MOVING BEYOND PROJECT COMPLEXITY: EXPLORING EMPIRICAL DIMENSIONS OF COMPLEXITY IN THE CONSTRUCTION INDUSTRY

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Complexity is not an under-researched concept within the construction industry. However, because of the nature and characteristics of this concept, most of the works have traditionally tended to approach it in a reductionist manner, concentrating on project complexity above all others. Therefore a more comprehensive understanding aimed at being able to make more informed decisions correspondent to the specification of new construction in the age of digital tectonics should be developed. As there is an undeniable need for new vantage points, the data should come directly from the immediate context in which complexity is to be scrutinised. A deductive approach based on in-depth study of live cases is deemed appropriate for this purpose. With reference to our previous theoretical framework, this paper deepens the quest for a more intelligent decision process by investigating construction case studies. This review of cases will be carried out using our alternative way of reading complexity which is nurtured by its meaning in many other disciplines, encompassing all aspects of complexity in a more holistic manner. The findings of the study are to be further developed through additional research in order to substantially contribute to a more up-to-date, fit-for-purpose decision framework to effectively manage complexity comprehensively where and when required in the construction industry.

Keywords: complexity, case study, systems, complexity science.

INTRODUCTION

The building sector has traditionally been taken for granted by those who are involved in it, ranging from professionals to users and from academics to practitioners. This is because they all have been used to having a selective and fragmental interpretation of it. Despite this very tradition, the building sector is by nature tremendously and arguably contradictory and complicated. The complexity and contradiction are mainly rooted in the differences inherited in the construction processes and their cross -sectional relation. By tradition the processes, as the container, are linear whereas the relations between those processes, as the contained, are usually non -linear. The Chartered Institute of Building (CIOB) (2007&2013) found that complex projects are highly likely to run over time using traditional management techniques and that a new way of thinking is required. This paper aims to highlight the importance of considering all aspects of complexity in the Architecture, Engineering and Construction (AEC) industry, and not focusing purely on those aspects that we are familiar with. The paper uses case studies of 'complex projects' to demonstrate the

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varying scope of complexity that is experienced in the industry to identify the need for a rereading of the concept of complexity in the AEC industry.

COMPLEXITY

Adhering to a neutral standpoint with an exploratory nature in our enquiry, in a previous paper we investigated different types of complexity and classified them as: Behavioural; Organisational; Project; Systematic; Social; Organic; Data; and Technological (Wood *et al*. 2013). Deuchars (2010) believes that the social sciences, in comparison [with pure sciences i.e. physics, biology and mathematics] have been relatively less successful in their attempts to understand complex social systems. Therefore it would seem amiss to artificially separate physical systems from social ones. However, it is essential to remember that more often than not it is very difficult if not impossible at all to: study complexity merely and exclusively in one discipline and; ignore how the concept of complexity in one discipline is formed, and/or informed by its meaning in other fields. Complexity refers to the fact that in a system there are more possibilities than can be actualised (Luhmann 1985) and irreducible heterogeneity is tantamount to complexity (Katz 1986). The formal definitions of complexity as Stewart (2001) suggests fits into two main groups: algorithmic complexity, deriving largely from computer mathematics; and organisational complexity, deriving from the new biology and a revivified systems theory. As a rather simple algorithmic definition, the complexity of a system is tentatively the quantity of information needed to describe it (Cohen and Stewart 1995). Organisational complexity, by contrast, is more concerned about the behaviour of a system and its analysis (Nicolis and Prigogine 1989). Or as Coveney and Highfield (1995) suggest within science… complexity is the study of the behaviour of macroscopic collections of basic but interacting units that are endowed with the potential to evolve. Some other characterisations within social science disciplines can be of significant help in casting light onto the notion of complexity with specific purposes of the current research, despite Deuchars' (2010) suggestion that social sciences have been less successful in their attempts to understand complex social systems: '…the degree of complexity in organized social systems…is a function of the number of system components…, the relative differentiation or variety of these components…, and the degree of interdependence among these components' (La Porte 1975:6). What can be adopted from this and adapted to the specifics of this research is first of all the elements (referred to as system components), secondly their variation (variety or differentiation) and lastly but equally important, their degree of interdependence.

