A DECISION EVALUATION MODEL TO CHOOSE BETWEEN MANUFACTURING OFF-SITE OR ON-SITE METHODS FOR CONSTRUCTION OF HOUSE BUILDING PROJECTS

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Despite the wealth of knowledge and information on off-site manufacturing systems, current decision making models do not adequately provide a clear cut choice between using offsite manufacture of building elements and onsite in-situ construction, especially at the pre-construction stage. This paper describes the development of a Decision Evaluation Model (DEM) that provides this opportunity particularly for house building projects. The primary objective of the model is to improve the quality of information on which the decision is based. Having carried out an extensive literature review, primary research data and information was collected from 30 structured interviews, questionnaires completed by 30 selected respondents, and 30 case studies made up of 15 manufacturing 'offsite' projects and 15 projects using 'onsite' construction methods. A robust set of factors have been identified, measured and ranked according to their significance in the decision. Using these factors, a methodology has been developed to measure and evaluate the characteristics of a project, which forms the core of the DEM. The developed model enables decision makers to clearly establish whether to use offsite or onsite construction as a construction strategy. The DEM model provides the opportunity to assist the construction practitioners and clients in making decisions based on adequate data and predictable outcomes against any given project within its environment.

Keywords: decision making, decision evaluation, construction strategy, off-site manufacturing

INTRODUCTION

Since 1998 when Egan recommends the use of offsite innovations in construction (Egan Report, 1998), the UK house building industry has faced additional demands such as: the call for a reduction in CO2 emission and the environmental impacts of buildings, shorter project duration and costs savings, reduction in defects, elimination of accidents and ill health, and improvement in house building supply rate (NHBC

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Elnaas H, Ashton P and Gidado K (2013) A decision evaluation model to choose between manufacturing off-site or on-site methods for construction of house building projects *In*: Smith, S.D and Ahiaga-Dagbui, D.D (Eds) *Procs 29th Annual ARCOM Conference*, 2-4 September 2013, Reading, UK, Association of Researchers in Construction Management, 59-67.

House, 2009; Ross et al., 2006 and Housing Forum, 2004). Experts have suggested that traditional form of construction is failing to meet these and future demands. Blismas and Wakefild (2007) stated that Off-Site Manufacturing (OSM) can contribute to meeting some these demands facing the construction industry. Housing Corporation (2007) suggests that the potential of using OSM may be a key vehicle for driving the process and efficiency improvements within the house building sector. However, despite this opportunity, Goulding et al (2012) stated that the uptake of OSM is much lower than expected in the UK construction industry. The reason for this has been identified to hinge on the many issues and questions that need to be addressed within the client's or the practitioners' decision making process that leads to the use of OSM for building projects. This work provides the evidence to support the need for the development of a new model to assist the construction professional to make decisions on whether to use offsite systems or onsite methods of the construction particularly for house building projects.

THE NEED TO ESTABLISH THE CONTEXT OF THE DECISION MAKING PROCESS

Whilst there exists decision support systems and evaluation techniques, Pasquire and Gibb (1999) argued that decisions to use offsite techniques in construction are still largely based on unreliable/subjective evidence rather than accurate data, as no formal measurement procedures or strategies are available. Further, Blismas et al. (2006) stated that the decision making process that is used to evaluate to what extent a component or a building system should be produced offsite is inadequate. Elnaas el al. (2012) argued that despite the wealth of knowledge and information available in the UK, the house building industry seems to be failing to use existing models and systems designed to improve decision making.

Industry professionals have expressed their interest in the process of Off-Site Manufacturing (OSM) systems in construction, however due to the lake of expertise in the area of OSM decision making, some professionals have simply avoided the use these technologies (Ogden, 2010). A major reason, established by Pasquire and Gibb, (2002) is that contractors are unwilling to adopt OSM because they have difficulty ascertaining the benefits that would add to their individual project.

CIRIA (2000) reported that the decision making process used to evaluate the application of OSM in the construction process is poorly understood. Pasquire et al (2004) have re-emphasised the inadequacy of the decision making process, while Blismas et al. (2006) said that decisions regarding the use of OSM are often unclear and complex. Pasquire and Gibb (2002) added that the decisions used in the construction industry seem to be based on anecdotal evidence rather than reliable data, as no formal measurement procedures or strategies are available. Pan et al (2008) reminded practitioners 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.

The literature review clearly indicates that there has been very little evidence to suggest that the existing decision making systems designed in the context of OSM are meeting the current needs of the construction practitioners. Therefore, there is a need for a mechanism to be designed based on robust knowledge of decision making methodology in the house building industry.

