Managing Large Projects: Is There a Way to Employ Informal Networks and People's Processes?

Huda Almadhoob[a*]
[a] Department of Architecture and Interior Design, University of Bahrain, Isa Town, Bahrain
Email: halmadhoob@uob.edu.bh
ORCID identifier: https://orcid.org/0000-0001-9836-6008

Abstract

Managing large infrastructure projects is always a complex issue, because they are often rapidly changing. They are also nonlinear, unpredictable interconnected, interdependent, multilateral, and these affect any planned and systematic completion. Popular project management techniques often depend on hierarchical structures and strict professional boundaries, to manage such projects. However, they often fail to take advantage of the 'temporary' systems that always exist and emerge to respond to increasing complexities. The popular professional techniques overlook the informal self-organising people's networks, although they offer unforeseen opportunities and resources to manage large projects.

This paper examines this phenomenon and offers a case-specific illustration of self-organising phenomenon in a large infra-structure project, using complexity theory as a theoretical framework and social network analysis as an investigative lens.

The study findings substantiate that complex projects can be observed and manged as self-organising systems that are delivered through multi-layered social networks, comprising of multiple actors. They demonstrate small-world topology similar to those observed in diverse real-world self-organising systems. In particular, their temporary and contextual nature, which forms due to the continual evolution and decay of relationships, supporting communication between project actors. Self-organising networks represent the vehicle by which project complexity and uncertainty are reduced, given their ability to facilitate information flow necessary to achieve effective coordination and problem resolution.

Keywords: Large Construction Projects, Complexity Theory, Self-organising Networks, Social Network Analysis (SNA)

Introduction

This article questions the effectiveness of the predetermined formal structures, giving precedence to ongoing change over stability (Tsoukas and Chia, 2002). It examines the role of informal communication in a large infrastructure project and presents self-organising as a generative mechanism that could influence stability and change, and thus the (re)creation of organisational informal structures over time. The paper aims to bridge the knowledge gap in understanding the evolutionary nature of project organisational structures as they move between different stages. This is done by demonstrating how the concept of self-organising networks can be located within the contexts of managing complex projects. The examination of this issue is timely given the increasing complexity of projects and the call for alternative approaches to understand and analyse them. Undeniably, it will help the building practitioners who struggle with complexities of managing large projects in their daily work.

The objective of this paper is to investigate the phenomenon of 'self-organisation' in large construction projects. The research asks the question how the self-organising networks can either support or constrain coordination in large construction projects. For this purpose, the Complexity Theory (CT) and Social Network Analysis (SNA) are utilised in an empirical setting, seeking to shed light on this issue. The research examines the case of the Bank Station Capacity Upgrade (BSCU) Project which is a complex infrastructure project. Secondary data was gathered through a Knowledge Transfer Partnership (KTP) between the University College London (UCL) and Transport for London (TfL), as the project client.

Complexity Theory places great emphasis on the concepts of discontinuity, continuous change, disorder, instability, nonlinearity, and unpredictability; yet it postulates that complex systems also exhibit a greater degree of adaptability and resilience (Mitleton-Kelly, 2003). CT is chosen to establish the theoretical framework because it has the potential to enrich the project management area of this inquiry by expanding the application of the systems perspective to the nonlinear operation of sufficiently complex, fragmented, diverse, and coordinated activities, such as the management of large infrastructure projects (Pryke *et al*., 2018). Adaptability and resilience in such complex systems is explained as an outcome of having a high degree of self-organisation. This is a natural process that allows complex systems to acquire the characteristics of flexibility, effectiveness, and adaptivity to continually adapt around the changing needs of the project actors and the project itself over time (Pryke, 2017; Stacey, 1996). According to Glass *et al*. (2020), such understanding is necessary under the current circumstances such as globalisation and the pandemics, pushing the building industry towards rapid transformations.

The Complexity Theory has resulted in a paradigm shift when it was first introduced to project management post-2000 (Bakhshi *et al*., 2016; Padalkar and Gopinath, 2016), but is yet to be unpacked in its full potential to understand how it can be operationalised to understand the reality of how projects are designed and delivered. This also responds to the growing interest to bridge the theory-practice gap and to search for further theorisation capable of understanding the growing complexity of projects, exploring patterns of emerging action in project organisations, and the actualities of how projects are designed and manged (Winter *et al*., 2006; Addyman, 2020).

Therefore, CT is complemented with a number of SNA tools to help reveal the underlying interrelationships and the structure of BSCU project networks. Undeniably, such a combination allows moving away from the relatively abstract conceptualisation of project activities and delivery functions to a much more finely grained approach.

Drawing from an extensive review of the complexity theory and the project-based network research, the philosophical underpinning of this paper is based on the following assumptions that stem from the earlier academic work.

1. Projects are delivered through social networks, comprised of multiple actors responding to the pressures of finding and information dissemination in a highly uncertain environments (Pryke *et al*., 2018; Chinowsky *et al.,* 2010; Ruan *et al.,* 2013). From a project management perspective, this approach "*views managing social relationships as a means to manage and add value to, and through, projects*" (Smyth and Morris, 2007:425).
2. These networks evolve and naturally decay over time, influenced by actors' interactions and their network positions. Hence, this highlights the pervasiveness of change and transformational nature in organisations/networks, and the intrinsic flux of human actions (Tsoukas and Chia, 2002; Pasian, 2015; Magoon, 1977).

3. A huge emphasis is placed on the context of a project being investigated and how it influences and shapes the relationships between the project team, leading to self-organisation as an emergent property. Hence, adopting an 'organisational becoming' perspective which means that projects, and the coordination process, as a social phenomenon are continually being created from the consequent actions of those actors involved (Bryman, 2016; Grove *et al.*, 2018). This places social interactions as the primary locus of social order. Tsoukas and Chia advocate that '*change is ontologically prior to organization*', while '*organization is an outcome, a pattern, emerging from the reflective application of the very same rules in local contexts over time*'(2002:570).
4. This entails adopting a Network Approach to managing and understanding projects. This is facilitated by Social Network Analysis (SNA) as a research analytical method. SNA entails turning our thinking from artificial boundaries imposed by the traditional hierarchies and procurement terms (such as project phases, contracts and subcontracts, organisational charts) towards the idea of viewing the values delivered to the clients and stakeholders as a product generated by the networks of relationships, that usually span organisational and project-related boundaries (Pryke, 2012). Hence, it provides insights into the invisible self-organising aspects of the projects, focusing on the actors, their activities and interactions, rather than using fixed hierarchical models (Blomquist *et al.,* 2010).

The paper is organised as follows: the theoretical background is set out in the first part by discussing the network approach in relation to understanding projects, the application of the Complexity Theory and the concept of self-organisation as a means to understand project networks. The SNA terminologies and research methods are then explained before describing the case study and the project's context. The findings and the discussion are then presented to contribute to the understanding of complex projects as self-organising networks. The paper closes with research limitations highlighting opportunities for further research.

