

UNDERSTANDING COMPLEXITY IN THE AEC INDUSTRY

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Complexity is not new to the AEC industry. It dates back well beyond the invention of construction management as an independent field within the building disciplines. Yet the introduction of construction management added a new magnitude to the understanding about, and handling of complexity. This however started with a positivistic reductionist approach which was understood as a scientific method and only defensible academic approach to portray complexity. A simple classification of complexity based on the project size or simply dividing it into 'organisational' and 'technological' may have been deemed sufficient as of in 1980s or 1990s. On the other hand introduction of new construction technologies, new building materials, new structural optimisation tools and techniques have introduced new factors into the building process throughout its lifecycle. All those added by more demanding clients' briefs, more complicated and ambitious design intents, ever-tightening legislations and building regulations, and growing awareness about how the buildings behave beyond their physical boundaries and outside their traditionally understood lifespan have introduced new layers to complexity in the AEC industry. Although still valid in some respects and to some extents, our traditional view of construction complexity is not considered 'inclusive' anymore; nor is it ample enough to address the ever-growing 'complexity of complexity'. This paper takes a cross-sectional approach to present a qualitative comparative analysis. It maps out complexity, its definitions and implications and the impact it has upon the construction process. The aim of this review paper is to provide a ground upon which more in-depth systematic research into understanding, management and handling of complexity can be based, thereby suggesting a 're-reading of the concept of complexity' to be able to more informally feed it back into construction process in the AEC industry.

Keywords: complexity, design complexity, organisational complexity, project complexity.

INTRODUCTION

Advancements in the application of physical agents – both structural and non-structural – as well as non-physical agents – both people and organisations – have resulted in extreme complexity of projects. The diversification of the end users and multiplicity of the stakeholders as a major player in human agents group have also

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added to the degree of complexity. Baccarini (1996) suggests that building projects have become increasingly complex since WWII, to the point that [in 1996] project complexity is now regarded as one of the critical project characteristics that determines its success.

Added by the performance, successful implementation of a project has been acknowledged since Baccarini by many including Austin et al. (2002), Chan et al. (2004), Molenaar and Songer (1998), Raymond (1995), and Wood (2010), to name a few. Despite this very fact to date, there is still no all-inclusive yet clear definition of the project complexity (Bertelsen and Koskela 2002, Corning 1998, Kauffman 1995, Williams 1999, Wood, 2010). Quoting Casti (1994), van Dijkum (1997) suggests that the definition of complexity is connected to the subjectivity of the observer. This is also mentioned by Corning (1998) where he draws attention to 'subjective complexity' as opposed to 'objective complexity'. Also many researchers and scholars have concluded that project complexity would have an impact on time, cost, and quality of a project (Chan 1998, Chan and Kumarawamy 1997, Dissanayaka and Kumaraswamy 1999, Gidado and Millar 1992, Nassar and Hegab 2006, Raymond 1995, Tatikonda and Rosenthal 2000, Walker and Sidwell 1996, Wood and Gidado, 2008).

This paper attempts to provide a general framework of understanding for the concept of complexity in the AEC industry by reviewing the precedent work on general complexity. It starts with some definitions of complexity in the context. Then touching on the concept of complex systems and complexity theory, it will move forward into aspects, types and viewpoints on, and approaches to complexity in the AEC industry. In the next step the paper reviews the impacts and implications of complexity within the context of this study. Finally discussing the results of the reviews, it will provide a new standpoint which will lead to a new strategic recommendation for more in-depth further studies to revamp and reshuffle the significance and need for a re-reading complexity in the AEC industry.

COMPLEXITY DEFINED

Complexity can be difficult to define as it has a number of different connotations. Etymologically derived from Latin *complexus* [past participle of *complecti* 'to include (many different things)'] (Longman 2005), complexity is defined by the Collins English Dictionary (2006) as "the state or quality of being intricate or complex", where complex is defined as "made up of many interconnecting parts". The definition also highlights that it should be noted that complex is sometimes used where complicated is meant. Complex should be used to say only that something consists of several parts rather than it is difficult to understand, analyse or deal with; what 'complicated' inherently means.

