AN OVERVIEW OF COMPLEXITY THEORY AND ITS APPLICATION TO THE CONSTRUCTION INDUSTRY

Hannah L Wood[1] and Kassim Gidado[2]

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

The theory and science of complexity are relatively new in the world of academia; this new way of thinking holds much scope when considering modern issues and problems. The term complex refers to a system that is made up of a large number of interacting parts and in essence complexity science is the study of these interactions. As part of a global research project aimed at establishing the impact of project complexity on project risks at the pre-construction stage, a literature search type investigation concerning complexity science and its potential application to the construction industry has been carried out. Initial investigation reveals that there is a limited number of studies in the meaning and application of complexity science within the construction industry; therefore the literature search put more emphasis on how other industries understood, applied and managed complexity in order to draw lessons learnt which may be applicable to the construction industry. It is a common statement that construction projects are considered to be one of the most complex operations, therefore an understanding of project complexity and how it might be managed is of significant importance. Although some research work around the area of project complexity in the construction industry has been carried out in the past, there is still no real clear acceptable definition of project complexity in construction by today's standards. Therefore this paper aims to evaluate the potential application of complexity science in construction industry and attempts to provide a clearer definition of project complexity in the construction industry.

Keywords: construction industry, complexity science, project complexity.

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

[1] hw35@brighton.ac.uk

[2] k.i.gidado@brighton.ac.uk

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benefit in successfully managing projects and reducing the risks associated with complexity.

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; 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.

APPLYING COMPLEXITY THEORY TO PRACTICAL PROBLEMS

When complexity is discussed it is often at a theoretical or abstract level with little practical application. A number of authors have noted the difficulties of turning theory into practice in relation to complexity science. Smith and Graetz (2006) and Brodbeck (2002) document some of these opinions by stating that the practical applications of complexity theory are less obvious than the theory itself. Smith and Humphries (2004) concluded that complexity theory is difficult to translate into practice and Moldoveanu and Bauer (2004) said that while complexity theory has made significant progress it still remains an elusive perspective when it comes to articulating sharp formulations. However, there is also the opinion that complexity science can be a realistic solution for modern scientific and industrial problems. McElroy (2000) described complexity theory as a confident solution in search of unorthodox problems providing an explanation for the means by which living systems engage in adaptive learning. Smith and Graetz (2006) go on to explain that the limitation with complexity theory however is that its explanatory value is more apparent than its prescriptive implementation; a by-product of its very nature, that of non-linear systematic interaction. In spite of all these claims, it is established that complexity theory can be applied practically in management of organisations and in manufacturing process as described below:

Complexity in Management of Organisations

Stacey et al (2000) discusses how within the natural science there are differences on what the new sciences of complexity mean. He continues to discuss that similarly, in the field of management and organisation the ideas emanating from the complexity sciences are also being taken up in very different ways. For some it justifies a return to simpler and more fundamental ways of managing people and organisations that are more in touch with the deeper nature of human beings. While for others, it amounts to a call for more democracy in organisations, or greater shareholder participation. Then there are those who claim that human freedom liberates people from self organisation and allows them to design or condition emergence. There are also those who see the complexity sciences as requiring managers to push their organisations into the dynamics of instability. For others it raises question marks over strategic planning and the possibility of forecasting, so calling for a reconsideration of the nature of control in organisations. Others fear that nonlinear dynamics will be used to justify untrammelled market competition, or social and psychological "engineering".

Applying complexity theory to management is not straightforward and simple. Smith and Graetz (2006) suggest that despite the promise complexity theory holds as a conceptual framework for organising, some further paradox and ambiguity remains in its application to organisations. It has also been suggested that complexity principles do not transfer well to social systems like organisations, and at the very least complexity is difficult to analyse in action (Houchin, 2005). When discussing how to apply complexity theory to management in organisations, it is first important to understand the problems being experienced.

Rosenhead (2001) explains how the traditional management style does not fit with complexity theory summarising some of the received wisdom about how well managed businesses (and the public sector agencies which emulate them) should proceed. He goes on to suggest that there should be a Chief Executive Officer presiding over a cohesive management team with a vision or strategic intent supported by a common culture. The organisation should stick to its core business and competencies, build on its strength, adapt to the market environment and keep its eyes focused on the bottom line. He also suggests that despite the critical hammering taken by 1970's style long term planning, strategic management will nevertheless incorporate the tasks of goal formation; environmental analysis; strategy formulation, evaluation and implementation; and strategic control, all of which are completely wrong from the perspective of management writers influenced by complexity theory. Rosenhead (2001) completes his argument stating that the kind of management theory and practice described above which bears the hallmarks of the over rationalist thinking which has dominated since the triumphs of Newton and Descartes where the organisation , like the universe, is conceptualised as a giant piece of clockwork machinery which is thought, in principle, to be entirely predictable. However, discoveries by theorists of complexity and chaos show that even the natural world does not operate in this way – and this revelation of the role of creative disorder in the universe needs to be taken to heart by managers.