Elnaas et al., (2012) defined that decision making is an on-going task, carried out throughout the project life cycle and it is the process of problem solving activity, through making a conscious choice or selecting to achieve an objective or desirable outcome. Further, Lucey (1997) stated that making 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. While, Choo (2006) declared that an alternative decision is considered most favourable if it is greater to all other alternatives when a single, consistent set of criteria is used to compare all the available alternatives. Abdullah and Egbu (2010) argue that the best decision should be supported with sufficient information and knowledgebase of the decision making context.

In this research, the context of making the decision is to determine and choose between manufacturing OSM systems or onsite methods as a construction strategy for house building projects. This will require an optimum decision strategy which involves careful understanding, measurement and evaluation of a number of drivers, constraints and factors that can have the most influence on successful decision making process.

THE RESEARCH METHODOLOGY

Mixed methods were employed throughout this research using both qualitative and quantitative approaches for data gathering including literature search and review, semi-structured interview, questionnaire survey and case studies. A total of 30 interviews were carried out using semi-structured form with leading construction professionals and members of BuildofSite (BoS) organisation. All the interviewees were senior managers and directors with responsibility for making company policy decisions including clients, contractors, consultants, project managers, design managers and construction managers. This mixed range of views and opinions explored how decisions to use OSM systems were currently being made in the house building industry.

A further 30 case studies, which included 15 projects using OSM systems and 15 projects using on-site construction methods, were conducted. This provided a comprehensive set of factors and the impact of each factor on the outcome of the decision made when considering to use or not to use OSM systems for house building projects. This research has focused on typical domestic housing developments consisting of one to four bedrooms homes, flats, apartments or accommodations units.

A questionnaire survey targeted house builders using the data obtained from construction professionals on decision making to use of OSM systems; and further explored how decisions to use onsite construction methods were currently made within the industry. The survey was sent out to the top 100 UK construction contractors involved in house building projects. The questionnaire has been designed in a manner to enable respondent to answer either from past experience or from current on-going projects. There were 36 responses collected but only 30 were included in the data analysis simply to equal the number of interviews that have been conducted.

The outcomes of which were used to establish 16 themes of decision factors and a selection criteria. The data obtained from both offsite and onsite studies were analysed using a five point likert scale. In order to derive frequency index, importance index and significance index for each factor. The frequency index (Fi) was derived and established using the following function:

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

Where:

f = frequency of possible weighting

F = total number of respondents

Whilst, the importance index (Ip) was derived and established using the following function:

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

Where:

a = the weighting

A = maximum possible weighing

f = frequency of possible weighting

F = total number of respondents

Moreover, the importance indices were used to calculate a significance index (SI) for each factor on both offsite and onsite data using the following equation:

SI = Importance index (Ip) * Frequency index (Fi)

Having established the importance and significance indices of the sixteen themes factors, the severity indices (SvI) are calculated as the difference between significance indices of 'offsite' and that of 'onsite' for each theme in the matrix. If the value of severity index of a factor is positive (≥ 0), then the decision favours using offsite. However, if the value is negative (<0), it means that the decision is in favour of using onsite construction methods for a given project.

The decision maker may need to come back and check the impact and interrelationship of the importance indices of some factors if the value of severity index of a factor is equal zero (= 0). The severity index matrix could be presented using a simple Microsoft Excel spread sheet, which should give a summary of all information of the theme decision factors.

THE DEVELOPMENT OF DECISION EVALUATION MODEL (DEM)

A critical success factor for any model that is expected to be used by practitioners is its user friendliness and simplicity. The proposed new model has been designed in four phases, identified in Figure 1. The four phases were identified by this research whilst analysing the data and information collected from the interviews, questionnaires and case studies as part of the model development stage of the research.

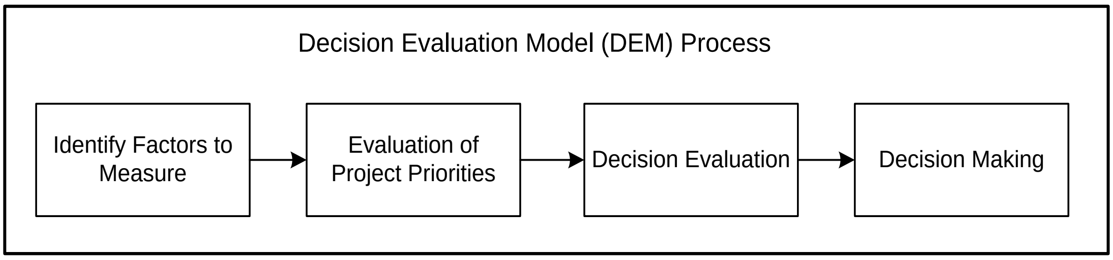

Figure 1: Illustrates decision evaluation model process

The first phase of the model deals with strategic planning of the project from the client's statement of need, brief development to project scheme development. It involved basically the identification of project priorities. Phase two involved the establishment of a means of measuring the impact of the 16 theme factors based upon the project in question. As part of the third phase, the severity index was developed using the importance and significance indexes of the factors to be used as database for the evaluation of decision. Phase four involved the development of mechanism for evaluating project characteristics in order to make a decision on whether to use offsite or onsite construction methods based on adequate data and predictable outcomes.

