on-

site time, there should also be a reduction in the preliminary costs associated with the major contractor's site setup costs.

Achieving the highest quality was also highlighted as one of the main key factors, may be because quality control and assurance procedures are easier to apply in the factory environment. Working under factory conditions also gives better control, productivity and quality of end product; where offsite works are completed in advance of the onsite installation, the products can be tested before they are transported and incorporated into the building.

The predictability, productivity, interface issues, environmental issues, performance, labour, safety and lack of space, are considered as moderately important. Predictability of building performance factor was on the top of moderately important factors with a 42% score, may be because clients' need to be able to control their risks and uncertainty by reducing or eliminating unknowns. The productivity factor is next on the list with an importance standing at 35%. Safety, project complexity and logistics issues factors were identified as neutral/usually importance influence. The less affected factors in terms of the importance were availability of resources, planning and market condition.

From the data review and analysis of the robust set of factors, the research has established the 10 most important factors that can have potential influence on decision when considering OSM as a construction strategy, namely highly important and moderately important as shown in Table 3.

5. Discussion on the Challenge to using OSM in House Building

Since Egan Report (1998), which identified the use of offsite innovations in construction as a part of the solution for improving its management process, various industry and research initiatives have attempted to consider the

concept in the construction industry. A study by Mullens and Arif (2006) demonstrated that significant cost savings and efficiency are achievable with manufactured construction. However, to quote Crowley (1998), 'solutions from the manufacturing industry cannot be simply applied to problems of the construction industry, without those solutions being re-engineered themselves'. Further, Polat et al. (2006) demonstrated that simply moving efforts offsite does not necessarily guarantee efficient construction.

Several researchers have identified many issues in manufacturing that could be beneficial at strategic-level (Gann, 1996; Crowley, 1998; Gibb, 2001), but many others have documented neither benefit at operational-level (Pan and Arif, 2011) nor at tactical-level.

It is therefore essential that the decision for using OSM is viewed from a project-wide perspective of key project drivers, and a suitable strategy is developed to optimise its use during the evaluation stage, which can be different from project to project. This research, therefore, has looked into the drivers in terms of decision making context in housing sector. With regard to decision making process, the research considered the Three-Levels of management in the following perspective:

- The drivers and constraints represent the Strategic-level.
- The robust set of decision factors represents the Tactical-level.
- At the Operational-level, there should be a mechanism or system that can aid construction practitioners to evaluate and quantify the decision system establishing significance for predictable outcomes of a project

Table 3. Key themes of decision factors to OSM

Themes		Responses %		Importance	Impact
F1	Time	45	100	97	
F2	Quality	39	87	76	Highly Important
F3	Cost	36	80	60	
F4	Predictability	26	58	42	
F5	Productivity	22	49	35	
F6	Interface issues	21	47	29	
F7	Environment issues	20	44	26	Moderate Important
F8	Performance	19	42	26	
F9	Labour	16	36	23	
F10	Lack of space	15	33	21	
F11	Safety	13	29	14	
F12	Project Complexity	10	22	12	Usually Important
F13	Logistics Issues	10	22	10	
F14	Availability of Resources	8	18	8	
F15	Planning Issues	6	13	5	Not Important
F16	Market Condition	5	11	4	

