FACTORS OF COMPLEXITY IN CONSTRUCTION PROJECTS

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Construction projects are often described as being complex; however, the relationship between project complexity and other key project components such as risk and uncertainty is not widely established. As part of a global research project aimed at establishing the impact of project complexity at the pre construction stage, research has been carried out to investigate this relationship. Interviews with industry experts were conducted to establish a current definition of project complexity in the context of the construction industry as well as to identify the factors of project complexity and other aspects of a project. At this stage in the research the definition has been established and factors have been identified but there is a need to develop a method to measure the effect of these. A function has been developed to show the importance of each factor to the complexity of a project which will aid in future work developing a methodology for measuring complexity and its impact upon projects.

Keywords: complexity , project complexity, risk, uncertainty.

INTRODUCTION

Complexity is a wide ranging topic which can relate to any subject and therefore there is a wealth of information pertaining to it, however, there is still little published literature in the area of complexity in the construction industry. 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). 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.

Before any measure of complexity can be obtained, it is essential to first identify what factors make the project complex. The aim of this paper is to establish what is meant by the term complexity and to identify factors which make a project complex.

PROJECT COMPLEXITY

Complexity can be difficult to define as it has a number of different connotations. The Collins English Dictionary (2006) defines complexity as "the state or quality of being intricate or complex", where complex is defined as "made up of many interconnecting parts". The dictionary definition also highlights that it should be noted that complex is sometimes used where complicated is meant. Complex should be used to say only

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that something consists of several parts rather than it is difficult to understand, analyse or deal with, which is what complicated inherently means.

Authors such as Baccarini (1996), Gidado (1996) and Bertelsen (2003) as well as organisations such as the International Project Management Association have defined project complexity, however no clear, universally accepted definition has been produced. Whilst the dictionary definition of complexity is applicable when describing project complexity, it does not fully encompass what is understood by the term in industry.

It is a common statement that the construction process is one of the most complex and risky businesses undertaken. Baccarini (1996) states that the construction process may be considered the most complex undertaking in any industry, however 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 successful projects for all the parties involved. This is supported by Mills (2001) who describes the construction industry as one of the most dynamic, risky and challenging businesses. Mills (2001) goes on to say however that the industry has a very poor reputation for managing risk, with many major projects failing to meet deadlines and cost targets. Mulholland and Christian (1999) support this further by adding that construction projects are initiated in complex and dynamic environments resulting in circumstances of high uncertainty and risk, which are compounded by demanding time constraints.

Baccarini (1996) proposes a definition of project complexity as "consisting of many varied interrelated parts and can be operationalised in terms of differentiation and interdependency." Baccarrini explains that this definition can be applied to any project dimension relevant to the project management process, such as organisation, technology, environment, information, decision making and systems, therefore when referring to project complexity it is important to state clearly the type of complexity being dealt with.

Gidado (1996) presents the results of a number of interviews to gauge what experts in the building industry consider project complexity to be; providing the following outcomes:

- That having a large number of different systems that need to be put together and/or that with a large number of interfaces between elements.
- When a project involves construction work on a confined site with access difficulty and requiring many trades to work in close proximity and at the same time.
- That with a great deal of intricacy which is difficult to specify clearly how to achieve a desired goal or how long it would take.
- That which requires a lot of details about how it should be executed.
- That which requires efficient coordinating, control and monitoring from start to finish.
- That which requires a logical link because a complex project usually encounters a series of revisions during construction and without interrelationships between activities it becomes very difficult to successfully update the programme in the most efficient manner.

From these results Gidado (1996) suggests that there seem to be two perspectives of project complexity in the industry:

- The managerial perspective, which involves the planning of bringing together numerous parts of work to form work flow.
- The operative and technological perspective, which involves the technical intricacies or difficulties of executing individual pieces of work. This may originate from the resources used and the environment in which the work is carried out.