Theories of Complexity

Theories of complexity stemmed from the attempts by meteorologists, biologists, chemists, physicists and natural scientists to build mathematical models systems in nature (Gleick 1988; Lorenz 1993; Styhre 2002; Burnes 2004). In this process some particularly distinct theories appeared. Some of key theories in this regard are as follows chaos theory, dissipative structures theory and the theory of complex adaptive systems. The main difference between these three mainstreams, according to Stacey (2003), is that chaos and dissipative structures theories seek to construct mathematical models of systems at macro level (that is, whole systems and populations), whilst complex adaptive systems theory attempts to model the same phenomena by using an agent-based approach. Instead of formulating rules for the whole population, it seeks to formulate rules of interaction for the individual entities making up a system or population (Burnes 2004). There are three essential notions which form the core of complexity theories: the nature of chaos and order, the edge of chaos and order-generating rules.

Chaos and order

Chaos is usually depicted as a complete randomness particularly because of its idiomatic connotation. From a complexity point of view, however, it is another type of order which differs from the classical types of orders with which we are familiar; an orderly disorder which occurs in nature more often than being ignored (Frederick 1998; Arndt and Bigelow 2000; Fitzgerald and Van Eijnatten 2002). Fitzgerald (2000) describes chaos and order as twin characteristics of a dynamic, non-linear (complex) system and then suggests that in chaos a hidden order may be concealed without which disorder looks like total randomness. Stacey (2003) suggests three types of order-disorder: Stable equilibrium, Explosive instability and Bounded instability. Under the first one, the system will ossify and die, under the second one the instability (as a result of disorder) will run out of control and may destroy the system. Only the second one can be deemed as a viable option under which a system can healthily survive.

Edge of chaos

Stacey *et al*. (2002) uses the phrase 'far-from-equilibrium' for this situatio, the best description for an ever-evolving condition between the order and disorder is perhaps given by Brown and Eisenhardt (1997) where they assert that complex systems have large numbers of independent yet interacting actors. Rather than ever reaching a stable equilibrium, the most adaptive of these complex systems (e.g., intertidal zones) keep changing continuously by remaining at the poetically termed 'edge of chaos' that exists between order and disorder. By staying in this intermediate zone, these systems never quite settle into a stable equilibrium but never quite fall apart. Rather, these systems, which stay constantly poised between order and disorder, exhibit the most prolific, complex and continuous change.

Order-generating rules

In complex systems, order is arguably generated by an act of simple order-generating rules. The nature and inclusiveness of the orders are crucially important. These rules on one hand limit the chaos to an extent by which the survival of the system could be guaranteed. Yet on the other hand they provide order to an extent that the system can keep on its routine activities and fulfil its ordinary tasks (MacIntosh and MacLean 2001; Stacey *et al*. 2002). In an astonishing variety of contexts, apparently complex structures or behaviours emerge from systems characterised by very simple rules. These systems are said to be self-organised and their properties are said to be emergent. The above account will form one of the basic principles for using apparently easy rules in handling a system of a relatively high complexity. However, it should carefully be noted that simple rules do not necessarily mean simplicity of solution. Proportionate solution to the degree of complexity is key to handle the situation, behaviour, structure or setting successfully at the edge of chaos. The rules are expected to manage the system in a way that not only is a factor or a relation not undermined or privileged under the influence of the others but also to make sure that no unwanted unpredictedness is likely to happen in the whole procedure. The former may happen simply when the rules are too dominating while the lack of an effective and interactive moderator/coordinator entails occurrence of the latter (Piroozfar 2008). Therefore, the concept of order-generating rules explains how complex, nonlinear, self-organizing systems manage to maintain themselves at the edge of chaos even under changing environmental conditions (Burnes 2004).

