MODELLING PROJECT COMPLEXITY

Hannah Louise Wood[1] and Philip Ashton[2]

School of Environment and Technology, University of Brighton, Brighton, BN2 4GJ, UK

It is a common statement that the construction process is one of the most complex and risky businesses undertaken, however it has also been suggested that the construction industry has developed great difficulty in coping with the increasing complexity of major construction projects Therefore an understanding of project complexity and how it might be managed is of significant importance for achieving success for all of the parties involved. The aim of this paper is to present the final stage of a global research project, the aim of which was to develop a model that could be used to evaluate the effects of project complexity at the pre construction stage in order to improve project planning. A number of methods have been used throughout the research process, interviews and questionnaires were used to identify the factors of project complexity, case studies were then analysed to establish the frequency and impact of the individual factors. Finally the information was modelled in order to provide a project complexity measurement and evaluation method and further case studies were used to test the model. Although a number of systems already exist to evaluate construction projects such as risk assessment methods, no system designed specifically to measure and evaluate the complexity of a project at the pre construction stage exists. The uptake and use of some software packages can be poor in the construction industry; therefore the model was designed specifically to be used by construction contractors when planning a project. Further developments are recommended in order to incorporate the system with other existing evaluation methods to make a complete project evaluation package.

Keywords: complexity, modelling, measuring complexity, evaluating construction projects.

INTRODUCTION

Project success in terms of cost, time and quality is historically poor in the construction industry (Bertelsen, 2003). It is a commonly held opinion that the reason for the poor performance is the design and construction process being particularly complex for a number of reasons (Baccarini, 1996), (Mills, 2001) and (Mulholland and Christian, 1999). In spite of this, there is currently no system available by which project complexity can be measured and evaluated.

Being able to measure the complexity at an early stage in a project will lead to a better understanding of the project and therefore could be of great benefit in successfully managing projects and reducing the risks associated with complexity.

This paper presents the final stage of a research project, the aim of which was to develop a model that could be used to evaluate the effects of project complexity at the pre construction stage in order to improve project planning. Information detailing the

[1] hw35@brighton.ac.uk
[2] p.ashton@brighton.ac.uk

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earlier stages of the research can be found in Wood and Gidado (2008) and Wood and Ashton (2009).

For the purpose of this research project complexity has been defined as a single or combination of factors that affect the standard response/actions taken to achieve the project outcomes.

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Method

A mixed methods approach has been adopted throughout the research process encompassing a number of data collection and analysis methods. In the early stages of the research, an extensive literature review and interviews were conducted in order to establish the factors that make a project complex and the importance of these factors. Case study analysis of construction projects was then carried out to establish the frequency with which the project complexity factors occurred and the impact of the factors in order to identify their significance. This stage of the research describes the development of the project complexity evaluation model using the information gathered from the previous research stages.

A number of different modelling techniques exist, ranging from purely mathematical and simulation models through to qualitative and conceptual models. Each of these models has a range of applications. However, although many of these models have a number of different applications, it is important to select the right kind of model in order to achieve the best results. Fowkes and Mahony (1994, p2) state that of the very many model possibilities arising out of a particular application, very few can usefully illuminate the processes involved and the useful models are not necessarily those of the most intrinsic mathematical interest. Fowkes and Mahony (loccit) go on to suggest that it is often the case that the qualitative insights gained from modelling are more important than any quantitative results obtained. In this research, a more practical, user friendly modelling technique has been applied in order to face less resistance to acceptance of the model in the construction industry. Whilst the model is underpinned with mathematical techniques, the interface uses a more qualitative approach to the data collection.

The model design and development took place in a number of stages. The information obtained from the interviews and case study analyses was used to calculate a significance index (SI) for each factor using the following equation.

SI = Importance index x Frequency

The significance index is used in conjunction with score that the participants give to each question generated from the factors in order to calculate the project complexity exposure. Once the significance index had been calculated for each factor, a number of questions were generated in relation to the project complexity factors, these questions were organized by the project complexity themes identified earlier. Each of these questions is then scored by the participant based upon the degree to which it relates to the project. The project complexity is then calculated using the score and the significance index and the results are presented theme by theme so that the participant can see which factors need improvement. These scores are then used in conjunction with the target minimum which has also been calculated from the significance index in order to highlight the areas which need improving in order to better manage the project complexity.