Rosenhead (2001) work identified that the lessons for managers that can be drawn from complexity theory can be divided, loosely, into two categories: general suggestions as to how managers should approach their jobs, and more detailed prescriptions for particular tasks. The general lessons concern how learning can be fostered in organisations, how they should view instability, and the (negative) consequences of a common internal culture. The need for an emphasis on learning stems from the central finding of this theory – that the future is in principle unknowable for systems of any complexity. If we accept that we can have no idea of the future environment, then long term planning becomes an irrelevance, if not a hindrance. This absence of any reliable long term chart makes learning crucially important. Rosenhead (2001) suggests that rather than trying to consolidate stable equilibrium, the organisation should aim to position itself in a region of bounded instability, to seek the edge of chaos. The organisation should welcome disorder as a partner, use instability positively. In this way new possible futures for the organisation will emerge, arising out of the (controlled) ferment ideas which it should try to provoke. Instead of a perfectly planned corporate death, the released creativity leads to an organisation which continuously reinvents itself. Members of an organisation in equilibrium with its environment are locked into a stable work pattern and attitudes; far from equilibrium, behaviour can emerge more easily.

Complexity in manufacturing

The manufacturing process could be reasonably compared with the construction process and it is therefore useful to identify how complexity theory can be applied to manufacturing. Today's competitive world means contradictory and barely achievable objectives for factories, which are frequently required to perform at the edge of their performance capabilities. Calinescu *et al.* (1998) suggest that in order to cope with this dynamic environment, companies introduce more flexibility in their processes and systems. Although flexibility may bring benefits such as increased production and product customisation, if not properly controlled it could also lead to ineffective decision making, longer lead times, unachievable plans, larger inventories, higher costs and customer dissatisfaction, namely to non predictable, non controllable, inefficient and ineffective systems. Adding flexibility to the factory floor increases the scheduling alternatives and hence, the decision making complexity. Furthermore, high levels of poorly controlled complexity leads to poor schedule quality, poor reliability and lack of stability. Calinescu *et al.* (1998) also highlight that the technological solutions currently offered for solving this trade off do not take adequate account of complexity and of its effect on system performance.

Like in construction, no global and unifying approach has been offered so far on manufacturing complexity. Calinescu *et al.* (1998) gave the reasons for the lack of a universal modelling framework of manufacturing complexity include the variety, dynamism and uncertainty of the sources of complexity and of the relationships between them, as well as the associated computational burden involved in modelling.. Calinescu *et al.* (1997) identified the following components as determining manufacturing complexity: the product structure, that is the number of different items, and for each product: number and type of sub-assemblies, lead and cycle times, lot sizes, type and sequence of resources required to produce it; the structure of the shop or plant, that is the number and types of resources (multi-skilled or not; global vs. dedicated), layout, set-up times, maintenance tasks, idle time, performance measures; the planning and scheduling functions, comprising of planning and scheduling strategies, the documents used for scheduling and the decision making process; the information flow: internal (during the decision making process, team working), intra-plant (with other departments), and external (with other plants, suppliers and customers); the dynamism, variability and uncertainty of the environment (customer changes, breakdowns, absenteeism, data inaccuracy and unreliability, scrap/rework, etc); and other functions within the organisation (training, political information, etc). These are similar to the components of project complexity identified in the construction industry.

Assessing the complexity in manufacturing systems is absolutely necessary for gaining a thorough description of the system and an awareness of the extent of the problems, or their causes and effects. The complexity measurement task presupposes the involvement of different resources in different departments, people and machines. So, it is time consuming; it also requires involvement, honesty and a genuine desire to learn and improve on the part of all involved in the project. Therefore, it may not be carried out thoroughly.

Deshmukh *et al.* (1998) states how manufacturing systems are often described as being complex and state that the dynamic nature of the manufacturing environment greatly increases the number of decisions that need to be made and system integration makes it difficult to predict the effect of a decision on future system performance. The manufacturing environment consists of physical systems in which a series of sequential decisions need to be made in order to produce finished parts. The sequence and nature of these decisions are not only dependent on the system capabilities but also on the products being manufactured in the system. Hence, any measure of system complexity should be dependent on both the system and product information. The difficulty in making production decisions arises from the number of choices available at each decision point and the unpredictability of the effects of each choice on the system performance. Deshmukh et al stress the need to quantify the notion of complexity in order to compare different system alternatives. The lack of understanding in this area has also hindered planners in deciding how much integration is beneficial and beyond which point integration is actually detrimental to system performance, since correct decisions are difficult to make due to high system complexity. Another important consequence of developing an analytical framework for complexity would be to assist manufacturing planners in managing desired levels of complexity in the system, since realistically it cannot be eliminated, depending on the changing operating systems. This statement is particularly relevant to the construction industry.