Review of Literature

A Network Approach to Understanding Projects

The conceptualisation of complex construction projects as numerous social networks, whose structures evolve over time, i.e. 'temporary systems' (Chinowsky *et al*., 2010), has been increasingly adopted by construction project management scholars as a useful theoretical construct to study and visualise actors and their relationships (Pryke, 2012; Ruan *et al*., 2013; Pryke *et al.*, 2017). The work of Cicmil *et al.* (2006), Cooke-Davies *et al*. (2008), and Winter *et al*. (2006) among others, emphasises the conceptualisation of construction projects as social networks and how this might help in understanding project actualities. This is unlike Barnes' (1988) idea of the 'iron triangle' that defines effective project management as a function of achieving specified cost, time and quality, which focuses primarily on realising certain quantitative measures but largely ignores the key drivers such as the role of relationships between project actors and impact of communication processes on project delivery. The conceptualisation of a project as networks provides '*an opportunity to look at a wide range of relationships between individuals and firms in a manner that is free from artificial boundaries*' (Pryke, 2012:9).

In response to the emerging perspective of viewing projects as network-based organizations, SNA has witnessed increasing attention in construction project management research over the past two decades which has covered different aspects and methodologies (Zheng *et al.*, 2016; Pryke *et al.*, 2017). For example, Pryke and Ouwerkerk (2003) have studied post completion risk transfer audits. They have underlined the benefits of adopting a network approach to map project relationships for effective risk identification and management. Similarly, Styhre (2008) has explored the role of social capital in knowledge sharing. The study has investigated the interpersonal relationships of a Swedish specialist rock construction company. The conclusions have highlighted that project social networks are built around professions and are activated when unexpected events occur. While these studies have recognised the crucial roles played by the social relationships, they lack the application of SNA tools and techniques, which could have provided fine-grained data that could be used to draw practical conclusions and provide recommendations to improve design and delivery of future projects. In a similar vein, Ruan *et al.* (2013) explain that there is a scant application of SNA in the UK construction industry. At best, there is a limited use of the SNA measures mostly relating to the general network attributes. Pryke (2012) advocates that despite the importance of informal networks and its contribution to performance, they are rarely recognised and understood by the organisations they are embedded in. This is a research gap and explains why the majority of the SNA applications in the last decade have remained concerned with the relationships that are formally prescribed by hierarchical organisational structures and/or contractual functions/obligations (Pryke, 2012; Ruan *et al.*, 2013). For example, the work of Chowdhury *et al.* (2011) has highlighted the benefits of using SNA in bridging the gaps in understanding the complex structure of the Public Private Partnership arrangements and identifying the main structural features and the influential actors. Their analysis, however, was limited to the formal contractual relationships between the parties involved in the agreements.

As project environments become dynamic and complex with the recognised importance of many stakeholders including those that are external to the client organisations, a growing body of research is adopting a sociological perspective and focus on informal relationships in project environments that extends beyond the contractual relationships (Zheng *et al.*, 2016). Recent research such as Almadhoob (2020); Kania *et al.* (2020), Nowakowska-Cicio (2020); Yang *et al.* (2019); Pryke *et al.* (2018); Steen *et al.* (2018) particularly focus on how coordination between diverse actors can be achieved to facilitate successful project execution.

Despite the seminal contributions, network theories have often been criticised for not being able to explain the emergence of collective actions (Salancik, 1995). Monsanto *et al*. (2013) highlight the need to have a better-developed theory relating to the study of projects. Winter *et al*. (2006) suggest that this entails moving away from the relatively abstract conceptualisation of project activities towards a more practice and practitioner oriented position. This brings our attention to a discussion of the Complexity Theory and the conceptualisation of projects as evolving self-organising systems.

The Theoretical Basis

Application of Complexity Theory to the Study of Large Projects

Given today's ever-increasing complexity and uncertainty, the mechanical understanding of organisations has been challenged over the recent years by many researchers (e.g. Cicmil *et al*., 2006; Handy, 1994; McMillan, 2006; Morgan, 2006; Pedler *et al*., 1996; Priesmeyer, 1992; Senge, 1990). Of particular interest, are the works of Stacey (1996, 2003, 2007), Englehardt and Simmons (2002), Lewin and Regine (2000) and Pascale et al. (2000) who have argued that organisations are Complex Adaptive Systems (CAS) with emergent properties that result from the numerous interactions between their employees and/or other stakeholders and external environments. This perspective is heavily grounded in the Complexity Theory and provides a better insight into the structure and dynamics of evolving organisations.

The Complexity theory suggests that coordinated activities with an inherent diversity, such as large construction projects, have the capacity to trigger a self-organizing process (Stacey, 2003). This transition occurs during the pre and post-contract phases of the projects (Pryke, 2017; Addyman, 2020), and is often influenced by the presence of multiple parties with different interests and values (Wild, 2002). This can lead to conflicting forces and consensus problems, eventually pushing a system towards a transition phase not governed by the contractual project life cycle (Stacey, 2003; Pryke *et al*., 2018). A project's success after this transition relies heavily on the ability to manage unpredictable and nonlinear interactions (Bertelsen, 2003; Geraldi, 2008; Almadhoob, 2020).

In reality, each agent acts based on their past experiences and expectations in the face of uncertainty (Arthur, 1994). If their actions are successful, they are reinforced and reused, but if they fail, new actions and thinking are developed, leading to evolution into a higher state. This unpredictability and nonlinearity can also be influenced by individual human choices as each person develops their own goals and actions to achieve them (Stacey *et al.*, 2000).

Applying a Complex Adaptive System (CAS) perspective to the study of large construction projects challenges the long-lived top-down agent-based models. The radical change here is that instead of having a concentrated authority that requires a detailed pre-planning, CAS implies having a dispersed authority where individual agents enjoy some sort of a shared control (Coleman, 1999; Ford, 2008). This means that the agents have inherent abilities to self-organise swiftly and freely without referring to any central or governing control, but are based purely on the local knowledge available at such micro levels (Heylighen *et al*., 2006).

However, putting such a model with a total freedom of action into an operation could result in extremely unpredictable outcomes and hence to maintain the balance, it is recommended that a composite of guidelines should be applied (Bertelsen, 2003). This is revolutionary compared with just following a pre-engineered rigid approach with a series of checklists or templates as it is usually the case with the pre-planned model (Bertelsen, 2003; Geraldi, 2008). Hence, the CAS perspective challenges the detailed planning approach to project management which assumes constant project goals over time (Fabianski, 2017; Almadhoob, 2020).

Complexity Theory can offer an integration capacity, opening up for a new perspective, rather than having a piecemeal approach to the problem (Bertelsen, 2003). That is, the Complexity Theory postulates that dealing with an adverse phenomenon, *e.g*. COVID-19 pandemic, leads to rapid technological adoptions and transformations across the industries. Another example is the rise of an opportunistic behaviour, which is counterbalanced by other forms of cooperative relationships which may emerge as a project progresses (Anvuur and Kumaraswamy, 2008; Bertelsen, 2003). These emergent relationships are coined by the term "informal organisations/networks" which have been found to rise above the prescribed contractual boundaries (Anvuur and Kumaraswamy, 2008; Bertelsen, 2003; Dainty *et al*., 2007, Pryke, 2012; 2017). The aim of such organisations/networks is to increase collaboration, coordination and goal alignment in the temporary project team and also help to improve problem solving, communication, fast track the processes, and expedite decision-making, regardless of any financial incentives (Anvuur and Kumaraswamy, 2008; Bertelsen, 2003, Coleman, 1999). The question is *how does this self-organising look like in projects?*

The Conceptualisation of Projects as Evolving Self-organising Systems

Self-organisation is defined as a nonlinear process of pattern formation that emerges from the interactions between the agents at the local level in a bottom-up fashion (Heylighen, 2013; Mitleton-Kelly, 2003). The latter implies an environment with a weak command, *i.e*. the process usually happens out at the organisational fringes where connectivity is dense with the existence of many local interactions. The key engines behind such self-organisations are the feedback loops as they can work to amplify some small events into global systemic phenomena (McMillan, 2006; Stacey, 1996). These loops define a relationship of interdependency between two or more components where the change in state of one element/actor affects that of another with this effect then in turn feedback to alter the source element/actor (McMillan, 2006; Stacey, 1996).