Measuring systems

In order to develop an appropriate model, a number of other measurement systems were investigated. The measuring systems included both systems currently used in the construction industry as well as those in other industries. Other industries were studied in order to investigate alternative means of measurement which may be adaptable to the construction industry. A number of quantities or factors are measured in the construction industry throughout the project lifecycle These factors include measuring risk, success, performance, productivity, value or cost and health and safety and many different methods exist for measuring these.

A common feature of many of the models, systems and methods investigated is that they are developed by first identifying a list of important factors or criteria which are then analysed and scored in some way. This is similar to the approach taken in this research, the interviews, questionnaires and case study analysis led to the identification of the project complexity factors and their importance and significance in construction projects.

Model development

The model took the form of a two stage Likert scale survey divided into the five themes of project complexity which were identified earlier in the research: planning and management; organizational; operational and technological; environmental and; uncertainty. The initial model has been developed using Microsoft Excel spreadsheet software, however it is recommended that at a later stage the model is developed into its own standalone software package as this was outside of the scope of this research.

Whilst developing the model it was important to consider the end user and how the model was going to be used. Marsh and Flanagan (2000) describe how the challenge to improve performance and reduce costs in construction has prompted development in a number of areas, including the use of information technology. Marsh and Flanagan (2000) highlight research undertaken by the Building Centre Trust (1999) which estimated that amongst the UK construction professional: 86% have a PC, over 81% use email and 88% have access to the internet, and it is anticipated that this will increase in time. However, in spite of this availability, studies have shown that the uptake of other information technologies to be slow (Construct IT 1995 1996, Flanagan *et al.*, 1998, Building Centre trust, 1999). This poor uptake may be because of poorly designed systems which are difficult to use and users find the benefit of the systems difficult to see. Therefore when the model was designed, keeping the interface simple and straightforward whilst returning useful and accurate results was of paramount importance.

The model consists of two parts, stage one poses a series of questions relating to the project which have been formulated based upon the five themes of project complexity and the factors relating to these. The project complexity is then calculated and the results presented in a series of graphs and tables. Stage two highlights the areas which need improving in order to better manage the project complexity, a new series of questions are posed relating only to the areas which need improving, these are scored in the same way as the original questions so that the project complexity can be recalculated. Figure 1 shows an overview of the different stages of the model and the processes that are involved in calculating the project complexity.

