Dictionary simply defines complexity as having a large number of interacting parts. Construction projects are often referred to as being complex; however there seems to be no universally accepted definition of the term project complexity in the construction industry. As part of a global research project aimed at establishing the impact of project complexity on project risks at the pre-construction stage, research has been undertaken to establish the current understanding of the term complexity in relation to construction projects in order to produce a clearer definition of the term project complexity for the construction industry. The application of complexity science to the construction industry is not widely researched, however, evidence has been found that the process of construction can in itself be thought of as a complex system. Literature search in the fields of systems thinking and complexity science have been carried out. Structured interviews with practitioners were conducted to confirm and build upon the findings of the literature review to gain an insight into what makes a construction project complex. The findings seem to suggest that the definition of project complexity involve a number of factors beyond simply having a large number of interacting parts. The research reported in this paper therefore provides a greater understanding of the science of complexity in construction and identifies what is understood by the term complexity in the construction industry context. The results seem to suggest that the definition of a complex project should refer to the interaction, interdependencies and interrelationships between parts of a project and that the greatest deal of complexity lies within the organisational aspects of a project.

Keywords: system, systems thinking, complexity science, project complexity.

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 construction industry. The concept of complexity science is still relatively recent in academia and holds much scope for modern problems that perhaps a more traditional scientific view has struggled with. With this in mind, exploring the science of complexity and investigating how it can be applied in industries other than construction could hold many insights into how the construction process could be improved.

Project success in terms of cost and time over runs, quality and even health and safety is historically poor in the construction industry. It is a commonly held opinion that the reason for the poor performance is the design and construction processes being particularly complex. Being able to measure the complexity at an early stage in a project will lead to better understanding of the project
and therefore could be of great benefit in successfully managing projects and reducing the risks associated with complexity.

2. Complexity science

In essence complexity science is a new approach to science, which studies how relationships between parts give rise to the collective behaviours of a system and how the system interacts and forms relationships with its environment. Complexity science represents a growing body of interdisciplinary knowledge about the structure, behaviour and dynamics of change in a specific category of complex systems known as complex adaptive systems – open evolutionary systems in which the components are strongly interrelated, self-organising and dynamic. Rain forests, businesses, societies, our immune systems, the World Wide Web, and the rapidly globalizing world economy can be thought of as complex adaptive systems. Each of these systems evolves in relationship to the larger environment in which it operates (Sanders, 2003). The interplays between order and disorder, predictability and unpredictability, regularity and chaos, are characteristics of complex systems. Complex systems abound in the real world, and they reflect the world’s inherent irregularity. The real world is a world of complexity, of messiness, of change, flow and process and cannot be pinned down to the simple, solid, unchanging objects people like to cut out of it (Merry, 1995).

There are a number of definitions in the literature describing complexity science and complex systems. Dent (1999) suggests that “complexity science is an approach to research, study and perspective that makes the philosophical assumptions of the emerging worldview (EWV)”. Merry (1995) describes complex systems as those that self-organise themselves into states of greater complexity. An overview of the Santa Fe Institute provided by Merry (1995) says that complex behaviours may emerge from a number of the basic rules controlling parts of the system. That behaviour is not predictable from knowledge of the individual elements, no matter how much we know about them, but it can be discovered by studying how these elements interact and how the system adapts and changes throughout time. What looks chaotic at first may be predictable from an understanding of the patterns and rules of complex behaviour. Richardson et al (2000) state that a complex (adaptive) system can simply be described as a system comprised of a large number of entities that display a high level of interactivity. The nature of this interactivity is mostly non-linear. Stacey (2001) summarises the structure of a complex adaptive system as follows: The system comprises large numbers of individual agents; These agents interact with each other according to rules that organise the interaction between them at a local level. In other words, an agent is a set of rules that determines how that agent will interact with a number of others and this interaction is “local” in the sense that there is no system wide set of rules determining the interaction. The only rules are the rules located at the level of the agent itself. Agents endlessly repeat their interaction referring back to their rules, that is, interaction is iterative, recursive and self-referential. Agents’ rules of interaction are such that the agents adapt to
each other. The interaction is nonlinear and this nonlinearity is expressed in the variety of rules across
the large numbers of agents. Ongoing variety in the rules is generated by random mutation and cross
over replication. Complex systems cannot exist in isolation. By their very nature they are tied to and
connected to other systems, thus creating a dense web of connections between complex systems
throughout the world. As Merry (1995) said, affecting one system has repercussions in countless other
systems.