The central role that feedback loops play in self-organisations is their ability to change the correlations between the agents' states within a system in order to coordinate them (Stacey, 2010). This type of mechanism is nonlinear and grows in an exponential fashion, through self-reinforcing. As this process of change continues, the system will reach a point in time where all the agents involved have correlated their states in some way, leading to a some form of global coordination based on the dynamic between competition and cooperation (Gherardi and Nicollini, 2000; Gkeredakis, 2008; Stacey, 2010). This is an important feature of the concept of self-organisation as it can transform systems to accommodate higher levels of complexity (McMillan, 2006; Capra, 1996). This is especially relevant to the context of project activities, as projects transition from the procurement stage usually aligned with the contractual conditions to the delivery stage largely reliant on non-contractual networks of individuals working together to realise project-related common goals (Pryke, 2012). Despite playing a crucial role to the delivery of the project, these informal self-organising networks are usually not managed in projects because they are largely invisible, *i.e.* have no contractual status (Pryke, 2017; Almadhoob, 2020).

Saynisch (2010) suggests a complete evolutionary cycle of system structures in large construction projects that goes through three phases. These are illustrated as in the phase change diagram below (Fig. 1). Phase 1 in the diagram represents the initial structure which largely mirrors the prescribed contractual lines of reporting and responsibilities. This formal structure suggests a "static" mode of dyadic interactions between the contracted firms or individuals (Pryke, 2017). However, over time, the involvement of complex and very tightly coupled systems in large construction projects may lead to inevitable changes due to the higher levels of uncertainty (Geraldi *et al*., 2010).

These, in isolation, would probably not have detrimental effects, but due to unanticipated interactions of multiple factors, a system could be forced to enter into a transition phase (Phase 2 in the diagram) through a co-creation process or otherwise disintegrate/get destroyed. From the Complexity Theory perspective, this is the self-organising phase where the system 'transitions' to another level of organisation. At this point, project actors cultivate on their informal relationships and power positions to support the design and delivery of the projects on a daily basis. The lower order system will collapse or bifurcate, and the result will be a new structure with a greater level of adaptability and complexity (Phase 3 in the diagram). This offers a framework to investigate the 'self-organisation' phenomenon in large construction project from the lens of Complexity Theory. To avoid falling into the trap of being just descriptive, operationalisation of the above model through the use of Social Network Analysis (SNA) is discussed next.

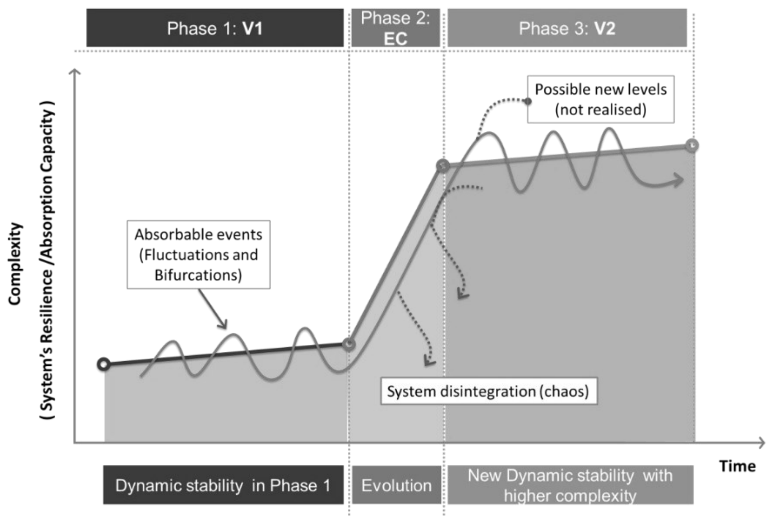


Fig. 1: Phase Change Diagram: A Complete Evolutionary Cycle of System Structures Source: Adapted from Saynisch, 2010:32-Fig. 7

Fundamental Concepts in Social Network Analysis

Drawing from a variety of research fields where researchers have examined a diverse set of complex self-organising real-world networks, using SNA, complexity researchers (e.g.

Hassas *et al*., 2006; Heylighen, 2011; Saha *et al*., 2015; Jackson, 2010) have observed that the complex and self-organised networks typically exhibit a number of distinct structural properties. These can be defined statistically using SNA and described as follows to provide a core working vocabulary and remove any ambiguity concerning the way they are applied in this research:

Actors are "*discrete individual, corporate, or collective social units*" (Wasserman and Faust, 1994:17). Graphically, these are represented by nodes. In this study, this term is given to the individuals involved in the project communication networks rather than the firms. This is because analysis of the informal communication project networks entail focusing and collecting data on the individual level rather than firms or organisational level. This is further underpinned by the fact that the construction industry is essentially a multi-disciplinary people-intensive arena which exhibits a high reliance on informal conversations and interpersonal communications in order to coordinate and facilitate daily activities, problem solving, and decision making (Hastings, 1998; Pietroforte, 1997; Middleton, 1996).

Relations are "*the collection of ties of a specific kind among members of a group…The defining feature of a tie is that it establishes a linkage between a pair of actors*" (Wasserman and Faust, 1994:20). Graphically, these are represented by links/connections. This research seeks to look at a number of different types of relationships between project actors involved in the resolution of the issues encountered at the detailed design stage of a project. This will allow investigating the evolving nature of project networks in response to the changing events and circumstances.

A path length refers to the number of connections between the actors. It is an important measure in project communication and information exchange networks, as it affects the speed of communication, problem resolution, and adoption of new technologies or innovations (Wasserman and Faust, 1994; Pryke *et al.*, 2018). Long, average path lengths imply that information go through several intermediaries and take more time to be delivered. Hence, the potential for information bias, hoarding, filtering and controlling increases and affects negatively the information flow (Wasserman and Faust, 1994; Scott, 2017).

Network Density is "*a concept that deals with the number of links incident with each node in a graph*" (Wasserman and Faust, 1994:101). It can be expressed as the total number of links present between the nodes in a given network in relation to the maximum number of links theoretically possible for that network (Pryke, 2012). This measure indicates network connectivity - *i.e.* Generally speaking, high density means an overall good connectivity or cohesion while low density could indicate network fragmentation (Pryke, 2017; Goddard, 2009) and thus provides a comparability measure between the networks of comparable sizes (Pryke, 2012; Scott, 2017). It also indicates the speed at which a spill over effect or information diffuses within a network, the degree of reciprocity, trust, and cooperation between the actors, and hence whether they have high levels of social capital or constraints. That is, the flow of information and exchange through multiple channels, allows the cross-checking of information as a basis for establishing reliability and trust, and thus supports their adaptive resilience through multi-connectivity (Lizardo and Pirkey, 2014).