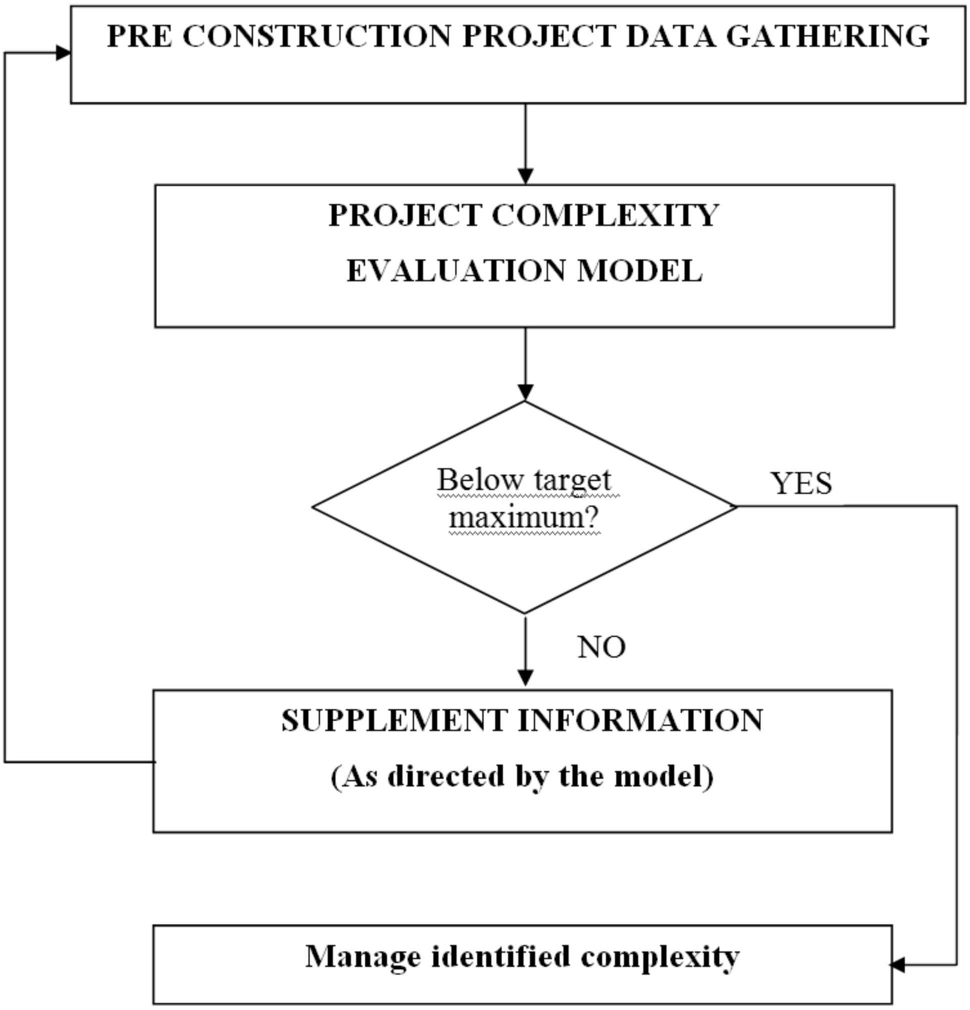

Figure 1 Model Overview

The model starts with a set of instructions explaining the purpose of the model and how to use it. The questions in each stage a broken down in to the five themes of complexity that were identified earlier in the research. These themes are then broken down into further sections as seen in Table 1.

Each theme and section contains a number of questions which the user of the model must score between zero and 10. The question should be scored zero if it has no significance or is not applicable to the project, for example, in the question “Is the clients brief complete, and if not to what degree is information missing?”, if the brief is complete the score should be zero. If the brief was missing a small amount of information a low number should be scored, with the score increasing towards 10 based upon the amount of information that was missing. Figure 2 shows an example of some of the questions with their scores.

1. Organisational theme		Score (0 to 10)
1.1	Clients Brief	
a	Is the clients brief complete, and if not to what degree is information missing	3
b	Is the clients brief clear and understood?	0
c	Is the clients brief achievable within the projects constraints?	8

Figure 2: Example of scoring the stage one questions

Table 1: Themes of project complexity

Theme	Sections within the theme
Organizational	Clients brief
	Organizational structure
	The client and project stakeholders
Planning and management	Project coordination
	Programming
	Information
Operational and technological	Technology
	New methods
	Inherent difficulty
	Project size
Environmental	Physical environment
	Project environment
Uncertainty	Location
	Existing structures
	Planning
	Uniformity

Once all of the stage one questions have been scored, the project complexity is calculated for each theme and the results are presented in two forms. The calculations for the project complexity are conducted within the model but on a hidden worksheet to ensure that the model is used correctly. Figure 2 shows an example of the average results for each theme plotted as a graph against the maximum complexity for each theme.

Figure 4 shows an example of the results broken down by theme; the results for the organizational theme are shown to illustrate how they are presented. Each theme is presented individually showing the calculated project complexity for the theme and a graph of the project complexity calculated for each question against the maximum complexity for the theme. In order to highlight those areas which have a complexity value higher than the target maximum, conditional formatting has been used. This is highlighted in the example in Figure 4, the numbers are highlighted in colours ranging from green to red to show which areas are good and which have a high complexity value. In addition to this the numbers below the target maximum are highlighted as "acceptable" and those above the target maximum are "poor".