Complexity science has emerged from the field of possible candidates as a prime contender for the top
spot in the next era of management science. Richardson et al (2000) suggests that the general message
from the popular complexity science literature seems to be that, where we once focussed on the parts
of a system and how they functioned, we must now focus on the interaction between these parts, and
how these relationships determine the identity not only of the parts, but of the whole system.

Classical science, as practiced in the twentieth century, for the most part makes the philosophical
assumptions that are labelled as the traditional world view (TWV), which include underlying
assumptions of reductionism, objective observation, linear causation, entity as unit of analysis and
others (Dent, 1999). This TWV which has allowed people to make significant achievements in many
fields is no longer serving as a reliable guide. The rise of complexity science has paralleled an
increase in dissatisfaction with the TWV. In essence, Dent (1999) is suggesting that a new way of
thinking is needed to solve modern issues. Complexity is a new science precisely because it has
developed new methods for studying regularities and not because it is a new approach for studying the
complexity of the world. Science has always been about reducing the complexity of the world to
(predictable) regularities. Consequently, rather than define complexity science by what is studied (i.e.
a complex universe); the focus should be on the methods used to search for regularities (Phelan, 2001).

Complexity science introduces a new way to study regularities that differs from traditional science.

3. Complexity in construction

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”. It should be noted that the word
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.

Complexity is a term often used when discussing construction projects. In general construction
projects are all made up of many interconnecting parts so in that aspect fit the dictionary definition of
complexity well. However, complexity can be viewed as more than the simple definition we have so
far. It is a common statement that the construction process is one of the most complex and risky
Project complexity in construction

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. 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 further, adding 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.” Baccarini 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, they see a complex project as the following:

- 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: (1) The managerial perspective, which involves the planning of bringing together numerous parts of work to form work flow and; (2) The operative and technological
Project complexity in construction

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 plan to achieve a number of quantifiable objectives. From this, Gidado (1996) organises the sources of complexity factors that affect the managerial objectives in construction into two categories: (1) 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 and; (2) 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. Gidado (2004) also identified that project complexity has six main components, each made up of a number of intersecting factors, these are:

- Inherent complexity
- Uncertainty; Number of technologies
- Rigidity of sequence
- Overlap of phases or concurrency
- Organisational complexity

Baccarini (1996) highlights the importance of complexity to the project management process by making the following statements:

- 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; and
• 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 into contracts, activities, work packages, assignments etc. to be executed more or less interdependently. 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. Bertelsen (2003) 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.

Bertelsen (2003) also suggests that the complexity aspect must be seen in at least three perspectives. Firstly, the project itself is an assembly like process which is often more complicated, parallel and dynamic, and thus more complex than traditional project management envisages. The mistake is the assumption of the ordered view of the surrounding world. All supplies are believed to be made in accordance with projects unreliable schedule, and all resources such as equipment and crew are supposed to stand by, ready for the projects beck and call. Secondly, the construction industry is highly fragmented and its firms cooperate in ever changing patterns, decided mainly by the lowest bids for the project in question. They are also interwoven, as every firm at the same time participates in more than one project, utilising the same production capacity. Almost all projects are divided into parts that are subcontracted to individual enterprises, and these contracts are almost always made to the lowest prices. Thus we have a production system consisting of individual operators, each trying against odds to get a reasonable earning for their own business out of their lowest bid. This can only be done through an optimal resource utilisation. But as they all work with the same resources on more projects than the one in question, this ties our project firmly, but secretly, more or less to all other projects that are being executed in our region, and maybe the whole country. Nobody knows where
the ties are so tight that we get strong and unplanned influence from unforeseen events in other projects. The construction sector, due to its contracting practice, forms an interwoven network of high complexity and a great dynamic. Thirdly, the construction site is a working place for humans and a place for cooperation and social interaction, which because of the temporary character, forms a highly transient human system. This aspect is often hidden by the fact that staff at the production facility, the construction site, are not hired and reimbursed by the place where they work. Their loyalty is divided between their own firm and the job at hand, often with the firm as the one with the highest priority. Traditional project management often overlooks this aspect and does not perceive the gangs on the sites as their own employees in the virtual firm, which is formed by the project.