A "Small-World" Property resonates the famous '*six degrees of separation*' theory which suggests that average distance between everyone on the planet is only six handshakes/steps (Powell *et al.*, 2005). That is to say self-organising networks are characterised by a relatively short average path length and a high clustering, *i.e.* the tendency of actors to concentrate their ties within certain groups (Baker, 2014; Watts, 1999). These characteristics result in networks with unique properties of regional specialisation and efficiency (Watts, 1999). This property also entails that a change in one node can rapidly propagate to the rest of the network. As a result, a network can swiftly react to perturbations or innovations. Although these characteristics make a given network surprisingly robust in facing the random removal of nodes in a counterpart, they make it extremely vulnerable to any strategic removal directed to nodes with a high connectivity (Hassas *et al.*, 2006; Lizardo and Pirkey, 2014). The latter eventually could lead to network dysfunction, meaning a small-world property can also be viewed as a "dyadic liability" rather than just a "diffuse strength" (Lizardo and Pirkey, 2014; Prell, 2012).

Clustering or high clustering is the reason behind small-world property. This stems from a distance-based cost structure, *i.e.* nodes that are closer or more similar (e.g. co-location, co-membership, co-participation, sharing attributes) find it cheaper to maintain links to each other leading to high clustering (Borgatti *et al.*, 2014). Borgatti *et al.* (2014) assert that such properties provide the conditions to maintain the system functionality as well as its holding capacity by creating 'inertia' to resist change.

In summary, the theoretical background discussed Complexity Theory and argued that project management has not kept pace, both theoretically and methodologically, with rapidly increasing complexity in large projects. Hence, the need for a new way of thinking.

This paper puts a great emphasis on the conceptualisation of projects as evolving self-organising networks. This is an uncharted area in the construction industry that holds a considerable promise for addressing complexity and delivering better outcomes for the clients and the stakeholders. It stresses on the need to focus upon relational and social aspects of projects (i.e. peoples' processes) as a means of understanding the non-linear, complex, iterative and interactive processes that projects constitute. The argument that self-organising networks are to be found primarily in the invisible area of organisational structures necessitate the use of a network approach and SNA measures as analysis methods.

Research Design

The broader ontological debate of this research is that project organisations are actually structured as networks. Its epistemology is how the structure of project organisations can be understood as a self-organising network. Hence, the primary object here is informal self-organising networks that are concerned with '*how to get the work done*'. Therefore, it adopts a 'practice-centred epistemology' to the generation of new knowledge, seeing practice and theory as mutually constituted (Jarzabkowski *et al.*, 2010; Sandberg and Tsoukas, 2011).

A practice-centred methodology recognises the interdependent and context-creating relationships between macro- and micro-levels in organisational settings (Knorr-Cetina, 1981). The underlying interactions at the local levels are spontaneous and contribute to the co-creation of the whole context as it is folding. That is, actors always are working together in a dynamic relationship to co-create their world "*for first time*" (Garfinkel *et al*., 1981); i.e. peoples' processes affect the evolution of informal networks. SNA can provide a novel understanding of the invisible, self-organising aspects of project organisations and thus it can be used as a means of understanding how projects are actually delivered in practice through the use of information exchange networks and how they can be analysed and managed. This approach offers a more fine-grained approach more closer to practice-centred project management, as it focuses mainly on what people actually do to get the work done, by way of informal behaviour, rather than what their official mandate dictates.

Drawing on the project management context rather than management *per se*, the paradigm of this research is placed within the relationship approach that "*views managing social relationships as a means to manage and add value to, and through, projects. It is based on social theory and tends to focus upon effectiveness […]. The approach is theoretically diverse and certainly not linear in thinking, and arguably has the broadest definition of managing projects of all the paradigms*" (Smyth and Morris, 2007:425).

This necessitates an in-depth analysis of a specific project in its context. Therefore, a case study approach was adopted, aiming to investigate informal project delivery related communication networks in a complex and temporary project environment. The studied case, data, and context are explained next.

The Case Study, Data, and Methodology

The Bank Station Capacity Upgrade (BSCU) project was a complex infrastructure project led by the London Underground Limited (LUL), a subsidiary of Transport for London (TfL). It was part of a larger program of major station capacity projects and aimed to accommodate the significant increase in passenger demand at the Bank Underground station. Over 250 engineers and staff worked daily on the project while the station remained open to the customers. Due to the project's complexity, it was not possible to establish a complete information exchange network. Therefore, a nominalist approach was taken, which narrowed the focus to the detailed design phase of the project, within the timeframe of a knowledge transfer partnership (KTP) between the University College London (UCL) and TfL. The KTP lasted for two years from 2014 to 2016 and was conducted as part of a consultancy study.

Despite its complexity, the BSCU project is a unique case study for TFL, as it is part of a several pilot projects focused on promoting collaborative working arrangements to reduce project risks and costs. The project team used a novel procurement approach called Innovative Contractor Engagement (ICE) to reduce project uncertainty and overcome the challenges causing time and cost overruns–a common problem in the industry (TfL, 2014). The BSCU case study highlights the importance of the ICE Procurement Model for creating value for project sponsors through a collaborative and relational approach. Instead of following the industry norms, ICE requires pre-qualified contractors to share innovative ideas with the client during a protected dialogue phase. This occurs early on, in the project timeline and before the invitation to tender, allowing for the maximization of design-and-build ideas and their long-term social benefits. This approach focuses on trade-off value criteria against the most "effective product" and "efficient method" as opposed to the traditional iron triangle of cost, time, and quality. As a result, the proposed solutions by bidders can diverge from fixed project requirements and designs imposed with traditional procurement approaches.

Collection of data focused on the communication between all parties involved in the detailed design of the BSCU station box and the new ticket hall. The design accountability is clearly defined in different design packages. The project involves various disciplines such as design, construction, operation, and maintenance, and has specific cost, time, and risk codes associated with it (Pryke et al., 2017). A BIM/CAD model was used to clarify the physical boundaries of the work package to all the participants, which helped to delineate a clear network boundary and capture the maximum inter-organizational interactions. Data was collected using a questionnaire in two different stages of the project and used to determine the connections between the project team members and categorize the direction, quality, and type of communication, whether formal or informal. The participants were asked to specify the people they communicated with in the past four weeks regarding the resolution of any problems. To define the relationships between the two actors, different forms of communications such as face-to-face discussions, letters, phone calls, and emails were taken into consideration. Seven-point Likert scales were utilized to assess the quality and frequency of communication. Following Pryke's approach (2012), the quality of communication was evaluated on five parameters: importance, accuracy, timeliness, clarity, and trust.

The questionnaire also sought to categorise BSCU interdependent networks into four types or layers, namely: information exchange, discussion, instructions, and advice; hence focusing on a multi-layer investigation (Borgatti *et al.,* 2009). This is justified since informal human relations might be classified by the nature of the interaction (Krackhardt, 1997). A 100% response rate was achieved, ensuring that the results properly reflect how the project was delivered. Table 1 below summarises the sample size of the study during the two stages, organised based on their organisational affiliation.

The data collected through the questionnaire was stored in a NoSQL database called MongoDB. The data was retrieved from the database, entered in the igraph package in RStudio software (Csardi and Nepusz, 2006) for network construction. A weighted network was created using the collected data which was then exported to Gephi and UCINET for quantitative analysis and visualisation. key SNA measures were used to analyse the issue resolution project networks at the two stages. That is, by analysing and comparing network characteristics–number of nodes and links, Density, Average Path Length, Average Clustering Coefficient, and the actors' Average Weighted Degree Centrality.