Gidado (1996) offers that project complexity is the measure of difficulty of executing a complex production process, where a complex production process is regarded as that having a number of complicated individual parts brought together in an intricate operational network to form a work flow that is to be completed within a stipulated production time, cost and quality and to achieve a required function without unnecessary conflict between the numerous parties involved in the process. Or it can simply be defined as the measure of the difficulty of implementing a planed number of quantifiable objectives.

From this Gidado (1996) organises the sources of complexity factors that affect the managerial objectives in construction into two categories:

- Category A: this deals with the components that are inherent in the operation of individual tasks and originate from the resources employed or the environment.
- Category B: this deals with those that originate from bringing different parts together to form a work flow.

This distinction between sources of complexity that are inherent in an activity and those which are brought about from the interaction between activities is an important one to make. By identifying the complexity that exists due to the interaction of activities it is possible to manage and control that complexity.

Baccarini (1996) highlights the importance of complexity to the project management process, in the following examples:

- Project complexity helps determine planning, co-ordination and control requirements.
- Project complexity hinders the clear identification of goals and objectives of major projects.
- Complexity is an important criterion in the selection of an appropriate project organisational form.
- Project complexity influences the selection of project inputs, e.g. the expertise and experience requirements of management personnel.
- Complexity is frequently used as criteria in the selection of a suitable project procurement arrangement.
- Complexity is frequently used as a criterion in the selection of a suitable project procurement arrangement.
- Complexity affects the project objectives of time, cost and quality. Broadly, the higher the project complexity the greater the time and cost.

Bertelsen (2003) discusses construction as a complex system; he explains that the general view of the construction process is that it is an ordered, linear phenomenon, which can be organised, planned and managed top down. The frequent failures to complete construction projects on time and schedule give rise to thinking that the process may not be as predictable as it may look. A closer examination reveals that construction is indeed a nonlinear, complex and dynamic phenomenon, which often exists on the edge of chaos. A firmly founded theory of project management should

start with an understanding of the nature of the project itself. Generally, project management understands the project as an ordered and simple, and thus predictable, phenomenon which can be divided in to contracts, activities, work packages, assignments etc to be executed more or less interpedently. The project is also seen as a mainly sequential, assembly like, linear process which can be planned in any degree of detail through an adequate effort, and the dynamics of the surrounding world is not taken into account. As a consequence project management acts top down (Bertelsen 2003). Bertelsen states that the perception of the projects nature as ordered and linear is a fundamental mistake and that project management must perceive the project as a complex, dynamic phenomenon in a complex and non linear setting.

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.

When discussing project complexity it is inevitable that the terms risk and uncertainty will be used. Risk and uncertainty can sometimes be confused as being the same; however it is possible to distinguish between the two terms. Uncertainty can be regarded as the chance occurrence of some event where probability distribution is genuinely not known. This means that uncertainty relates to the occurrence of an event about which little is known, except the fact that it may occur. Those who distinguish uncertainty from risk define risk as being where the outcome of an event, or each set of possible outcomes, can be predicted on the basis of statistical probability. This understanding of risk implies that there is some knowledge about a risk, as opposed to uncertainty about which there is no knowledge (Smith, 1999). Complexity may be a source of both risk and uncertainty in a project and therefore it is important to understand these terms and the relationship between these aspects of a project.

FACTORS OF PROJECT COMPLEXITY

Methodology

In order to establish factors which make a project complex, a series of semi structured interviews incorporating a questionnaire survey were conducted with industry experts, based upon findings from the literature review. The data collected has encompassed a mixture of both qualitative and quantitative information. This mixed approach has been used to gain the most appropriate data to fulfil the aim of the research. In total 16 interviews were conducted.