4. Methodology
The data collected has encompassed a mixture of both qualitative and quantitative data. This mixed approach has been used to gain the most appropriate data to fulfil the aim of the research. Questionnaires and semi structured interviews were designed based upon the information identified in an in depth literature review. The questionnaires comprised a number of questions asking the respondent to score each statement on a scale of one to ten. These statements relate to definitions and components of complexity that have been identified throughout the literature. The questionnaires were piloted on members of academic staff to ensure they were clear and concise. The semi structured interviews were used to build upon the information from the questionnaires and further explore how complexity is perceived in industry.

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

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
Project complexity in construction

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. The data from the questionnaires was used to derive an importance index and a severity index for each statement, allowing them to be ranked. From this a clear definition of complexity in construction can be generated and the most important components can be identified.

5. Results

These are preliminary results which are based upon the findings from the pilot study questionnaires and interviews. These interviews took place with experts in the field to ensure that relevant data was collected. Further interviews are to be carried out with a greater range of participants to expand the results. To date, seven interviews have been conducted, the participants have included directors of a large international project management consultancy, site based project managers and contracts managers and design managers for a large international contractor. It is clear from the results that project complexity is made up of a number of factors which makes project complexity a difficult entity to define and quantify, however, from the results it is also clear that some factors are considered far more important when defining project complexity therefore identifying what is considered to make a construction project complex.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Definition statement</th>
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<tbody>
<tr>
<td>1</td>
<td>Projects with a high interdependency between the parts</td>
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<tr>
<td>2</td>
<td>Projects with a high degree of interaction between the parts</td>
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<tr>
<td>2</td>
<td>Projects that are continuously changing/evolving</td>
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<tr>
<td>4</td>
<td>Projects made up of many interconnecting parts</td>
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<tr>
<td>5</td>
<td>Projects that are surrounded by an intricate environmental envelope</td>
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<tr>
<td>6</td>
<td>Projects comprising of entities with a high level of interface</td>
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<tr>
<td>7</td>
<td>Projects that have a high degree of non linear interaction with their environment</td>
</tr>
<tr>
<td>8</td>
<td>Projects that have a high level of non linear interaction</td>
</tr>
<tr>
<td>8</td>
<td>Projects having a number of complicated individual parts</td>
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<tr>
<td>10</td>
<td>Projects involving a high degree of diverse tasks</td>
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<tr>
<td>11</td>
<td>Projects that have high interaction with their environment</td>
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<tr>
<td>12</td>
<td>Projects that have a high dependency on their environment</td>
</tr>
<tr>
<td>13</td>
<td>Difficulty of executing individual tasks that make up a process</td>
</tr>
<tr>
<td>13</td>
<td>Projects with a great deal of intricacy</td>
</tr>
<tr>
<td>15</td>
<td>Projects with a large number of parts</td>
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Table 1 Definition statement ranking
Table 1 shows the ranking of the 15 definition statements from the questionnaire. Projects with a high degree of interaction between the parts scored the highest, followed by projects that are continuously changing/evolving and projects with a high interdependency between its various parts which scored equally and then projects made up of many interconnecting parts. Apart from projects that are continuously changing/evolving all the top scoring statements relate to the interaction and interdependency of the parts in a project. This suggests that the industry perceives projects with a high degree of interdependency, interaction and interrelationships between the parts as those projects which will be complex. This is in line with the dictionary definition of the term complexity; however, it is perhaps the components of project complexity which really identify what makes a project complex.
Table 2 shows the ranking of the main six components of complexity. Organisational complexity scored consistently highly in the questionnaires giving it the greatest importance index. Interestingly, although in the definition statements projects with a high level of interaction between its parts scored highly, in this section 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. Each of the main components is further broken down into a number of sub components of project complexity. By identifying the main component that makes a project complex, it is anticipated that the sub components 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 being identified as the top two of the 27 sub components that make a project the most complex shown in Table 3. Also rated highly are those sub components which relate to the interaction and interrelationship between parts in a project, this concurs with the high ranking of these factors in the definition statements. The components which were rated the lowest were those that related to the individual tasks in a project and the technical complexity involved.