The formal definition of complexity as Stewart (2001) suggests fits into two main categories of 'algorithmic complexity', derived largely from computer mathematics, and 'organisational complexity' resulting from the new biology and a revived systems theory.

As a rather simple algorithmic definition Cohen and Stewart (1995) believe that one may tentatively define the complexity of a system as the quantity of information needed to describe it. Having a language of pattern theory Katz (1986) suggests that

the complexity of a pattern is the size of the minimal precursor pattern – the minimal templet² – necessary for its construction.

By contrast, those definitions which may be counted for as an organisational complexity are more concerned about the behaviour of a system and its analysis (Nicolis and Prigogine 1989). For instance as Coveney and Highfield (1995) state, 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.

Larsen-Freeman (1997) points out ten characteristics for complex systems as dynamic, complex, nonlinear, chaotic, unpredictable, sensitive to initial conditions, open, self-organizing, feedback sensitive, and adaptive. Although some of those features might look self-explanatory, she attempts to compensate for this by clustering them into groups and carries on by adding ‘...such systems possess strange attractors, which are fractal in shape’ (Larsen-Freeman 1997).

Suh (2005) defines complexity as a measure of uncertainty in achieving the specified functional requirements (FRs). In the framework proposed by Suh, there are two kinds of complexity, each of which breaks down into two sub-categories:

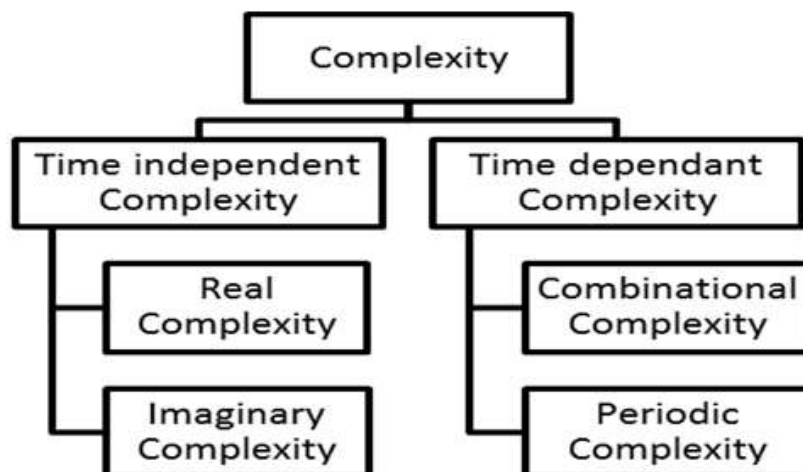


Figure 1: Complexity definition (Suh, 2005)

COMPLEXITY THEORY AND COMPLEX SYSTEMS

Complexity science represents a growing body of interdisciplinary knowledge about the structure, behaviour and dynamics of change. Complexity theory (within which chaos is a particular mode of behaviour) is concerned with the behaviour over time of certain kinds of complex systems. Over the last 30 years and more, aspects of behaviour became the focus of attention in a number of scientific disciplines. These range as widely as astronomy, chemistry, evolutionary biology, geology and meteorology. Each of these systems evolves in relationship to the larger environment in which it operates. To survive, the system as a whole must adapt to change (Sanders, 2003). Some social scientists like Stewart (2001) believe that using

² He develops the notion of “templets” as specific programmes of fabrication.

complexity theory (particularly in social context) with a paradigmatic horizon as a 'metatheory' has itself led to yet another course of reductionism as a result of lack of experience in the field they are entering. However, Morin (2006) suggests that complexity remained unknown in physics, in biology, in social sciences till it irrupted in mathematics and engineering at about the same time, and became connected at once, in the 40s and 50s, with Information Theory, Cybernetics, and General Systems Theory. This paper will briefly go through Complexity Theory and Complex Systems to clarify on the underlying theories. Indeed, there is no unified field of complexity theory, but rather a number of different fields with intriguing points of resemblance, overlap or complementarities (Rosenhead, 1998). 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). Merry describes complex systems as those that self-organise themselves into states of greater complexity. An overview of the Santa Fe Institute provided by Merry asserts 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. This new emergent behaviour of the system is important for understanding how nature operates on the macroscopic level. What looks chaotic at first may be predictable from an understanding of the patterns and rules of complex behaviour. The organisation of simultaneous interaction of many components of a system creates complexity.