Blismas et al (2006) argued that the evaluation method used within conventional decision making process is often by considering cost of materials, labour and transport and its associated costs into account when comparing various construction methods. While other sources of value, such as quality, health and safety, process, procurement benefits are not often evaluated in monetary context, either implicit or overlooked within the selection. Further, Laing et al (2008) stated that the large majority of cost modelling work focused onsite work, but a detailed appraisal of offsite procedures would in itself be a useful outcome. They also argued that accuracy in estimating must be drawn from an understanding of the factors in a given situation, rather than relying on a general mathematical technique. Thus, the new model was developed to address this significant challenge rather than to make decision based on subjective evidence. The DEM model has been developed to be used in practice to structure the decision making process, improve the quality of information on which the decision is based; providing the end user with a user friendly interface to assist in making decision against any given project within its environment.

PRESENTATION OF DECISION EVALUATION MODEL (DEM)

The Decision Evaluation Model (DEM) has been developed and presented as shown in Figure 2. The DEM follows the four basic phases described earlier:

- Decision Selection Matrix
- Evaluation Priorities Matrix
- Decision Evaluation Matrix
- Decision Making Outcomes

The four phases involved in the development and evaluation process of making decision will drive the process of identifying an optimum decision strategy involving careful measurement and evaluation of number of factors that can have the most influence on successful decision of choosing either manufacturing 'offsite' or using 'onsite' methods as a construction strategy of any given project. These phases are detailed as following:

Phase 1 - Decision Selection Matrix

The DEM model begins with the evaluation of client's statement of need and the outcome of brief development into its first phase, in order to identify project priorities and desirable outcomes of project. The project priorities need to be set and named according to the established16 themes of decision factors that need to be considered based upon their significance on the project.

Having identified priority factors of the project, the model functions by using codes for each of the 16 factors as shown in the figure (i.e. A: Time, B: Quality, C: Cost, D: Predictability, etc.), which is the only input data is required into the model. The user will evaluate those factors using the Decision Selection Matrix of the DEM depending upon their priorities and significance for given project. Each single factor will be evaluated versus the other 15 factors in the matrix, by putting the code of the right factor that can add value to the project depended upon its set up priorities in the suitable cell in the matrix. The value here can be referred to how desirable a particular evaluation outcome is, the value of alternative between each two factors versus each other, whether in money, satisfaction or other benefits, for willing project outcomes.

DECISION EVALUATION MODEL (DEM)

CLIENT	
PROJECT REF.	
PROJECT NAME	
PROJECT LOCATION	

DECISION FACTORS SELECTION MATRIX

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

EVALUATION PRIORITIES MATRIX

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	(Occurrence of Each Factor Code in the Matrix)
Frequency (Fi)	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	(Frequency (%) of Each Factor)
Rating (Ri)	F7	F1	F4	F9	F10	F11	F8	F15	F5	F16	F3	F12	F13	F14	F6	F2	(F1 to F16, Where F1 being the Highest Rate & F16 the Lowest Rate)

DECISION EVALUATION MATRIX

TOP 10 RATED FACTORS FOR PROJECT			Severity Svl	± QUANT	DECISION	
Highly Important	F1	B. Quality	48.75	48.75	*+ve* (off-site) *-ve* (on-site)	
	F2	P. Market Demand	1.74	50.49		
	F3	K. Safety	-14.85	35.63		
	F4	C. Cost	-41.16	-5.52		
	F5	I . Productivity	3.28	-2.24	ON-SITE	Decision based on the ***Top 5*** factors
Moderately Important	F6	O. Planning Issues	-3.06	-5.30	ON-SITE	Decision based on the ***Top 6*** factors
	F7	A. Time	35.47	30.16	OFF-SITE	Decision based on the ***Top 7*** factors
	F8	G. Performance	11.30	41.46	OFF-SITE	Decision based on the ***Top 8*** factors
	F9	D. Predictability	15.49	56.95	OFF-SITE	Decision based on the ***Top 9*** factors
	F10	E. Interface Issues	8.66	65.61	OFF-SITE	Decision based on the ***Top 10*** factors

FINAL DECISION SUMMARY

NUMBER OF FACTORS CONSIDERED	7
RECOMMENDED CONSTRUCTION METHOD	**Off-Site** Construction Methods
DATE	15/05/2013
DECISION MAKER / USER	GK

Figure 2: Illustrates the design of the Decision Evaluation Model (DEM)

