

The factors of project complexity

Abstract

Construction projects are often described as being complex, however, the factors which make a project complex and the impact that they have upon a project are not widely understood. 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 these factors. 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. Case studies were then analysed to establish the frequency and impact of the project complexity factors. The research has identified factors of complexity, however there is a need to develop a methodology to effectively measure the complexity of a project focussing specifically on the pre construction stage.

Keywords: complexity science, project complexity, risk, uncertainty.

1. 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 the factors which make a project complex.

2. 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 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) have defined project complexity, however there seems still to be 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 the construction industry.

Construction is often described as a complex and risky business, 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 and 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 accusation 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 planned 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 is that any project should start with a clear 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 and assignments 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 a combination of factors that affect the standard response/actions taken to achieve the project outcomes.

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).

3. Factors of project complexity

3.1 Methodology

In order to establish the factors which make a project complex a questionnaire and interview was developed based upon the findings from an earlier literature review. A series of semi structured interviews incorporating a questionnaire survey were conducted with industry experts. 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 provided a comprehensive list of complexity factors and enabled an Importance index (Ip) to be derived. From this a clear understanding of what is felt makes a project complex can be seen. The Ip was found using the following function:

$$I_p = \sum(af)/AF$$

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
- work in the south east of England

- have a construction related degree or equivalent qualification
- 10 years plus construction experience
- experience in planning/risk issues

It was essential that the interviewee had some experience of working on what they considered to be complex projects in order to establish what were considered to make project complex, it was also essential that the interviewee was in a management position so that they considered the whole of the project. It was preferable that interviewees were based in the south east of England in order to make travelling to conduct the interviews practical within the time limitations of a project of this type. It was also necessary that the interviewees have a construction related degree or equivalent qualification and had at least 10 years experience in the construction industry to ensure that they had relevant experience to contribute to the research. It was also beneficial if the interviewee had experience of either project planning or risk issues.

Interviewees were assured of confidentiality during the interview process, therefore no company names or names of interviewees will be published in any of the data resulting from the interviews.

3.2 Project complexity factors

From the literature 27 factors were identified which could be categorised by the following six main factors:

1. Inherent complexity;
2. Uncertainty;
3. Number of technologies;
4. Rigidity of sequence;
5. Overlap of phases or concurrency; and
6. Organisational inherent complexity.

During the interviews 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 components by their importance index. 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:

$$I_p = \frac{\sum(af)}{AF}$$

$$I_p = \frac{[(10 \times 4) + (9 \times 4) + (8 \times 4) + (7 \times 2) + (5 \times 1) + (4 \times 1)]}{(10 \times 16)}$$

$$I_p = 0.819$$

This was by far the highest scoring factor 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 subcomponents 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 makes up the project.

Table 1 Main factors of project complexity

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

Each of the 27 factors identified were categorised by a main factor. By identifying the main factor that makes a project complex, it is anticipated that the factors 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 components. Also rated highly are those 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 individual tasks in a project and the technical complexity involved.

The two 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.

From further analysis of the questionnaire and interview data, a total of 46 project complexity factors were identified. From the 46 factors, five themes of project complexity emerged. It is important to note that whilst 46 project complexity factors were identified, it is accepted that this is not an exhaustive list; however, it covers much of what is considered to contribute to the majority of project complexity experienced. The five themes encompass all of the factors identified from both the literature review and the questionnaire and interview process.

1. Organisational (people involved/relationships)
2. Operational and technological
3. Planning and management
4. Environmental
5. Uncertainty

The organisational theme of project complexity is related to the people involved in a project and the relationships between project parties. This is an important theme to include as it was often cited throughout the interviews and questionnaires as a major contributor to project complexity and as being the most difficult to predict and manage. The organisational aspect is made up of the following factors:

1. Poor relationships between the project parties
2. Having a large number of project stakeholders
3. Problems with the client
4. Poorly defined project roles
5. Poor communication
6. Poor decision making

The operational and technological theme combines the factors concerning the building process, the technology involved and the inherent difficulty of the process itself. The operational and technological aspect is made up of the following factors:

7. High amount of mechanical and electrical installations
8. High degree of technology
9. Incorporating state of the art/leading edge or new technology
10. Performing a process for the first time
11. Regulations to be adhered to
12. Physical size
13. High number of trades involved
14. High degree of physically complex roles
15. High degree of technically complex roles
16. Role that has no known procedure
17. The inherent difficulty of the building process