Richardson et al. (2000) assert 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 and contains manifest feedback loops. Stacey (2001) concurs with Richardson et al. by summarising the structure of a complex adaptive system as follows: large numbers of individual agents; agents' interaction according to rules that organise the interaction between them at a local level. The only rules are the rules located at the level of the agent itself; interaction is iterative, recursive and self-referential; adaptation of agents to each other based on the non-linear interaction rules; and random mutation and cross-over replication which cause rule variation.

ASPECTS, TYPES AND VIEWPOINTS OF, AND APPROACHES TO COMPLEXITY

Complexity in its own rights can be deemed as a paradigm in modern sciences. More importantly, however, is its contribution to other sciences, disciplines and philosophical standpoints. There are a number of definitions, aspects and types attributed to complexity, distinguished viewpoints of and approach to complexity, heavily determined by the disciplines they belong to, these can be summarised as behavioural; organisational; project' systematic; social; organic; data and; technological complexity. Studying complexity within each of the aforementioned framework will outline a new and unique setting which can cast light on its application to the AEC industry. This however is outside the scope of this paper which attempts to provide a general framework of understanding for the concept of

complexity in the AEC industry. Herein we will review the most directly related ones whose correlation with the construction industry is very well-documented over the past two decades to pave the ground for a more in-depth systematic study of complexity in the construction industry. Those include ‘project complexity’ and ‘organisational complexity’ which are intertwined and closely related to the construction process.

Design/Project complexity

Santana (1990) classifies construction projects by scales of complexity into normal, complex and singular. He also takes another step into classifying the characteristics of the construction projects into 10 categories including owner or investor, cost and financing, terms of study and execution, stages of the project, administrative and legal framework, impact on natural and social environment, physical localisation, technology, resources, and finally logistics of the construction, for a more in-depth study of project complexity using a 1 to 10 Likert scale. At a more detailed level which can be accounted for as an expansion to what Santana’s classification suggests, Campbell’s (1998) information processing approach to task complexity introduces two factors, namely ‘multiplicity’, which captures the number of approaches that may be employed and end states that must be satisfied to complete the project; and ‘ambiguity’, which represents the conflict among, and uncertainty in decisions, the team must make to complete the project. McComb et al. (2007) used this approach and developed those factors into four task complexity dimensions: multiple approaches to complete the task; multiple end states to be satisfied by the task; conflicts among approaches and uses that require trade-offs, and; decisions regarding the approaches to be employed and the end states to be satisfied. Mitchell takes another standpoint and defines the complexity of a design as ‘the ratio of added design content to added construction content’ (Scheurer 2007), or ‘the number of design decisions relative to the scale of the project’ (Mitchell 2004, Mitchell 2005).

None of the above viewpoints however, discredit the validity of the Baccarini’s (1996) proposed definition of project complexity as ‘consisting of many varied interrelated parts that can be operationalised in terms of differentiation and interdependency.’ Baccarini also 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. In a more detailed review, Gidado (1996) suggests that there seems to be two perspectives of project complexity in the industry: the managerial perspective and, the operative and technological perspective. He offers that project complexity is the measure of difficulty of executing a complex production process, where a complex production process is regarded as that having a number of complicated individual parts brought together in an intricate operational network to form a work flow that is to be completed within a stipulated production time, cost and quality and to achieve a required function without unnecessary conflict between the numerous parties involved in the process. Or it can simply be defined as the measure of the difficulty of implementing a planned number of quantifiable objectives. However, it is worthwhile that these viewpoints are revisited taking into account the newly introduced dimensions to the complexity in the AEC industry due to the recent advancements made since 1996. This includes Wood (2010) who defines project complexity as a single or a combination of factors that affect the standard response or actions taken to achieve the project outcomes.