Table 1. The Sample Size of the Study at Stage One and Stage Two of the BSCU Project, Organised based on their Organisational Affiliation
Source: Author

Organisation	Stage One	Stage Two
Alan Auld Engineering Ltd	7	6
Byrne Bros	2	2
Dr Sauer & Partners	10	14
Dragados	42	51
Fourway Communication	2	2
Geocisa	2	2
Geotechnical Consulting Group	1	1
Hyder Consulting	3	4
Keltbray	1	1
McNicholas	0	6
Munellys	0	1
Robert Bird Group	12	16
Scott Lister	3	4
T Clarke	16	21
Transport for London (TfL)	45	51
URS Infrastructure & Environment UK Ltd	7	4
Vision Survey	1	2
Wentworth House Partnership	1	1
Wilkinson Eyre	7	8
Total Number of Participants	**162**	**197**

Fig. 2 below illustrates the data collection timeframe. It captures the key events encountered in the detailed design phase, described as "*some of the toughest challenges*" by the project manager. These datasets, therefore, lend themselves to being crucial in understanding the self-organising concept and how actors behave to respond to project issues and risks/uncertainty faced. This becomes evident by studying the evolving nature of the BSCU networks by highlighting the structural changes between the two stages of the project, i.e. how the project actors and their interactions are co-created and/or terminated. These changes start at the local level and cascade to affect the global network structure, its functions and outcomes (Scott, 2017). This implies that there is a complex interplay between the individual behaviour and the structural characteristics.

The details of the key events encountered (*i.e.* context) through the two stages of the project are as follows.

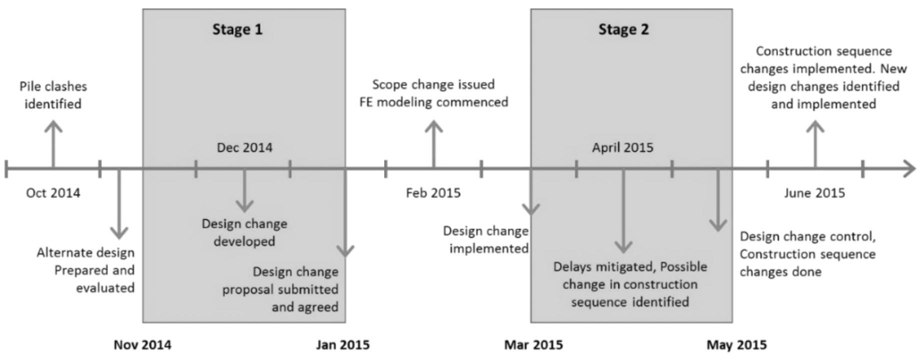


Fig. 2: Data Collection Timeframe.
Source: Adapted from Pryke et al., 2017:34-Fig. 3

Social Network Analysis (SNA) can only provide useful information and a comprehensive understanding of a situation when combined with qualitative data. Since the researcher did not have direct access to the original research participants, they utilized two main qualitative approaches. First, they identified the key informants who have had first-hand experience with the project and its actors, providing insights into the events that led to the changes in the communication patterns. The informants included the TFL project manager and the Knowledge Transfer Partnership team consisting of three research associates specialized in project management and social networks. They spent almost six months collecting data, including one hundred and thirty-one management meetings and seventy-nine interviews. Second, the researcher was granted access to project-related documents such as governance documentation, internal periodic meeting reports, and the TFL project manager's case study narrative on the project. These documents provided a holistic understanding of the project's wider context, specific practices, organization, people's processes and how it performed during different project stages. The combination of these qualitative approaches helped to establish a better understanding of the underlying interactions between project actors, "re-constructing" the reality of the project from the perspective of those involved.

In summary, the qualitative research methods used in the project provided a retrospective perspective on events as they were unfolding, and were affirmed by the key informants (Fabianski, 2017). Using both qualitative and quantitative data enhanced the research and facilitated cross-verification. The fine-grained structure of the data increased credibility and validity, supporting mathematical analysis and boosting confidence in the research findings (Barratt *et al.*, 2011; Steen *et al.*, 2018).

Findings and the Discussion

This section provides evidence that the BSCU project can be considered as a self-organizing network by examining its communication networks. The study utilizes complex systems probability distributions as a fundamental quantitative approach, which serves as a straightforward yet practical tool for describing the patterns and features of the project's organization (Sornette, 2009; Castellani and Rajaram, 2016). Examination of the BSCU informal networks at both stages, reveals a fat-tail, skewed-right degree distribution. This is most commonly observed in complex systems compared to the normal distribution usually found in the correspondent random networks (Castellani and Rajaram, 2016). The findings of these basic SNA measures are presented in the Table 2 below, calculated using UCINET software.

Table 2: BSCU Network Basic Measures.
Source: Author

Measure	BSCU - Stage One	BSCU - Stage Two
Number of Nodes	162	197 (22% growth)
Number of Links/Ties	1440	2207 (53% growth)
Network Density	0.055	0.057
Average Path Length	2.668	2.549
Average Path Length – Random Network	2.6	2.5
Average Clustering Coefficient	0.384	0.416
Average Clustering Coefficient – Random Network	0.057	0.059

The table above shows that the BSCU project networks possess characteristics of a "small-world" network. This is because their average clustering coefficient, as per the model proposed by Watts and Strogatz in 1998, is notably higher than that of a randomly generated network with the same number of nodes, while their average path length is roughly equivalent. This creates a well-clustered network wherein short paths or direct links connect clusters or groups. This sort of small-world structure is frequently observed in many different self-organizing networks, such as those described by Wagner and Fell (2001), Newman (2001), and Braha and Bar-Yam (2004), among others. The BSCU networks share these same features, which facilitates the quick dissemination of information essential for efficient coordination and issue resolution.

The number of actors (nodes) increased by approximately 22% from stage one to stage two, going up from 162 in the stage one to 197 in the stage two. This increase was due mainly to the appointment of new resources from the project controls and commercial management disciplines, which were brought in to mitigate the reported design delay from several disciplines and to support the input for the public inquiry. As the number of nodes grew, so did the number of connections, which increased by 53%. This indicates that changes were made to network topology and resources. Despite this growth, density remained flat, which shows that network actors were able to quickly adapt to the new structure by maintaining and/or establishing new connections with those who could help get the work done.

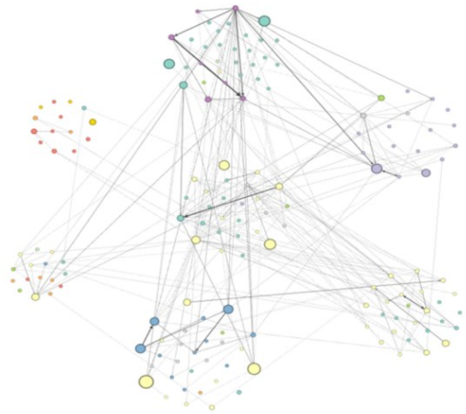
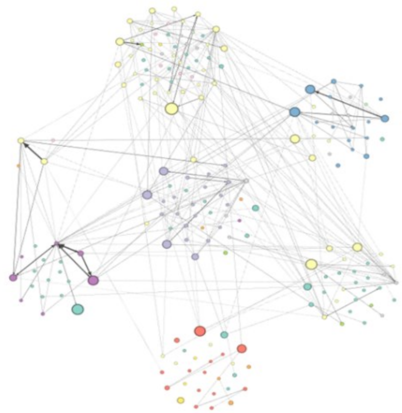
As part of the research questionnaire, participants were asked to classify their communication activities into four distinct types: instructions, advice, information exchange, and discussions. This framework was proposed by Pryke (2012) for the purpose of studying multi-layer networks. Table 3 summarizes the basic measurements of the BSCU sub-networks or layers, in terms of size (i.e. the number of nodes and connections) and density. These key findings illustrate the distinctive qualities of each communication layer and help to elucidate the multi-layered nature of the co-existing project networks, which exist simultaneously within a non-linear, self-organizing system.