An important concept to note is the fact that whilst alone many of these factors contribute to making a project complex, 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.

In addition to the information gained from the questionnaires, a number of interesting issues were identified as a result of the semi structured interviews which took place with industry experts. There is a general consensus that although technical aspects of a project can greatly add to the complexity, it is in fact the organisational aspects which contribute more to the complexity of the project. Whilst technical complexity is a definite factor in project complexity, it was felt that this was much easier to deal with than complex relationships and organisations. When rating the components from the questionnaire, the factors concerning organisational complexity were rated consistently high. Poor communication and poor use of information were seen as significant factor contributing to the complexity of a project.

Part of the organisational complexity that was highlighted was to understand the stake holder’s positions in the project, for example where there is a multi headed client, it was noted that this situation could greatly add to the complexity of a project due to the different interests of different stakeholders.
Another important factor relating to the complexity that was emphasised by the industry experts was the need to have a clear and well defined project brief and to understand the client’s needs. Without this understanding a project may become needlessly complex. It is vital that the client has a clear idea of what they want and that their needs are clearly communicated to other parties involved in the project.

Also identified was the need to distinguish between managing projects and programmes which include a number of projects as this has an obvious impact upon the complexity. A project that has a single building or development for example an office development project can be affected by all of the components identified earlier, however if this development is part of a much larger scheme including residential developments, school buildings, leisure facilities and all of the infrastructure needed for these, the complexity of the scheme as a whole becomes much greater as not only is each individual project subject to all of the factors of complexity already identified, but the interaction between each project must also be taken into account.

6. Conclusion
The aim of this paper has been to provide a greater understanding of the science of complexity and its applications to construction and to identify what is understood by the term complexity in the construction industry. This has been accomplished through means of an in depth literature review investigating complexity science and complexity in construction and then followed by a number of semi structured interviews and a questionnaire survey. The application of complexity science to the construction industry is not widely researched, however, evidence has been found that the process of construction can in itself be thought of as a complex system. It is argued that too often the construction process is thought of as an ordered, linear, and thus predictable, phenomenon which can be divided into contracts, activities and work packages which can be managed top down. This view of construction may be leading to the poor success rates in terms of time, cost and quality which are often experienced and a different perspective may improve this. The construction process should be perceived as a complex, dynamic phenomenon in a complex and non linear setting.

The findings presented here are from the early stages in the research and therefore will be further built upon via more widespread interviews with more industry experts. The results of the questionnaire and interviews seem to suggest that the definition of a complex project should refer to the interaction, interdependencies and interrelationships between parts of a project, which is similar to the dictionary definition of complexity. However, when investigating what actually makes a project complex, the organisational aspect of a project was seen to be the most important component. Findings support the observation made by Gidado (1996) that complexity has two perspectives in the industry, firstly the managerial perspective and secondly the operative and technological perspective. However a greater
deal of emphasis has been placed on the managerial or organisational structure than on the operational or technological perspective as these were felt to be simpler to.

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.

7. References