Reviewing Gidado's aspects of project complexity, i.e. the employed resources, the environment, the level of scientific and technological knowledge required, the number of different parts in the work flow, and the interaction of different parts in the work flow (1996); Chan's casual factors of project complexity: client's attributes, site condition/site access problems, buildability of project design, quality of design coordination and quality management (1998); Akintoye's project complexity's principle components, namely expected project organization, type of structure, site constraints, method of construction and construction techniques, scale and scope of the project and complexity of design and construction (2000); Cicmil and Marshall's three aspects of complexity, which are: complex processes of communicative and power relating among project actors, ambiguity and equivocality related to project performance criteria (success/failure) over time, and the consequence of time flux (change, unpredictability and the paradox of control)(2005), Xia and Chan (2011) conclude '...that most of the factors are those broad and vague concepts, and some of them are related to the concept of complexity theory (such as the unpredictability of the work). As a result, it is very difficult to quantify the project complexity based on these findings'. Subsequently they suggest 6 complexity measures for building projects in the People's Republic of China with a Weight Factor for each indexed through Delphi method including building function and structure (WF: 0.189), construction method (WF: 0.179), the urgency of the project schedule (WF: 0.177), project size/scale (WF: 0.157), geological condition (WF: 0.153), and neighbouring environment (WF: 0.145).

Organisational complexity

Construction projects can be studied as organisations. There are numerous parties involved in any construction project which form a temporary organisation. The coordination and relationship between the different parties can greatly affect the complexity of any project. It has been shown that the behaviour of firms differs considerably from what is common in other industries, particularly in terms of the absence of inter-firm adaptations, the pattern of couplings in construction is characterised by the tight couplings in individual projects and loose coupling in the permanent networks (Dubois and Gadde, 2002). Bertelsen (2003a) states how 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. As well as individual projects forming complex systems, projects are also interwoven, as every firm at the same time participates in more than one project, utilising the same production capacity. In addition to the aspect of firms creating project organisations, the concept of the social complexity must also be accounted for. The project is a working environment for humans and a place for cooperation and social interaction, which because of the temporary character forms a highly transient social system. This system can be thought of as a virtual firm which employs all personnel involved in the project (Bertelsen, 2003a). Radosavljevic and Bennett (2012) discuss worst case construction projects vs. more straightforward projects, as seen in Figure 2. Worst case scenarios are often related to the organisational complexity of the project, in a complex project, the whole project organisation is beset by massive and repeated interactions with the organisations hostile, rapidly changing and entirely uncooperative ways.

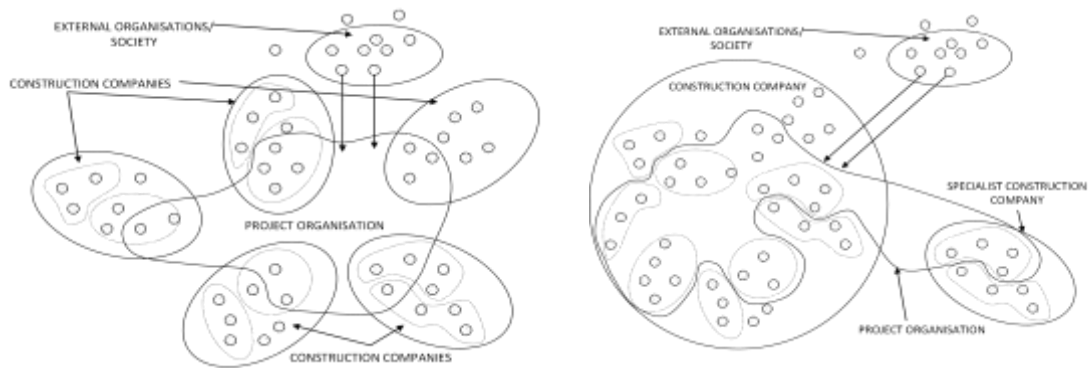


Figure 2: A complex construction project network vs. a straightforward project network (Radosavljevic and Bennett, 2012).

THE IMPLICATIONS OF COMPLEXITY FOR, AND ITS IMPACTS ON THE AEC INDUSTRY

Complexity can arise from systems with just two variables. However, construction is far more complex, where many more than two interacting variables are involved and the project progress, outcomes, and success in the future depend on an array of intertwined organisational interactions involved in the process, the quality of relationships between interacting agents 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) which follows from what Bertelsen (2003b) discusses of construction as a complex system. He 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. A closer examination reveals that construction, despite the established understanding, is indeed a nonlinear, complex and dynamic phenomenon, which often exists on the edge of chaos. In order to demonstrate this, Bertelsen (2003a) conducts an analysis of the characteristics of a complex system and those of a construction project. Through this analysis evidence is provided which highlights how complex the construction process is.