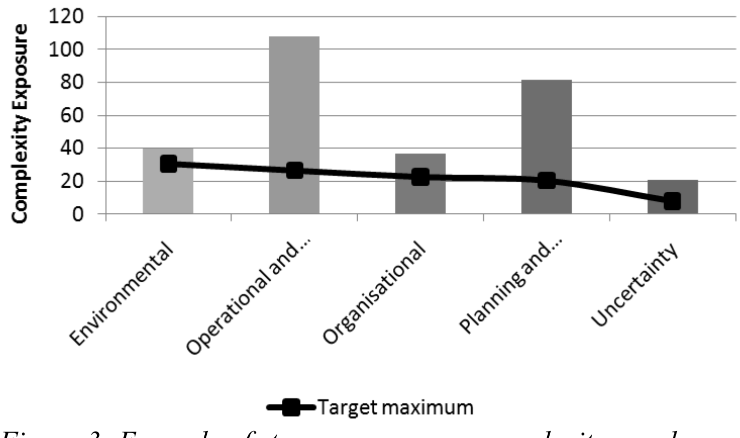

Figure 3: Example of stage one average complexity graph

Section 1: Organisational theme		Average Complexity	36.875	
		Target maximum	22.393	
Q No	Subject	Score	Complexity	
1.1	Clients Brief			
a	Complete	3	30	Poor
b	Clear	0	0	Acceptable
c	Achievable	8	80	Poor
1.2	Organisational Structure			
a	Roles defined	2	20	Acceptable
b	Channels of communication	3	30	Poor
c	Regular communication	6	60	Poor
d	Team experience	0	0	Acceptable
e	Decision making	4	40	Poor
f	Dispute resolution	8	80	Poor
1.3	The Client and Project Stakeholders			
a	Multi-headed client	0	0	Acceptable
b	Realistic aspirations	3	30	Poor
c	Too little input	0	0	Acceptable
d	Too much input	5	50	Poor
e	Changes	5	50	Poor
f	Large number of stakeholders	4	40	Poor
g	Same aspirations	8	80	Poor

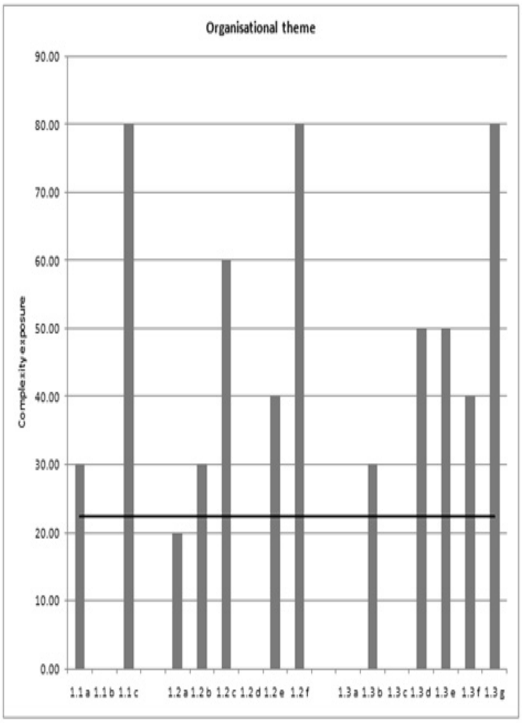

Figure 4: Example of stage one results by theme

Stage two of the model asks a new set of questions based upon the scores given in stage one and the complexity values calculated. Only those areas with a score above the target minimum need to be answered and conditional formatting is used again in order to highlight the questions to be answered, Figure 5 gives an example of this, the questions highlighted in red with an X in the score box are those that require new scores, the questions that do not require a new score are not highlighted and the original score appears in the score box so that it can be used in the recalculation. If any questions that need a new score are left blank, the complexity will not be calculated for that theme which will be highlighted in the results graph.

1. Organisational theme			Score (0 to 10)
1.1		Clients Brief	
a	Answer	**Your score indicated that the brief was incomplete and therefore more information needs to be obtained from the client.** If all of the missing information has been obtained score 0 If not all of the information has been gathered score between 1 and 10 based upon the degree of information still missing If no further information has been gathered use you original score	X
b	OK	**Your score indicated that the brief was not clear or understood and therefore clarification must be sought from the client.** If clarification has now been sought and the brief is now clear score 0 if the brief still has some parts that need clarification score between 1 and 10 based upon the level of clarification still required If no further clarification has been sought use your original score	0
c	Answer	**Your score indicated that the brief was not achievable within the project constraints and therefore these issues need to be brought to the attention if the client and rectified.** If the brief has been adjusted according to the project constraints score 0 If some modifications have been made but there are still some outstanding issues score between 1 and 10 based upon the severity of the outstanding issues If no modifications to the brief or project constraints have been made use your original score	X

Figure 5: Example of stage two scoring

Once the second stage questions have been scored, the results are presented in the same manner as before, an overall graph showing the average complexity against the target maximum and broken down by theme.