RESEARCH METHODOLOGY

This research utilises a case study research approach. Case study research is a thorough investigation of a phenomenon in its natural setting, and often makes use of a variety of data sources (Benbasat *et al*. 1987). It can help form the basis of building new theories (Eisenhardt 1989) or refine existing ones (Siggelkow 2007). As a methodology, case study is a popular approach in social sciences but also has a long history in different disciplines (Creswell 2007). Similar to established quality checks in empirical social research, Yin (2003: 34) quotes precedent works including Kidder and Judd (1986:26-29) to suggest four operationalisation of rigor quality indicators for case study research, viz. (1) construct validity, (2) internal validity, (3) external validity, and (4) reliability. Case study research is based on a constructivist paradigm (Stake 1995) hence concepts are assumed to be subjective. As such meanings are informed by researcher's experience, their interactions with historical, societal and cultural norms and settings as well as their community of practice (Creswell 2009). It has always been criticised for lack of generalisability of its knowledge claims. However, it should be noted that the type of generalisation for case studies – what is known as analytic (al) generalisation (Yin 2014) or theoretical generalisation (Sharp 1998) – is fundamentally different from statistical generalisation. Reliance on different sources for data query and multiple data analysis techniques are regarded as the primary strengths of case study research. This increases the validity of findings (Ridenour & Newman, 2008). For these reasons this research will utilise a multiple-case design with multiple-units of analysis approach to enrich and deepen the findings, increase its construct validity, internal validity, external validity and reliability (Beverland and Lindgreen 2010). In order to demonstrate the wide ranging complexity present in the AEC, a number of case studies were chosen based upon the criteria for complex projects as set out by the CIOB (2011) in Table 1. Data was gathered in the form of a desk study to be expanded upon through the use of interviews in the next phase of the research.

COMPLEXITY: AN INDUSTRY FRAME OF REFERENCE

It has been demonstrated that complexity is a wide ranging subject with a number of different connotations; however, the concept of complexity in the AEC industry is fairly narrow in the subject of complexity, concentrating mainly on project complexity, possibly at the disadvantage of the industry. An important point to bear in mind is that talking about systems, the terms *"complex"* and *"complicated"* denote different notions which might easily get mixed up. The difference between *"complicated"* and *"complex"*, as Cilliers suggests, is that in a complicated system, the components can be clearly identified whereas in a complex system, the interaction between the components of the system, and between the system and environment, are so intricate that it is impossible to completely understand the system simply by studying its components. A complex system is not constituted merely by the sum of its components, but also by the intricate relationship between these components (Cilliers 1998). In other words, in a complicated system what counts is just the set of elements whereas in a complex system in addition to that what really dominate the system characteristics are the way in which those elements interact with each other and the way in which the system personifies itself within its context.

Table 5 Simple vs. Complex projects (adapted from CIOB, 2011)

Simple projects comprise those in which construction has all the following characteristics	Complex projects comprise those in which construction has any one or more of the following characteristics
Design work is completed before construction starts; Work comprises a single building (or repetition of identical buildings); Construction is lower than 5-storey height; Without below ground accommodation; Carried out to a single completion date; Without phased possession, or access dates; With services not exceeding single voltage power, telephone, hot and cold water, and heating; With a construction period shorter than nine months; With a single contractor; and With fewer than 10 subcontractors	Design work is to be completed during construction; Work comprises more than one building; Construction is higher than 5-storey height; Contains below ground accommodations; To be completed by multiple key dates and/or sectional completion dates; With multiple possessions, or access dates; With short possessions; Work contains services exceeding single voltage power, telephone, hot and cold water, and heating; Construction work is accompanied by work of civil engineering character; or The construction period is longer than 12 months; Construction to be carried out by multiple contractors; or By more than 20 subcontractors

The Chartered Institute of Building has, following consultations, launched its Complex Projects Contract 2013 (CPC13). The contract is intended for complex projects, in the UK or internationally, which are likely to have one or more of the complex project characteristics, which distinguish it from a simple project as identified in Table 1. It has been suggested that simple projects can be managed intuitively and have a high chance of finishing on time using (CIOB, 2007). However so called complex projects of complex projects are extremely likely to be late when using traditional time management techniques.

These features concur with many of the factors identified by Wood (2010) relating to project complexity. Although it is encouraging to see that the industry is responding to the increasing complexity of modern construction projects, the focus of the industry appears to be on the project complexity aspect, dealing with the practical aspects such as project size and duration. Complexity can arise from systems with just two variables, however, construction is far more complex, instead of dealing with just two variables construction projects have a number of interacting teams where outcomes in the future depend on the number of teams involved, the quality of relationships between interacting teams and their performance variability. In addition there is also unpredictable interface which may arise from numerous external factors which form an additional set of parameters and make construction inherently difficult (Radosavljevic and Bennett, 2012).