The data from the questionnaires was used to derive an importance index for each factor, allowing them to be ranked. From this an understanding of factors which make a project complex can be seen. Whilst the list is not exhaustive it is felt that the main factors have been identified and the list may be built upon in the future. The importance index (Ip) was found using the following function:

$Ip = \sum(af)/AF$

Where:

- a = the weighting
- A = maximum possible weighing
- f = frequency of possible weighting
- F = total number of respondents

For the interviews at this stage of the research a constant comparison grounded theory approach was selected. The term grounded theory means theory that was derived from data, systematically gathered and analysed through the research process (Strauss and Corbin, 1998). In this method, data collection, analysis and eventually theory stand in close relationship to one another. Theory derived from data is more likely to resemble the 'reality' than is theory derived by putting together a series of concepts based on experiences or solely through speculation (how one thinks things ought to work). Grounded theories, because they are drawn from data, are likely to offer insight, enhance understanding and provide a meaningful guide to action.

All the participants were selected via criterion sampling, criterion sampling is where all cases meet some criterion which is useful for quality assurance (Miles and Huberman, 1994). The aim of sampling the potential interviewees is to ensure that a realistically achievable amount of interviews can be conducted whilst still representing the views of the wider community. This type of sampling has also been used to obtain information that will be the most pertinent to the research. The criteria for the selection of interviewees are as follows, they must:

- have experience of 'complex' projects
- work at a management (strategic) level in construction
- have a construction related degree or equivalent qualification
- 10 years plus construction experience
- experience in planning/risk issues

Project complexity factors

From the literature, a number of factors of project complexity were identified. Six main factors were identified which are then further broken down in to a number of sub factors. These factors are as follows:

7. Inherent complexity;
8. Uncertainty;
9. Number of technologies;
10. Rigidity of sequence;
11. Overlap of phases or concurrency; and
12. Organisational inherent complexity.

The Inherent complexity factor is made up of the following intersecting factors:

- Physically difficult role that requires simple or no equipment;
- Physically difficult role that requires the use of complex equipment;
- Technically complex role due to the sophistication of the equipment or method;
- Technically complex role that requires locally available special skills;
- Technically complex role that requires a special skill, knowledge and equipment; and
- Role that has no known procedure.

The Uncertainty factor is mainly made up of the following intersecting factors:

- Lack of uniformity due to lack of working space and or access;
- Lack of uniformity due to continuous change in material or other resources;
- Lack of uniformity due to mechanical or other resource breakdown;
- The effect of weather or climatic conditions;
- Unpredictable sub-surface (e.g. excavation in ancient city grounds);

- Unpredictable work in a defined new structure (e.g. as in new work added to old buildings without record drawings);
- Due to undefined structure or poor buildability assessment (e.g. refurbishment works of old buildings);
- Due to lack of working drawings (e.g. installation of M and E services in new buildings);
- As a result of overlap of design and construction;
- Due to environmental influence
- Cultural/social/legal environmental layer (e.g. a similar project in a new location)
- Technical core environmental layer (e.g. underwater construction, chemical);
- Due to lack of experienced local work force; and
- Conducting or managing such a role for the first time.

The Number of technologies factor is made up of two influencing factors:

- Repetition of the roles in each technology; and
- Interdependencies between the roles of various technologies in a task.

The Rigidity of sequence factor is affected by the following factors:

- Repetition of the same task;
- Rigidity of sequence between the various tasks within an operation;
- Rigidity of sequence between the various operations within a package; and
- Rigidity of sequence between the various packages within a phase.

The Overlap of phases or Concurrency factor is affected by the following factors:

- Degree of overlap of phases; and
- Interrelationships between activities in different overlapping parts.

The organisational inherent complexity is affected by the following factors:

- Information generation, transmittal, usage and feedback; and
- Decision making.

During the interviews a questionnaire survey was completed where each factor of complexity that had been identified was given a score on a Likert scale of one to ten based upon how much effect it had upon the project. The importance index (Ip) was then calculated using the function described earlier. Table 1 shows the ranking of the main factors by their importance index. It should be noted that only factors which were felt would increase the complexity were considered and therefore factors such as repetition of the same task were not included.