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”. 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 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.” 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, 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 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; and 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 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 in to 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 a project's 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.

CONCLUSION

The aim of this paper has been to evaluate the potential application of complexity science in the construction industry and to attempt to provide a clearer definition of project complexity. This has been accomplished through means of an in depth literature review investigating complexity science in general as well as how complexity is viewed in construction and other industries. 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 definition of project complexity for construction provided by Gidado (1996) seems to have captured most of the issues, while Gidado (2004) has identified the components. However, further investigative work is to be carried out in this area which may lead to a more advanced definition being formulated.

As a result of the work described in this paper, it is identified that an additional component of construction project complexity needs to be added to the list of components in Gidado (2004). The new component is information flow (internal, intra-plant, and external) which is identified by Calinescu et al (1997) in their work on complexity in the manufacturing process.

By studying the literature on complexity science and how complexity is perceived in other industries a number of themes have been identified. More than anything else complexity science is about a new way of thinking, challenging the traditional scientific view of systems, it has been suggested that a good way to deal with complexity is to think creatively. Also highlighted in the literature is the idea that complexity doesn't have to be perceived as negative and threatening, much the same as risk, complexity can be viewed as an opportunity for gain. In addition to this the idea of having a practical measure of complexity in order to be able to better manage complexity has been identified, especially in the literature concerning other industries. Another issue identified is the need to consider the system as a whole, looking not only at the parts of system itself but also the environment in which it operates; this is of key importance in construction project.

REFERENCES

Baccarini, D (1996) The concept of project complexity: a review. *International Journal of Construction Management*, **14**, 201-4.

Bertelsen, S (2003) Complexity: construction in a new perspective. *In: 11th Annual conference in the international group for lean construction*, Blacksburg, VA.

Brodbeck, P W (2002) Complexity theory and organization procedure design. *Business Process Management*, **8**, 377-402.

Calinescu, A, Efstathiou, J, Sanders, T and Bermejo, J (1997) Modelling and simulation of a real complex process based manufacturing system. *In: 32nd International Matador Conference*, UK, 137-42.

Calinescu, A, Efstathiou, J, Schrin, J and Bermejo, J (1998) Applying and assessing two methods for measuring complexity in manufacturing. *Journal of Operational research society*, 49, 723-33.

Dent, E (1999) Complexity science: A worldwide shift. *Emergence*, **7**, 5-19.

Deshmukh, A V, Talavage, J J and Barash, M M (1998) Analysis of static complexity: special issue of design and manufacturing on virtual manufacturing. *IEE Transactions*, **30**, 645-56.

Dictionary (2006) *Collins English dictionary and thesaurus*. Fourth edition ed. Glasgow: Harper Collins.

Gidado, K (1996) Project complexity: The focal point of construction production planning. *Construction Management and Economics*, **14**, 213-25.

Gidado, K (2004) Enhancing the prime contractors pre construction planning. *Journal of Construction Research*, 5, 87-106.

Houchin, K and MacLean, D (2005) Complexity theory and strategic change: An empirically informed critique. *British Journal of Management*, **16**.

McElroy, M (2000) Integrating complexity theory, knowledge management and organisational learning. *Journal of Knowledge Management*, **4**, 195-203.

Merry, U (1995) *Coping with uncertainty: insights from the new sciences of chaos, self organisation and complexity*. Westport: Praeger publications.

Mills, A (2001) A systematic approach to risk management for construction. *Structural survey*, 19, 254-2.

Moldoveanu, M and Bauer, R (2004) On the relationship between organisational complexity and organisational structuration. *Organisation Science*, **15**, 98-118.

Mulholland, B and Christian, J (1999) Risk assessment in construction schedules. *Journal of Construction Management*, JAN/FEB 99, 8-15.

Phelan, S (2001) What is complexity science, really? *Emergence*, **3**, 120-36.

Richardson, K, Cilliers, P and Lissack, M (2000) Complexity science: A grey science for the stuff in between. *In: 1st International conference on systems thinking in management*, Deakins University, Australia.

Rosenhead, J (2001) *Rational analysis for a problematic world revisited: Problem structuring methods for complexity, uncertainty and conflict*. Second Edition ed. Chichester: John Wiley and Sons.

Sanders, T I (2003) cited 2007 *What is complexity*. [Available online from http://www.complexsys.org/.] Accessed on 26th October 2007.

Smith, A and Humphries, C (2004) Complexity theory as a practical management tool: A critical evaluation. *Complexity and Organisations*, **6**, 353-60.

Smith, A and Graetz, F (2006) Complexity theory and organising form dualities. *Management Decision*, **44**, 851-70.

Stacey, R D (2001) *Complex responsive processes in organisations: Learning and knowledge creation*. London: Routledge.

Stacey, R D, Griffin, D and Shaw, P (2000) *Complexity and management: Fad or radical challenge to systems thinking*. London: Routledge.