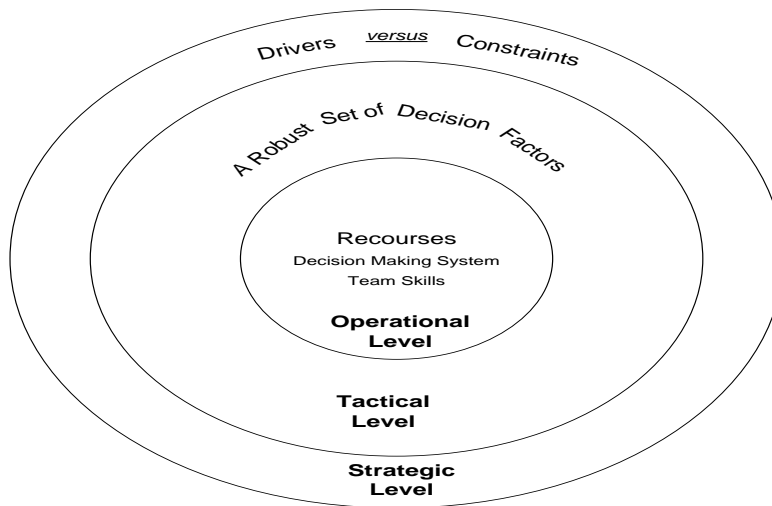


Fig. 1. Illustrates drivers, constraints and decision factors to OSM on the Three-Levels of management process

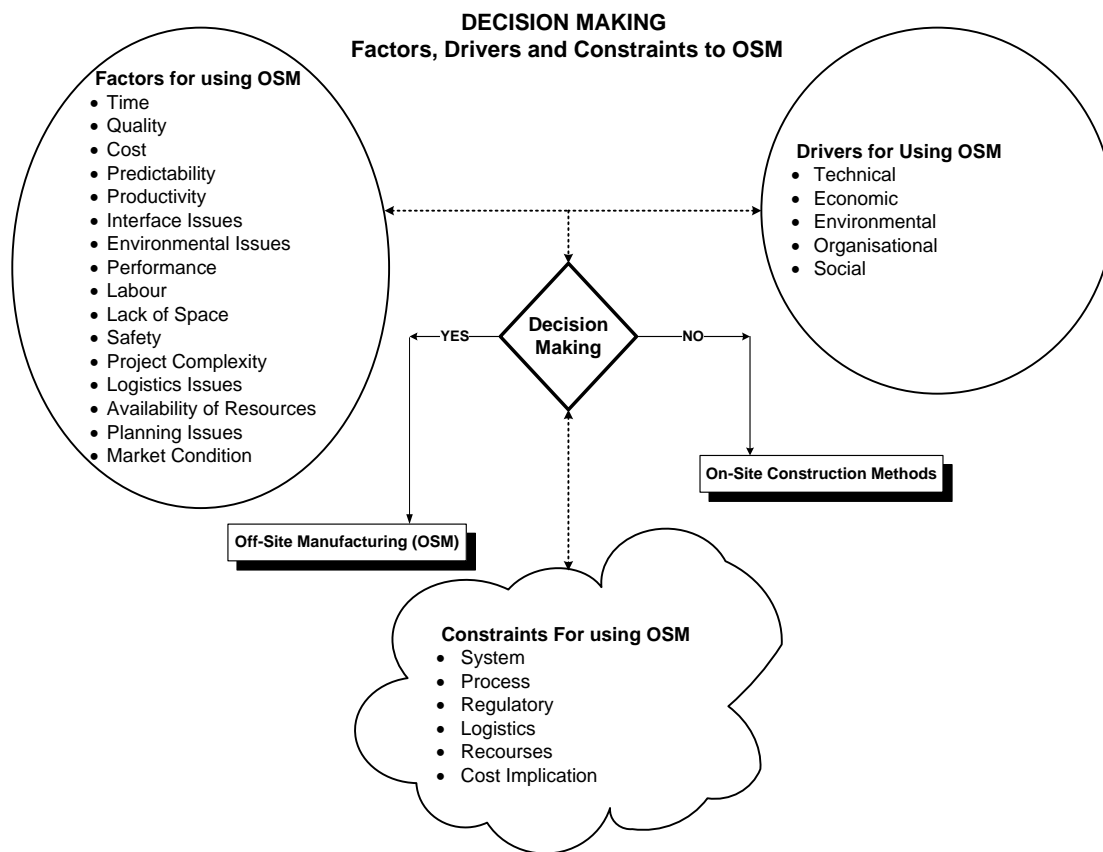


Fig. 2. Relationships between drivers, constraints and decision factors to OSM

This is depicted as shown in Fig. 1.