Organisational complexity scored consistently highly in the questionnaires giving it the greatest importance index (Ip) of 0.819. This was calculated using the following method:

$Ip = \sum(af)/AF$

$Ip = [(10x4)+(9x4)+(8x4)+(7x2)+(5x1)+(4x1)] / (10 \times 16)$

$Ip = 0.819$

This was by far the highest scoring component with the next highest being uncertainty with an Ip of 0.733. This indicates that organisational complexity has a considerable impact upon the project complexity. Uncertainty also scored highly, this may be due to the fact that uncertainty can relate to many of the sub factors meaning it can affect the project in many different ways. Overlap of construction elements, inherent

complexity and rigidity of sequence followed with Ip's of 0.675, 0.644 and 0.600 respectively. Number of trades was ranked the lowest with an Ip of 0.488. Interestingly, although the definition of complexity indicates that it is the interactions between many parts that make something complex, the number of trades scored the lowest, indicating that it is about the interaction between the parts that is important in terms of complexity, not necessarily the number of parts that make up the project.

Table 8 Main factors of project complexity

Rank	Main factors	Importance index
1	Organisational complexity	0.819
2	Uncertainty	0.733
3	Overlap of construction elements	0.675
4	Inherent complexity	0.644
5	Rigidity of sequence	0.600
6	Number of trades	0.488

Each of the main factors is further broken down into a number of sub factors of project complexity. By identifying the main factor that makes a project complex, it is anticipated that the sub factor scoring the highest would be those relating to organisational complexity. This is indeed the case with poor channels of communication and poor generation and use of information having the two highest Ip's of the 27 sub factors (all of which can be seen in Table 2). Also rated highly are those sub factors which relate to the interaction and interrelationship between parts in a project, this concurs with the definition of complexity. The factors which were rated the lowest were those that related to the technical complexity involved.

The two sub factors relating to the organisational complexity, poor channels of communication and poor generation and use of information were ranked the highest with Ip's of 0.906 and 0.800 respectively. The factor ranked the lowest was physically difficult role that requires simple or no equipment with an Ip of 0.338. An important concept to note is that whilst alone many of these factors contribute to making a project complex; it is the premise of this research that it is in fact when a combination of these factors are encountered that the greatest effect is experienced. Simply having a project that has a high degree of overlap between design and construction can be complex but manageable, however when this is coupled with poor channels of communication and high interdependencies between roles the project becomes much more complex. In practice, it is unlikely that any large project will only encounter one of the factors which can make a project complex and therefore understanding where the complexity comes from and the combinations of the factors is of key importance to being able to properly manage and deal with the complexity in any project.

Table 9 Sub factors of project complexity

Rank	Sub factors	Importance index
1	Poor channels of communication	0.906
2	Poor generation and use of information	0.800
3	Lack of working drawings	0.775
4	Role that has no known procedure	0.763
5	Lack of uniformity due to continuous change in material or other resource	0.750
6	High degree of overlap of design and construction	0.731
7	Technical core environmental layer (e.g. underwater construction, chemical)	0.719
8	High degree of interrelationship between activities in the different overlapping parts	0.706
9	High interdependencies between the roles of various trades in a task	0.700
10	Lack of uniformity due to lack of working space and or access	0.694
11	Technically complex role the requires special skill, knowledge and equipment	0.675
12	Conducting or managing a role for the first time	0.656
12	High degree of overlap of construction phases	0.656
14	Lack of experienced local workforce	0.650
15	Unpredictable work in a defined new structure (e.g. as in new work added to old buildings without record drawings)	0.631
16	Undefined structure or poor buildability assessment (e.g. refurbishment works of old buildings)	0.625
16	Environmental influence – cultural/social/legal environmental layer	0.625
18	Unpredictable sub-surface	0.606
19	Rigidity of sequence between the various operations within a package	0.594
20	Physically difficult role that requires the use of complex equipment	0.588
21	Technically complex role that requires locally available special skills	0.581
21	Rigidity of sequence between the various packages within a phase	0.581
23	Technically complex role due to the sophistication of the equipment or method	0.575
24	Rigidity of sequence between the various tasks within an operation	0.565
25	The effect of weather or climatic conditions	0.538
26	Lack or uniformity due to mechanical or other resource breakdown	0.494
27	Physically difficult role that requires simple or no equipment	0.338

The questionnaire was completed as part of the interview and therefore clarification could be sought if necessary. Whilst the interviews provided additional information pertinent to this field of research, Table 2 provides a summary of the factors of complexity taken from the survey.