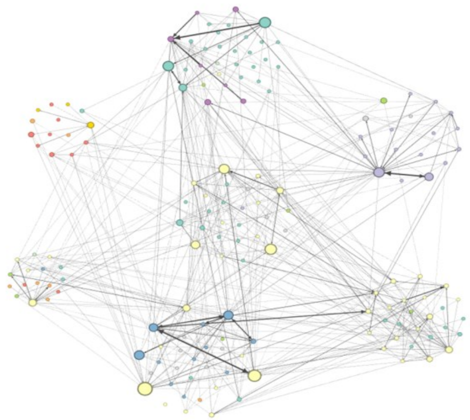
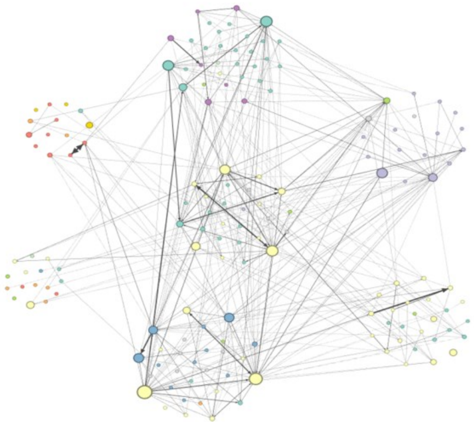
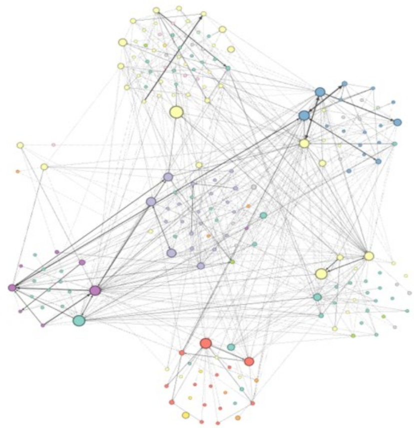
Apart from the instruction layer, the measures of the BSCU sub-networks highlight that the increase in nodes was associated with an increase in connectivity while the density remained almost flat. This is in line with the earlier results for the whole BSCU network. It suggests that the topologies of the sub-networks have changed between the stage one and the stage two, given the introduction of the new actors who have adopted quickly to the new environment, establishing new connections with the rest of the team. Information and advice layers reported the highest growth scores. This is explained by their crucial role in the situations requiring the problem-solving techniques, such as those encountered at the BSCU (Pryke, 2012).

The Instructions layer stood out from the rest in the sense that growth in nodes was associated with a reduction in connectivity and hence density. This is an interesting result. Pryke (2017:96) explains this by arguing that "*the issuing of 'instructions' is one of the few types of communication referred to in forms of contract for delivering construction or engineering projects*"; hence suggesting a formal approach to communication. Actors involved in the Instruction layer are usually assuming managerial positions, given the nature of their order-based communications (Pryke, 2012). It can be concluded therefore that other actors at the stage two were resistant to engage through formal channels. They preferred establishing more informal relationships in response to the higher uncertainties/risks faced. Such disengagement by the managers also indicates a shift in decision-making power from formal/contractual arenas towards the informal ones available at the local levels; hence, constraining contractual roles of project managers.

This high-level analysis of the sub-networks demonstrates the non-linearity of the BSCU project communication networks. This arises from the non-additive nature of these different communication layers when combined and studied as a single-layer network. It is also an indication of co-existence, where actors are simultaneously engaging in different layers to satisfy their communication needs. Hence, peoples' processes are crucial elements affecting the dynamics of informal networks. Moreover, a non-linear growth between the stage one and the stage two was observed across the different communication layers. That is, the number of nodes or links increases nonlinearly with time (Bauer and Kaiser, 2017).

Table 3: Basic Measures of BSCU Multi-Layered Networks at Stage One and Two, Nodes are sized by Betweenness Centrality and Coloured by Organisations.
Source: Author

<table>
<tr><th>Name of the Layer</th><th colspan="6">Sociograms of Stage One and their Basic Measures</th><th colspan="6">Sociograms of Stage Two and their Basic Measures</th></tr>
<tr><td rowspan="2">Information Exchange Layer</td><td colspan="6"></td><td colspan="6"></td></tr>
<tr><td>No. of Nodes</td><td>128</td><td>No. of Links</td><td>571</td><td>Density</td><td>0.035</td><td>No. of Nodes</td><td>172
(34% growth)</td><td>No. of Links</td><td>1080
(89% growth)</td><td>Density</td><td>0.037</td></tr>
<tr><td rowspan="2">Discussion Layer</td><td colspan="6"></td><td colspan="6"></td></tr>
<tr><td>No. of Nodes</td><td>121</td><td>No. of Links</td><td>506</td><td>Density</td><td>0.035</td><td>No. of Nodes</td><td>144
(19% growth)</td><td>No. of Links</td><td>726
(44% growth)</td><td>Density</td><td>0.035</td></tr>
<tr><td colspan="13">TfL, Dragados, T Clarke, Wilkinson Eyre, Robert Bird Group, Dr Sauer & Partners, Alan Auld Engineering, URS Infra. & Env. Ltd., McNicholas, Other; Less Brokerage – More Brokerage; Weaker Relation – Stronger Relation</td></tr>
</table>

Name of the Layer	Sociograms of Stage One and their Basic Measures						Sociograms of Stage Two and their Basic Measures					
Instructions Layer												
	No. of Nodes	107	**No. of Links**	269	**Density**	0.024	**No. of Nodes**	119 *(11% growth)*	**No. of Links**	251 *(7% decrease)*	**Density**	0.018
Advice Layer												
	No. of Nodes	70	**No. of Links**	94	**Density**	0.019	**No. of Nodes**	98 *(40% growth)*	**No. of Links**	150 *(60% growth)*	**Density**	0.016

Additional basic measures are calculated for the BSCU multi-layered networks at both the stages, as follows:

Table 4: Key Characteristics of BSCU Stage One and Two Multi-Layered Networks.
Source: Author

Layer Name	Ave. Weighted Degree		Ave. Path Length		Ave. Clustering Coefficient		Density	
	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
Whole BSCU Network	0.661	0.885 (↑)	2.668	2.55 (↓)	0.384	0.416 (↑)	0.055	0.057 (↑)
Information Exchange	0.326	0.5 (↑)	3.098	2.75 (↓)	0.209	0.225 (↑)	0.035	0.037 (↑)
Discussion	0.298	0.382 (↑)	3.001	2.93 (↓)	0.213	0.252 (↑)	0.035	0.035 (-)
Instruction	0.209	0.181 (↓)	3.557	3.65 (↑)	0.092	0.071 (↓)	0.024	0.018 (↓)
Advice	0.098	0.121 (↑)	4.001	4.68 (↑)	0.03	0.03 (-)	0.019	0.016 (↓)

(↑) *indicates a growth between the two stages;* (↓) *indicates a decrease between the two stages;* (-) *indicates no change*

The basic measures of the BSCU communication networks indicate that the network characteristics are quite comparable for both stages at the overall level. However, a closer look at the sub-networks reveals that each single layer has its own specific characteristics that represent a specific social dynamic.