The global aim of this research project is to develop such mechanism or system that can be used at the operational-level. This will enable decision makers to evaluate the project characteristics before choosing to use OSM systems as a construction strategy.

Fig. 2 graphically maps out the relationship between the drivers, constraints and decision factors in the context of decision making process when considering OSM as strategy for house building construction.

Figs. 1 and 2 highlight that the decision for using OSM systems in house building is driven by defining the project priorities in form of key factors that can have influence on decision making based upon their significance, and then considering the benefits of various options (offsite vs. onsite) against those drives. The model clearly indicates the significance of feedback and continuous improvement of the quality of the decision making process.

The identified five key drivers and the six constraints categories are used as framework to guide the project decision making process, each with sub-divisions as were presented in previous sections. Whilst the project drivers

are usually seen to be the important issues in decision making process, it is the constraints that have the greater potential to influence the project outcomes. These together will be used to identify the potential impacts on decision outcomes on whether to use or not to use OSM as construction strategy for a project.

The research confirms that time-quality-cost management triangle are the main key factors having importance standing at 97%, 76% and 60% respectively. Time is 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 offsite and onsite activities. It is expected that the reduction in project time should lead to reduction in the overall cost of project including reduction in the preliminary costs associated with the major contractor's site setup costs.

Cost is still challenging factor to OSM; using OSM may appear more expensive than onsite methods due to lack of understanding of the construction process. However, if considering long term benefits of using the system then this perception will dramatically change. Achieving the highest quality was highlighted as an important factor because quality control and assurance procedures are easier to apply in the factory environment. Working under factory conditions will give better product control, productivity and quality of end product. Therefore, OSM can be a strategy which if properly implemented could deliver the specified quality within the cost plan and the agreed timetable.

6. Conclusion

The importance of this research is that the house building industry has the potential to address some of the key challenges facing the UK's construction industry

However, the traditional construction methods used by the housing industry have struggled to meet these challenges; initial research suggested that using OSM in place of the traditional approaches could contribute to achieving the government and industry targets; but, in order to achieve these improvements, this research has established the need for a robust decision making system at the very early stages of house building projects. To be able to achieve this goal, the paper revealed that the decision for using off-site construction methods needs to be better understood.

Making a decision is an important part of all construction industry sectors, where specialists apply their knowledge that fit a robust set of indicators; relying upon analysis of massive amounts of information, facts and belief. Decision making criteria used to evaluate OSM in house building if better understood, will become more recognized and accepted by end users, builders, regulators, lenders and government and clients. This research has identified the key drivers, constraints, and factors of using OSM for house building. It established the interrelationships between them by revealing that the application of OSM systems in housing can be part of a strategy to speed up onsite activities, quality of end facility, predictability of quality and performance and increase overall productivity, reduce labour onsite with its associated costs, provide fewer trades and interfaces to manage and coordinate onsite, and minimise environmental impacts.

This paper provides the basis to help understand what key drivers, constraints and factors that exist in the house building industry; all of which need to be considered at the very early stage in making a decision to use OSM in house building projects. This work has developed a conceptual model that describes the relationships between the identified key drivers, constraints and factors in house building decision making. The model clearly indicates the significance of feedback and continuous improvement of the quality of the decision making.

The research findings are based on data collected from the UK house building industry and therefore may not claim to provide the views and opinions of the entire construction industry. It is also important to note that the research focuses at the very early stage of the project, at the time when the contractor or builder is probably yet to be appointed.

Having identified the factors, drivers and constraints; the next step for the research is to focus on the global research aim which is the development of a model that now maps, measures and evaluates the relationship and impact of the factors, drivers and constraints in order to provide a Decision Evaluation Model (DEM) to determine when to manufacture off-site or on-site for the construction of house building projects in the UK.

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