The idea that every project is different and therefore complex for its own reasons was one that was raised a number of times throughout the data collection process, however

it was also recognised that there are certain similarities and common processes between many projects that are undertaken. It was accepted that to some degree all of the project complexity factors had some effect on project complexity; however, some were identified as having a greater impact than others. When describing what made a project complex, both from the semi structured interviews and the questionnaire surveys, issues relating to the people working on a project were consistently identified as those which make the project most complex and those which are the most difficult to deal with. These included poor communication between project parties and having a poor brief at the outset of a project. Having to deal with a large number of different stakeholders all with different interests or aspirations for the project was also highlighted as an issue which had the greatest impact on the project. As well as being the most difficult to deal with, these sorts of issues were also suggested to be the most difficult to predict.

Issues regarding the technical or physical complexity were also identified as having an impact upon the project complexity, although it was recognised that these may be easier to contend with and predict than the organisational aspects of complexity. The factors that were identified as having the most effect on project complexity relating to the technical or physical complexity of a project were those concerned with the interactions and interdependencies between elements of a project. Also identified were those having a high degree of leading edge technology and issues concerning the environment in which the project is carried out.

From this it is therefore proposed that project complexity is split into two aspects, the organisational aspect and the technical or physical aspect. However, it is essential that whilst these can be considered as separate aspects of project complexity, it is understood that one can affect the other and vice versa and therefore they should not be considered irrespective of each other.

CONCLUSION

The aim of this paper was to identify the factors which make a project complex. This has been achieved via literature review and semi structured interviews incorporating a questionnaire survey. Six main factors of complexity and 27 sub factors have been identified and ranked by establishing their importance index.

The data collection and analysis methods were carefully selected in order to collect the most relevant and appropriate data for the purpose of this research. Semi structured interviews were conducted with industry experts identified through a stringent selection criteria. As part of the interview process, a questionnaire survey was used in order to ascertain the effect of a number of different sources of project complexity. This mixed approach of both qualitative and quantitative data collection was used in order to collect the most useful data and to avoid some of the negative aspects of using just one form of data collection such as poor questionnaire response rates. Whilst it is accepted that a small sample was used in this stage of the research, the findings will be built upon through further investigations in the next stage of the research. Mixed methods research is becoming a much more widely adopted methodology and is particularly appropriate in a study such as this where both qualitative and quantitative data are useful.

It is important to identify the factors of project complexity in order to be able to better manage projects and successfully achieve the project outcomes. Complexity can impact the project in a number of ways and therefore it is necessary to identify and

understand the project complexity in order to understand the consequences to the project.

The factors which were felt to have the greatest impact were those relating to the organisational aspect of a project. The technical and operational aspects of the project were also seen to affect the complexity but it was suggested that they caused less difficulties. This has a great impact upon the study as the technical and operational issues are much simpler to identify and anticipate that issues relating to the organisational aspect of the project. The next stage of the research will focus more on how great an impact the factors have and the implications that each factor or combinations of factors has on projects.

Whilst identifying the factors of complexity, it was recognised that a better understanding of the terms risk, uncertainty and complexity was needed in order to identify actual complexity issues. Many of the factors which were discussed in the interview process related more to risks or the management of risk issues than actual complex issues and therefore a methodology for identifying complexity factors is needed. This will be developed as part of the wider research project. This research has been undertaken as part of a global research project which aims to develop a model that can be used to evaluate the effects of project complexity at the pre construction stage in order to improve project planning. The next stage in this research will be to undertake case studies in order to assess the frequency with which the factors of complexity occur in projects and the impact that they have in order to identify the most significant factors and develop a methodology for measuring complexity.

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