The planning and management theme consists of the factors relating to the planning, rigidity of sequence and concurrency of a project. The planning and management aspect is made up of the following factors:

18. Large number of elements that make up a process
19. High level of interdependencies between processes
20. Project coordination
21. Organisational structure
22. Having substantial critical path activities
23. High cost/value
24. Long timescale projects
25. Rigidity of sequence
26. Degree of overlap of phases
27. Interrelationship between activities in different overlapping parts
28. Poor information generation, transmittal, usage and feedback

The environmental aspect consists of all the factors relating to the projects environment, including the physical, social, legal and economic. The environmental aspect is made up of the following factors:

29. Sites in a restricted environment
30. Sites in a public environment
31. Sites in an ancient environment
32. Sites in an exposed environment
33. Sites on contaminated land
34. Brownfield sites
35. Understanding the market conditions
36. Understanding the legal environment
37. International projects

The uncertainty theme consists of factors relating to a number of different areas of the project but specifically those that can not be or are difficult to accurately predict. The uncertainty aspect is made up of the following factors:

38. Lack of uniformity due to continuous change in resources
39. Lack of uniformity due to mechanical or other resource breakdown
40. The effect of weather or climatic condition
41. Unpredictable sub surface
42. Undefined work in a defined new structure
43. Undefined structure or poor buildability assessment
44. Lack of working drawings
45. Uncertainty resulting from overlap between design and construction
46. Lack of experienced local workforce

It has been accepted that it may have been possible to classify some of the factors into more than one of the themes identified. However in order to model the project complexity, it is necessary to sort them into one theme only, and therefore the most relevant theme has been selected.

3.3 Discussion

By studying the data it can be seen that there are a number of themes of project complexity, each incorporating many factors which can add to the complexity of a project. 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. This similarity has allowed for a number of common factors which make a project complex to be identified. It is however recognised that there may be unique situations in some projects which are not covered by the factors identified.

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. Poor communication between project parties and having a poor brief at the outset of a project were cited as some of these problems. Having to deal with a large number of different stakeholders all with different interests or aspirations for the project was also often suggested as one of the issues which had the greatest impact on the project. These types of problems relating to the people involved in the project were also suggested to be the most difficult to predict and manage.

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 previously discussed. 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, having a high degree of leading edge technology and issues concerning the environment in which the project is carried out. Therefore project complexity can be viewed in 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. This concurs with the earlier research conducted by Gidado (1996) where project complexity was seen in two similar perspectives.

This is also in conjunction with the views of Baccarrini (1996) who also describes complexity as consisting of the technological aspect and the organisational aspect. This research has built

upon this earlier work by identifying the specific individual factors that make a project complex and categorised them into five themes. Whilst incorporating the two aspects already discussed, organisational and technological, three further themes have been added, including planning and management, environmental and uncertainty factors.

4. Conclusion

The aim of this paper has been to identify the factors that contribute to project complexity and to establish the current understanding of the term complexity in the construction industry. This has been achieved by conducting semi structured interviews incorporating a questionnaire survey with industry experts and analysing the results accordingly.

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 appropriate data and to avoid some of the negative aspects of using just one form of data collection such as poor questionnaire response rates.

A number of outcomes have resulted from the data collection and analysis process. The primary deliverable of this paper is the list of factors and themes of complexity. From the findings, it was shown that the sources of project complexity could be divided into two distinct categories. These were the sources of complexity originating from the organisational complexity and the sources of complexity originating from the technical or physical complexity. The organisational complexity consists of factors such as relationship difficulties between the project parties which may lead to poor transmittal of information, having an unclear brief at the outset of a project and having a large number of stakeholders in the project. The technical or physical complexity consists of factors originating from problems with the environment in which the project is taking place, the types of technology incorporated into a project and the interdependencies and interrelationships between project factors. Whilst this distinction can be made between the sources of project complexity, it is important to keep in mind that the factors in each of these categories can affect each other and therefore these cannot be considered as completely separate entities. In addition to these two aspects of project complexity, five themes were identified into which the 50 factors could be categorised.

Of key importance to the research was that the complexity in a project needs to be identified at the earliest stage possible in order to be able to manage it appropriately. Whilst it wasn't seen as necessary to have a numerical measure of complexity, identifying where the complexity lies in a project was identified as a critical factor to project success.

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 use information regarding the frequency and effect of these factors which has been gathered from case studies in order to identify the most significant factors and develop a methodology for measuring complexity.

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