Phase 2 – Evaluation Priorities Matrix

The focus in the second phase is to evaluate the project priorities into three sub-stages. Firstly, the factors codes entered in Decision Factors Selection Matrix (stage one), will be used to generate number of occurrence automatically for each factor. The function used to derive the Occurrence Indexes (Oi) as follows:

$$Oi = \sum (a \ * f)$$

Where:

a = weighting
F = frequency of possible weighting

Secondly, the number of occurrence will be used to calculate frequency indexes of each factor. The equation used to derive the frequency Indices (Fi) is as follows:

$$Fi = 100 * \sum \left({}^{Oi}/_{F} \right)$$

Where:

Oi = Occurrence index of each factor
F = total number of possible factors

Thirdly, ranking those factors based upon their significance, which will be automatically generated using the frequency indexes. This ranking system will rank and put in order the factors that can have the most influence on decision for project from F1 to F16, where F1 the highest and F16 the lowest ranked factor in the evaluation of project prioritisation stage. The characteristics of each factor will possess to a greater or lesser extent of value on decision and outcomes. In this stage, each single factor can be ranked from F1 to F16. Thus, multi-equations of probability used to derive the rating Indices (Ri). This means that there is a 16 probability of a chance for example to be F1.

Phase 3 – Decision Evaluation Matrix
The function of Decision Evaluation Matrix is quantified by taking the top ten ranked factors from the outcomes of previous stage to be considered at this stage in order to evaluate them in favour of project. The model will record those factors automatically based on their significance ranking F1, F2, F3 – F10, respectively in column three of the matrix. A severity index will also be recorded for each factor in column four of the matrix using Severity Index Matrix (database), in order to calculate and generate quant indices (Qi) and recorded in the fifth column of the matrix. This will indicate and make a decision on whether the project is in favour of using offsite or onsite construction methods at F5, F6, F7, F8, F9 and F10. The DEM will automatically indicate based on Quant indices (Qi) that the decision is to use offsite at any factor, F5, F6, F7, F8, F9 and F10 if its value to use offsite is greater than or equal zero (≥ 0) or if the value indicated positive (+) value. In contrast to this, the decision is to use onsite at any factor, F5, F6, F7, F8, F9 and F10 if its value to use offsite is less than zero (<0) or if the value indicated negative (-) value.

Phase 4 – Decision Making Outcomes
Having the mode deliberation and the inclusion of factors 5, 6, 7, 8, 9 and 10 all indicated to use either offsite or onsite construction methods should be used. The user or decision maker has essential role in this final phase of the model to decide how many factors should be considered among the top ranked factors if not all ten factors, which have the most potential for achieving predictable of project outcomes. Because, there can be different decision outcomes on whether to use offsite or onsite methods at each factor F5 to F10. Among the development of the model, the authors established that the decision should be based on minimum of 5 factors and maximum 10 factors. This was taken into account because all the 30 case studies were conducted on both

offsite and onsite projects for data collection throughout the research process were considered between 5 and 10 factors for evaluating their decisions.

The final decision of recommended construction method, therefore, will be the indicated methods at the end of decided number of factors to be considered at the Decision Evaluation Matrix as construction strategy for a given project. If factors that have been identified as the priorities of project did not appear among top 10 then the user/decision maker may need to go back to the first stage of the model to review his/her input data, in order to make the right decision based on project priorities and willing outcomes.

CONCLUSION

The house building industry has the potential to address some of the challenges facing the UK construction industry. The study highlighted that traditional construction methods have struggled to meet these demands. This research concurs with others that suggest the use of OSM systems could contribute to achieving government and industry targets. In order to achieve these improvements, decision making to choose 'offsite' or 'onsite' needs to be better understood. This developed a Decision Evaluation Model (DEM) to enable this to be realised.

This paper makes a contribution to knowledge in two aspects. Firstly, it has established a robust set of decision factors that need to be considered and the establishment of severity indices matrix that maps the impact, the importance and the significance of these factors particularly for house building projects. Secondly, since there is currently no formal method or decision support systems used within the industry designed in the context of decision making, the paper presents the development of new decision support system, DEM. The DEM 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 offsite against onsite construction methods. The project decision is quantified based upon the evaluation and priorities for project, using the database of the severity indices of those factors.

The DEM model has been developed in collaboration with construction professionals, to be used in practice to structure the decision making process, improve the quality of information on which the decision is based, providing the opportunity to assist the construction practitioners in making decisions based on adequate data and predictable outcomes against any given project within its environment. Obtaining the right construction strategy has to be the highest probability of project success and best fits with the project goals, as well as overall company outcomes. The model has been designed to be user friendly interface and to minimise the time and the quantity of data required by the user to complete the exercise of the evaluation.

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