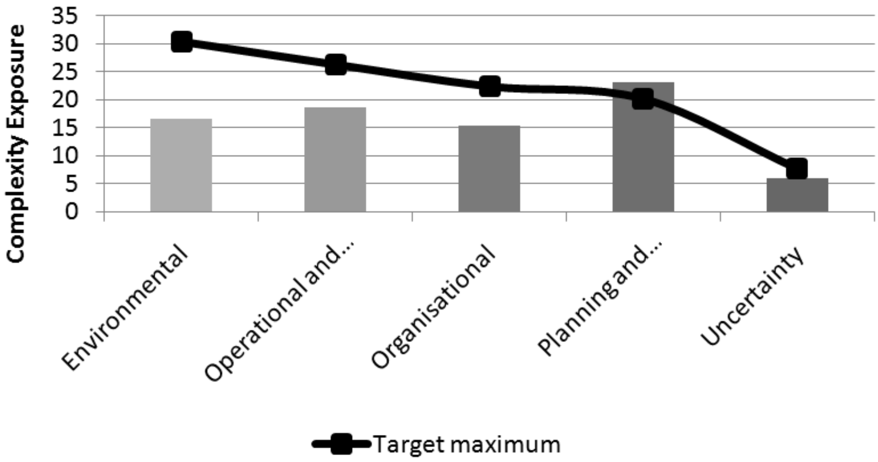

Figure 6: Example of stage two average complexity graph

Figure 6 shows an example of the average complexity against the target maximum complexity graph for the stage two results.. The graph shows that most of the themes average complexity is now below the target maximum line as step have been taken to reduce the project complexity.. If the average complexity values for any of the themes were still significantly above the target maximum line, further work is required and the stage two questions should be answered again to recalculate the complexity values.. Figure 7 shows and example of the results for the organizational theme.. Although the average complexity for this theme is below the target maximum, some of the individual measures of complexity are significantly above the target maximum for the theme. It may be necessary therefore to carry out further work in order to bring the complexity of these individual sections down. As before, conditional formatting has been used to highlight the areas which are significantly above the target maximum to more easily identify those that require further assessment.

Section 1: Organisational theme — Average Complexity 15.278 — Target maximum 22.393

Q No	Subject	Score	Complexity	
1.1	**Clients Brief**			
a	Complete	2	25	Poor
b	Clear	0	0	Acceptable
c	Achievable	3	37.5	Poor
1.2	**Organisational Structure**			
a	Roles defined	2	25	Poor
b	Channels of communication	2	25	Poor
c	Regular communication	3	37.5	Poor
d	Team experience	0	0	Acceptable
e	Decision making	4	50	Poor
f	Dispute resolution	1	12.5	Acceptable
1.3	**The Client and Project Stakeholders**			
a	Multi-headed client	0	0	Acceptable
b	Realistic aspirations	0	0	Acceptable
c	Too little input	0	0	Acceptable
d	Too much input	2	25	Poor
e	Changes	0	0	Acceptable
f	Large number of stakeholders	1	12.5	Acceptable
g	Same aspirations	2	25	Poor

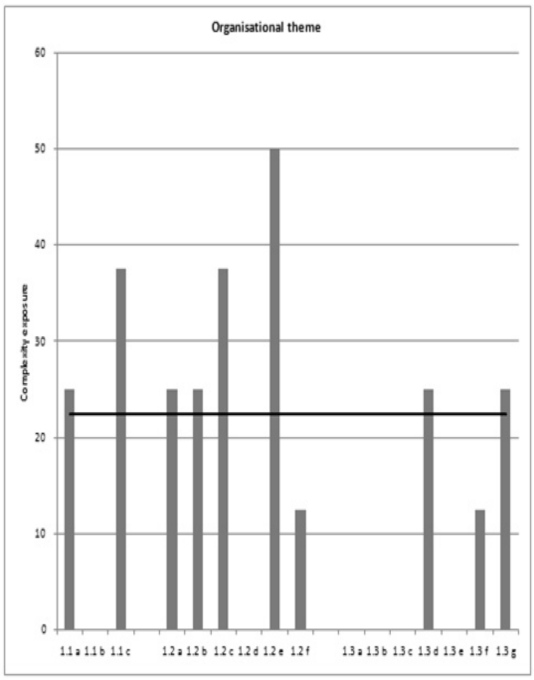

Figure 7: Example of stage two results by theme

Testing

In order to test and validate the model, three further case studies were analysed. These case studies were not included in case study analysis conducted earlier in the research but were selected using the same criteria and analysed in a similar manner as before. The criteria for the case study selection were: the project must be carried out by one of the top 100 contractors in the UK (by turnover 2007-2008); the project must be carried out by a CIOB member contractor; the project must have taken place in England or Wales only due to differences in regulations in other parts of the UK and; the project must have been completed in 2005 or later. The analyses carried out and the data entered into the model came from desk study data of the three case studies. As with the earlier case studies, a broad range of projects were selected in order to test the model in a number of situations.