The Table 3 shows that Information Exchange and Discussion layers had the highest network sizes (i.e. number of nodes and links). It means that the BSCU communications in both the stages were concentrated at these two layers. This is expected as Information and Discussion layers usually prevail in projects since they are centred on problem-solving (Pryke, 2012) and conceptualised as information processing systems (Winch, 2002). Apart from the Instruction layer that largely represents formal communications, the BSCU stage two networks also reported an improved connectivity. This is evident in the higher degree scores. Given the relational nature of the ICE approach, the results support those demonstrated in Pryke (2012), stressing on building collaborative relationships to facilitate knowledge transfer and the exchange in response to the project complexity/uncertainty. The low degree score of the Instructions layer, on the other hand, implies that this form of communication was discouraged as the main method because it could defeat the purpose of adopting a collaborative procurement model. These findings are opposed to those envisaged by the Joint Contracts Tribunal which promotes the use of the standard form of construction contracts in the UK, that are structured around the allocation of risks between the parties and using instructions as the primary form of communication (Pryke, 2012; Higgin and Jessop, 1965).

The scores for the average path length were found to be below 5 degrees across all the BSCU networks and layers. In fact, the whole BSCU network remarkably scored just above 2.5 degrees at both stages. This is lower than the 6-degree average path length between the two nodes in a random network (Watts and Strogatz, 1998). This finding means that the ICE model was successful to bring the BSCU actors closer to each other, enhancing access to the resources. This is a key benefit in adopting a relational model because project teams must make decisions in a constant manner given the ongoing internal and external developments (Tsoukas and Chia, 2002). That is, in large projects, actors usually do not have the luxury of time or the capacity to go through a lengthy process or carefully analyse all the issues involved (Tsoukas and Chia, 2002).

Table 2 shows that BSCU networks have clustering coefficients much larger than those of their corresponding random networks of equal size. This highlights the network inherent tendency to form tightly knit groups characterised by a relatively high density of ties (Watts and Strogatz, 1998). Investigations of clustering coefficients at the sub-networks level highlights that Information Exchange and Discussion layers have comparatively high scores compared to the others (Table 4). This is an indication of the higher nodes' embeddedness at these two layers. It means that adoption of the ICE model helped to foster collective participation and collaborative decision-making. This is a key benefit as it implies that different views can be heard, and control and authority are better distributed. Every agent therefore can take part in the process (Stacey, 2010). The increased level of average clustering coefficients in the stage two also indicates that the actors have evolved to operate relying more on the collective participation and knowledge. This finding is supported by the increased level of trust observed at the stage two, as highlighted by the questionnaire results. On the other hand, the relatively low clustering coefficient at the Instruction layer, which consists largely of formal communication, indicates to some extent the existence of the so-called structural holes. This can be understood as a gap between the two individuals who have complementary sources to information (Pryke, 2012). It means that formal communication was inadequate at both stages of BSCU, adversely impacting its effectiveness.

Reflecting on the issue from several sources and particularly from the project periodic reports (October 2014 – June 2015), it is revealed that the identified pile clashes in the stage one weighed heavily on the delivery programme. However, this issue was eventually solved resulting from the emergence of coordination due to the increased level of trust between the project participants. Particularly, the disengagement of the project management team in resolving the pile issue suggests that they have trust in the competence of the designers and engineers to self-organise. This is explained by the TfL Project Manager during the interview:

> *'My reflection is that the engineers and the designers sorted it out, once they have kind of clicked, it was sorted. As a senior management team, we weren't really that kind of worried about the issue [i.e. pile clash identified in stage one], as we had the confidence in the engineers that they will get on with it'.*
>
> TfL Project Manager, Interview

The high clustering coupled with high connectivity of Information Exchange and Discussion layers indicates that the actors at the BSCU project tend to discuss and exchange information in (more or less) stable groups (Borgatti *et al.*, 2018). Such groups provide a forum in which the actors can shape the rules and norms of engagement, and deliberate and articulate their agendas to solve the encountered issues (Stacey, 2010).

This may also indicate the success of the ICE approach in bridging the gap between the project participants (and supply chain tiers) through the integrated team approach. It facilitated a more collaborative and collective approach to decision-making and problem solving. In other words, through the ICE approach, the client managed to facilitate the co-creation of a project culture designed to encourage shared practices and decision-making (Silvius and Karayaz, 2018). This has led to the creation of a project collective power emerging organically from the core design-delivery team involved in the front end as part of the ICE approach and grows stronger the more it is used (Gaventa, 2006). Such a collective approach creates new possibilities from the very differences that might exist in a group and find a common ground among the different actors, reducing the social conflicts and promoting equitable relations (Gershenson, 2007).

Results have shown that project networks, from both single-layer and multi-layer perspectives, are characterised by very low density (i.e. they are sparse networks). This clearly reflects the relational basis of the ICE collaborative approach where global non-hierarchical nature of communication is expected to succeed. These low scores also indicate fragmented communication and decision-making processes (Goddard, 2009). Given their non-hierarchical nature, BSCU networks therefore can be considered loosely coupled systems (Weick, 1976; Dubois and Gadde, 2002).

This is an interesting finding. It suggests that there is no single group or actor in full control and thus managers, for example, have low levels of power to exert on the network as a whole. This is in line with the definition of the self-organising systems highlighted in the literature review earlier. BSCU networks are found to be no exceptions. When unexpected issues/events are encountered, responsibilities are distributed among the loosely-coupled actors, functions, and network layers, despite the tightly-coupled nature of the tasks and interdependencies in large complex projects (Duggal, 2018; Dubois and Gadde, 2002).

The same characteristic of low density has also been observed by Pryke (2012) when partnering arrangements were investigated. The latter are known for having non-hierarchical project networks, promoting trust, long-term relationships, openness, etc. Furthermore, it is observed that the density scores of Information Exchange and Discussion layers are the closest to the whole network's density score. However, the overall density is not determined by a simple addition of the sub-networks/layers. This finding supports the nonlinearity of the project networks as *the whole is greater than the sum of its parts*.

Conclusions

Although there is a growing body of research concerned with the Complexity Theory and self-organising behaviour, very little has been done to focus on construction project networks. As a result, there is a lack of awareness and understanding on how these systems are established and coordinated, how they evolve and decay, and the changing nature of roles that are acquired to support or constrain the design and delivery of the large projects. This dearth of research means self-organising project networks are usually not facilitated or managed in practice. This article demonstrates how the concept of informal networks can be located within a context of managing complex projects. This has yielded a number of important contributions to the literature as well as the practice of project management.

First, it enriches the research of self-organising networks within the construction industry, specifically in the infrastructure sector. This was achieved by empirically analysing a case study of a large complex project using SNA tools and techniques. This allows exploiting this analytical method to transform the Complexity Theory (which has a high level of abstraction especially for the practitioners) into an applied science.

Second, self-organisation expands application of the Complexity Theory by taking into account the informal interpersonal relationships. Such complementarity helps explain how things work in a broader system (covering both formal and informal relationships) that is not always recognised, especially in project management. This highlights the importance of social aspects and the peoples' processes, as a factor affecting the establishment of effective project delivery networks and their evolution and maintenance over time. Therefore, this finding recognises that socialisation is important in forming relationships in the complex and uncertain environments which most large construction projects constitute.