CASE STUDIES

It is clear that the traditional view of the construction process as linear is outdated and inappropriate when considering modern projects with research indicating that complex projects cannot simply be organised into separate components to be managed individually, but must be considered as a system as a whole taking into account the interactions and interdependencies both identified and unidentified. The case studies were selected based on their size, time schedule, budget and the common understanding of the level of their complexity. The cases were studied using intensive content analysis of the commonly available data on projects' websites as well as more specific but commonly available data sheets and documents of each project. The following section will provide a general introduction on each case followed by a critical reflection of them within the theoretical framework of this study. The detailed analysis of case studies will be used for developing a framework for analytical generalisation of findings which will then be used, in the next stage of research, to expand the more in-depth enquiry using discussion through steering/focus groups of industry experts.

Crossrail

Crossrail is Europe’s largest infrastructure program with a budget of £14.5 bn. The project consists of 42km of tunnels and seven new stations with construction of the tunnels weaving between existing underground lines, sewers, utility tunnels and foundations at depths of up to 40m below some of the world’s most iconic buildings. When complete the project will increase London’s transport capacity by 10%. It has multiple, complex construction projects running concurrently across the whole route. At the same time as constructing eight new underground stations, which have been connected to the existing London Underground and rail networks, and four overground spurs, Crossrail must minimise the disruption to the existing transport system and the millions of commuters that use it each day (Crossrail, 2013).

London 2012 Olympic Games

The project consisted of over 70 projects including and encompassed the delivery of a 14 permanent structures such as the main stadium, aquatics centre, velodrome, athlete's village and press centre as well as some largely temporary structures such as the aquatics training centre, basketball arena and water polo venue. In addition 20km of roads, 26 bridges, 13km of tunnels, 80 ha of parkland and new utilities infrastructure were required (Davies & Mackenzie, 2013). The timescale of the project was spaced over 6 years, starting with the handover of the site in 2006 and ending with the build phase and testing of the facilities in the approach to the games with a cost of £6.8 bn. Due to the nature of the project, the organisational structure established to construct the venues and infrastructure was arranged in two interacting level of systems integration to match the complexity of the project, this was structured as the Olympic Delivery Authority (ODA) acting as the public sector client organisation and a temporary joint venture acting as the private sector delivery partner.

REREADING CASE STUDIES WITHIN THE STUDY CONTEXT

The conventional intellect

If considering the more traditional *"project complexity"* aspect of the project such as those characteristics set out in Table 1, it is clear to see that the Crossrail project would be considered as complex, however in order to fully understand the complexity of the project the wider aspects of complexity theories can be considered. When considering the Crossrail project as a system it is evident that there are a large number of actors or components within the project as a whole and as sub components within the various aspects of the project. This leads to a great deal of interdependencies and interactions both between the internal components but in the case of this project also with the external environment which adds another substantial layer of complexity. This situation places the project in a continuously changing state (edge of chaos) and is thus deemed to be complex in nature.

In a similar way to the Crossrail project, the construction of the London 2012 Olympic and Paralympic Games was a major project that encompassed a number of large independent but interacting projects. Again, when considering the Olympics project in terms of the more traditional project complexity route, it demonstrates nearly all of the characteristics of a complex project as identified by the CIOB (2011 - Table 1). However, when considering the complexity of the project in a wider perspective, as with the Crossrail project, it can be seen that the complex nature is derived from more than just these individual components but from the interdependencies and interactions required within the system, especially considering the organisational structure and environment in which the project was running.

Complexity above and beyond project levels

Both projects are perceived as complex by different accounts. However, the perceived complexity is above and beyond project level. From a systemic point of view, a project i.e. 'system' has interrelations with its subordinates i.e. 'sub-systems', as agents, elements, components, individuals who/which have been working hand-in-hand to make the project happen. At an upper systemic level, each system sits in a context next to other systems collectively ruled or governed by a superordinate namely a 'super-system'. A super-system is formed not only of its components or member constituents at different levels/tiers but also of relationships, flow of knowledge, information and data between agents inside and out, and also authority (in form of leadership, conventions, ethical codes, political power, society forces, lobbying, etc.) and last but not least financial drivers and the cash flow. That is where a systemic view of complexity helps address or prevent many problems which might otherwise be hard to manage hence overlooked.