The first case study used to test the model was a £300 million hotel and conference facility development in an extremely busy city centre location. The development consisted of 14 storeys of hotel accommodations with the addition of three basement levels providing most of the conference facilities, constructed mainly using an in situ concrete frame. In total the development size was 64,000 metres squared incorporating over 1,000 guest suites, 2,700 metres squared of flexible meeting space, 30 meeting rooms, a signature restaurant and spa facilities. The project was procured on a construction management contract and the construction lasted 112 weeks.

The second case study was a state of the art museum in a city centre location on the riverfront. The project incorporated a particularly troublesome roof design which had not been attempted before. In total the project cost was £72 million and the construction duration was approximately two and a half years.

The third project was an extensive refurbishment and addition to a 1930s theatre in a riverside location. The project cost in excess of £120 million and construction lasted approximately three years. The project consisted of retaining the original external structure whilst providing a completely new internal space. Key heritage elements of the building such as the foyer also had to be retained and worked into the new development. In addition, a new circulation tower was required and additional administrative and teaching/workshop space was needed. The new internal structure included the new 1,000 seat theatre which included a basement area under the stage, improved backstage facilities for cast and crew and new facilities for the public including a new roof top restaurant. Outside performance space was also provided as part of the scheme.

The model was used to evaluate the complexity of these three projects and to highlight the areas that needed attention in order to reduce and better manage the complexity. The three projects had a range of complex issues which were highlighted by the model, ranging over all five themes of project complexity therefore utilizing all areas of the model. The main aim of the testing process was to ensure that the methodology behind the model worked effectively and that the model is fit for its purpose. Further real time testing of the model at the pre construction stage of projects is recommended but was outside the scope of the research.

CONCLUSION

The aim of this paper was to present the model development stages of a research project, the aim of which was to develop a model that could be used to evaluate the effects of project complexity at the pre construction stage in order to improve project planning. It is widely recognized that modern construction projects are increasingly complex, there is currently no formal method by which project complexity could be measured and evaluated at any stage in the construction process. It has also been suggested that the increasing complexity of construction projects could be a significant factor in contributing to the poor success rates of construction projects and there is therefore a need to better understand project complexity at an early stage in the project so that it can be managed appropriately.

The model consists of two stages each containing a number of questions in relation to the five themes of project complexity. The project complexity is calculated based upon the answers to the questions and the results are presented by theme giving an average complexity exposure and a target maximum value which this should not exceed. In addition to this, the individual factor results are shown to highlight the exact areas where further work is required in order to better understand the project complexity. The second stage of the model asks only those questions which relate to the factors that scored above the target maximum complexity exposure in the first stage. This means that in the second stage a much smaller amount of questions need to be answered making the system more user friendly, less repetitive and therefore more likely to be used properly to give accurate results.

Three case studies were analysed in order to test the model. The testing showed how the model could be applied to real life construction projects and also identified if there were any problems concerning the way the model works. Although this testing stage was essential in ensuring that the model worked properly, the testing was done retrospectively with projects that had already been completed. In order to fully test the model, real time testing and analyses would be required, using the model in the planning stages of a project and following the project through to completion to ensure the model could be used effectively in industry. This type of testing was also outside of the scope of this research due to the time constraints involved. It is felt however that the use of case studies was sufficient to ensure that the methodology behind the model works, which is the aim of this research.

The model presented in this paper shows how the method demonstrates how the theory of measuring project complexity can be applied to real construction projects in practice. There are however some recommendations to develop the model further. The model has been designed using spreadsheet software which works well, however a standalone software package would be more appropriate for the model but was outside of the scope of this research. The development of the model as a separate software package would allow for it to be made more user friendly, for example, instead of scrolling through a worksheet to answer the questions, an electronic survey style could be used, posing the question theme by theme. Using this kind of approach may make the model look less daunting than being presented with a long list of questions to answer all in one block. Further development of the model may also allow for examples to be given for each question, which may assist the user in scoring each question appropriately. In addition to this the scoring could be changed into phrases, rather than numbers. As well as developing the user interface of the software to make it more user friendly, it is also recommended that the model itself be developed into a system that "learns" and grows with every use, for example, the significance of certain factors may be reduced for the planner if the model is used on a number of similar projects. It is also possible that new factors may arise which need to be incorporated in to the model and therefore a way to update the model in the future is recommended.

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