The implications that complexity may have in a project may vary from trivial – where the mistakes made are ‘Fixable’ – or minor – where a ‘Fault’ may (have) happen(ed). At a higher impact level this may vary from a major defect – which can result in a potential ‘Failure’ of the project – to a catastrophic incident – with a ‘Fatal’ consequence either for the project or the parties involved. This will potentially have an effect on the actions, measures and techniques to address and deal with complexity in construction projects.

DISCUSSION

Organisational and project complexities are discrete faces of complexity in the construction industry. However, they are not mutually exclusive. In fact in many cases they are too intertwined to be fully and utterly distinguished. Although organisational complexity vis-à-vis project complexity per se stands at a higher hierarchical level, it scales down and fuses with project complexity in many cases. This particularly happens when the outside agents come into play; those whose systemic standing may be lower compared to the organisation(s) involved in a construction project but their roles as commissioner/client and/or user/client is by far more significant. The primary

client i.e. the owner or developer influences the project as per their specifications. The end client as the user will, on the other hand, have their own needs, wants and requirements which need to be taken into account through client brief and project brief. Clients, whether they are primary or end client add to the complexity at project level. On the other hand organisational and inter-organisational agents who develop the project from the conception stage through to the completion stage into the physical product of the built environment are the project complexity enforcement agents on behalf of and for the clients while adding another dimension of complexity inherent in their organisational hierarchy within the AEC industry, i.e. organisational complexity. These agents may include non-structural agents who are in charge of architectural design, structural agents who take care of structures, mechanical agents who deal with MEP and last but not least construction and implementation agents who manage people, contracts, sites and the construction process itself (see Figure 3).

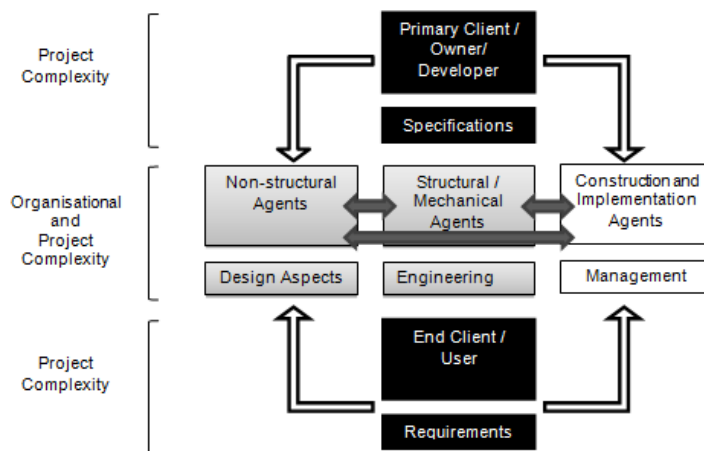


Figure 3: Intertwined Organisational and Project Complexity and their Respective Agents

CONCLUSION AND RECOMMENDATIONS

Complexity is not a new concept in construction and the issue of complexity has been studied for several years. However, despite increasing complexity in the process of undertaking construction projects, there is still no long-lasting resolution for or understanding of complexity in the AEC industry. Although many scholars have studied complexity in the industry within different contexts, there is still a lack of an in-depth systemic and holistic framework which is proportionate to the level of complexity that the topic itself presents to overarch the different possible approaches to deal with complexity.

As a result, this paper presented a review of the most influential areas of complexity in the construction industry, project/design complexity and organisational complexity. The overview portrays these issues from an alternative viewpoint in order to gain a better understanding of the complexity that affects the industry. More importantly, what is now required is a comprehensive research concerning the origins, disciplines and contexts of complexity and to start a re-reading of the topic in the AEC. We therefore propose a systemic study of complexity in the construction industry with an aim of developing a methodological approach to the concept which is proportionate to specifics of the setting, context and people involved in any particular project.

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