Every project even at a much lower level than the Crossrail or London 2012 introduces a new order in many respects. Such projects define the ways in which societal, economic, political, technical and environmental constructs are comprehended. They set new orders ranging from individual to community, urban, national or international levels, least by introducing precedents and new conventions. They introduce new trends way beyond their time and geographical contexts. In such situations the existing orders need to be challenged, manipulated, diverted, redirected, and, from time to time, even broken. Once this took place a new order needs to be successfully and effectively formulated, introduced and enforced; what takes account of all previous mechanisms in their new setting yet is also capable of embracing the new relationships between the existing agents and those between the existing and the new ones. There is always a level of intertwined, multi-faceted, multi-disciplinary complexity imposed by such projects when they break the exiting order and once they are about to introduce the new order - regardless of their level of success in introducing and establishing that new order - which is almost unconsciously inevitably unknown. The matter of the fact, however, is that this is an unknown unknown, which suggests that there are some levels of unperceivable uncertainty involved. This brings along the issue of 'chaos and order', one of the commonly shared principles between distinct theoretical accounts of complexity.

Furthermore in such complex projects, driving forces - both physical and non-physical - exist; both internally and externally. A project is up and running while the driving forces behind it are in a relative balance. This is a real-time, dynamic, ever-changing balance with such a fast pace and so vulnerable-to-collapse nature that takes up on the entire working mechanism within the system (i.e. project) from within and in interaction with its external driving forces and pushes it onto a fragile 'edge of chaos'. It is noteworthy, however, mentioning that, chaos is an order in its own, where the rules are changing so fast that the orders cannot be framed in long enough a period of time - a time frame - clinging to which habitual familiarity can introduce a sense of a recognisable pattern; what can be perceived as an 'order'.

To expand on this very fast-paced change in the existing constructs, introduced as a result of such project, any such trivial, minuscule and short-lived chaotic order, no matter how insignificant or instantaneous they are, is bound to be generated by a rule. The source, effectiveness, origins and roots, reasons and causes of such rules and their resultant orders may not be easily subject to observation, investigation or tracking. In fact this might not even be that important altogether. What is more important is to map such rules - and their corresponding orders - within the bigger picture of the entire system and gauge their effects and implications both in terms of their severity, frequency and importance. This way the whole system can be most effectively and dynamically kept on the 'edge of chaos' so that while the existing 'circumscribing' order is being challenged, altered or dismantled altogether, mini trivial orders can successfully maintain the balance between the chaos and order, leading it into and handing it over to a permanent new order - most likely to be a bigger and more comprehensive one with a corresponding level of complexity - to manage the new setting.

CONCLUSIONS

This paper has demonstrated the viewpoint that complexity in the AEC industry is often characterised by aspects more traditionally identified as factors relating to 'project complexity', with aspects such as the physical size (e.g. storey height), project duration, technical difficulty (e.g. below ground accommodation) and number of contractors involved, being used to indicate the complexity of a project, or whether or not the project is 'simple' or 'complex'. Whilst the industry is responding to the increasing complexity of projects with documents such as the CIOB CPC13 looking to address areas such as collaborative working, integration of the team and disputes (Pickvance and Lane, 2013) there is still a long way to go in terms of fully understanding the complexity of the industry and its impact upon projects. It has also demonstrated that complex systems cannot be studied in isolation and therefore there is a need to broaden the understanding of complexity in the AEC industry and to recognise that it is no longer possible to break a project down into individual components which can be managed in isolation. This has been highlighted through the study of projects deemed to be complex by conventional standards and showing how, when considered from a complexity and systems theory standpoint that projects are highly complex due to their ever changing nature on the edge of chaos due to the high level of independent but interrelated components. It is anticipated that further investigation of the cases highlighted here, as well as other cases will significantly contribute to the understanding of complexity and will facilitate a more up-to-date, fit-for-purpose decision framework to effectively manage complexity comprehensively where and when required in the construction industry. On the other hand it is believed that such contribution can help build up a 'theory of complexity' - the first of its kind - in the construction industry using a grounded theory approach. This will be investigated further in next stage of research.

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