Third, the study of self-organisation gives precedence to ongoing change over stability. This necessitates challenging the predetermined and prescribed forms of organisation and rational-based project management approaches. It entails understanding how people collaborate to deliver projects in an increasingly complex environment, rather than being constrained by the hierarchical-based terminologies or an array of discrete systems, such as those dedicated to the management of value or cost or design.

Forth, the ICE procurement model was highlighted as the key feature of the project. It is an innovative model based on a relational approach, focusing primarily on the creation of value for the project sponsor. The process of ICE happened early in the project life cycle at the front-end, even prior to invitation to tender. This was found to play a crucial role in shaping the communication networks as they emerge. This suggests the crucial role of formal organisational structures, that are based on relational approaches, at the front-end. These are found to be able to shape the project environment and power relations significantly, yet do not determine them entirely. Contextual circumstances and individual behaviours are therefore crucial elements that should always be considered.

Finally, the research has demonstrated the appropriateness of using a network approach to investigate the operation of complex infrastructure project networks. SNA has proved to be useful to project managers as it allows the identification of the invisible (i.e. self-organising aspects of project organisations), project network functions, structures, dysfunctions, and also enables evidence-based interventions to improve project execution. In particular, the study of the information exchange networks offers a more fine-grained approach that is more close to practice-centred project management.

Limitations and Further Research

This was a study of a single case and a single life cycle phase utilising the SNA tools. This brings limitations in data collection for SNA research especially in such large and complex projects. A method that is a time-consuming and requires a high-level of granularity. It is argued however, that the use of a secondary dataset offered an opportunity to conduct a long-term research, since it was collected at two different stages. This responds to the rare use of such research approaches in SNA studies, to understand the development and evolution of organisational networks, as highlighted recently by several researchers (e.g. Williams and Shepherd, 2015; Jackson, 2010; Borgatti *et al.,* 2014; Steen *et al.*, 2018). Hence, this paper contributes to more recent efforts to bridge such methodological research gaps.

The unique and temporary nature of the construction projects (*i.e.* in terms of their context, scope, location, etc.) means that limitations have to be accepted in relation to the generalisability of research findings. This is a common issue in the study of projects and was partially mitigated in this study by focusing on the ways in which organisations are conceptualised rather than looking into specific configurations of project organisations. In this way, the study sought to deepen the understanding of self-organising networks in the field of project management. It suggests that self-organising networks are ubiquitous in large projects. It thus identified several features that can be applied and tested in other cases. These can potentially identify repeated interactions and recognisable patterns across different projects.

In today's business environment, the pace of change and the contexts in which the projects are delivered are becoming more complex, uncertain, and dynamic. While this study investigated only two discrete points of time, it misses the true dynamic ongoing changes, happening in between the two datasets. To mitigate this issue, reflections on the data supported by the project documentations and follow-up discussions were used in this study. However, it is acknowledged that this could only approximate the continuously changing process. That is, networks are not static, but evolve as actors intentionally and unintentionally change their relational patterns by activating or terminating their ties to other actors (Schipper and Spekkink, 2015). A cross-case analysis using multiple case studies and perhaps from more than one life cycle stage will allow research to go beyond the contextualising factors and draw new conclusions based on recurring observable patterns across cases/projects; hence addressing the issue of the generalisability of the findings.

Using SNA provides a powerful tool to analytically apply the practice-centred methodology. While this study adopted this approach, SNA measures are still not used in full. This is a promising area for both researchers and practitioners and it would be interesting to study how the SNA dimensions are reflected in practice by using a detailed process research design based on mapping and measuring of deliberation.

References

Addyman, S., Pryke, S., & Davies, A. (2020) Re-creating organizational routines to transition through the project life cycle: A case study of the reconstruction of London's bank underground station. Project Management Journal, 51 (5), pp. 522-537.

Almadhoob, H. (2020) At the Interface: When Social Network Analysis and Supply Chain Management Meet. In Pryke, S. (Eds.), Successful Construction Supply Chain Management: Concepts and Case Studies, pp. 43-61. Oxford: John Wiley & Sons Ltd.

Anvuur, A. and Kumaraswamy, M. (2008) Better collaboration through cooperation, in Smyth, H. and Pryke, S.D. (Eds.), Collaborative Relationships in Construction: Developing Frameworks and Networks, Oxford.: Wiley-Blackwells.

Arthur, W. B. (1994) Inductive reasoning and bounded rationality. The American economic review, 84 (2), pp. 406-411.

Baker, W. (2014) Making pipes, using pipes: How tie initiation, reciprocity, positive emotions and reputation create new organizational social capital. Contemporary perspectives on organizational social networks, pp. 57-72.
Bakhshi, J., Ireland, V., & Gorod, A. (2016) Clarifying the project complexity construct: Past, present and future. International Journal of Project Management, 34 (7), pp. 1199-1213.
Barnes, M. (1988) Construction project management. International Journal of Project Management 6 (2), pp. 69–79.
Bauer, R., & Kaiser, M. (2017) Nonlinear growth: an origin of hub organization in complex networks. Royal Society open science, 4 (3), pp. 160691.
Bertelsen, S. (2003) Complexity–Construction in a new Perspective. IGLC-11, Virginia: Blacksburg.
Blau, P. M., & Scott, W. R. (1962) Organizations: A comparative perspective. San Francisco: Chandler.
Blomquist, T., Hällgren, M., Nilsson, A., & Söderholm, A. (2010) Project-as-practice: In search of project management research that matters. Project Management Journal, 41 (1), pp. 5-16.
Borgatti, S. P., Brass, D. J., & Halgin, D. S. (2014) Social network research: Confusions, criticisms, and controversies. In Contemporary perspectives on organizational social networks pp. 1-29. Place: Emerald Group Publishing Limited.
Borgatti, S. P., Everett, M. G., & Johnson, J. C. (2018) Analyzing social networks (2nd Edition). London: Sage publishers.
Braha, D., & Bar-Yam, Y. (2004) Topology of large-scale engineering problem-solving networks. Physical Review E, 69 (1), pp. 016113.
Bryman, A. (2016) Social research methods. 5th Edition. Oxford: Oxford university press.
Capra, F. (1996) The Web of Life: A New Scientific Understanding of Living Systems. Place: Anchor Books.
Chinowsky, P. S., Diekmann, J., & O'Brien, J. (2010) Project organizations as social networks. Journal of construction engineering and management, 136 (4), pp. 452-458.
Chowdhury, A. N., Chen, P. H., & Tiong, R. L. (2011) Analysing the structure of public–private partnership projects using network theory. Construction Management and Economics, 29 (3), pp. 247-260.
Cicmil, S., Williams, T., Thomas, J., & Hodgson, D. (2006) Rethinking project management: researching the actuality of projects. International journal of project management, 24 (8), pp. 675-686.
Coleman, Jr, H. J. (1999) What enables self-organizing behavior in businesses. Emergence, 1(1), pp. 33-48.
Cooke-Davies, T., Cicmil, S., Crawford, L., & Richardson, K. (2008) We're Not in Kansas Anymore, Toto: Mapping the Strange Landscape of Complexity Theory, and Its Relationship to Project Management. IEEE Engineering Management Review, 36 (2), pp. 5–21.
Cross, R., Borgatti, S. P., & Parker, A. (2002) Making invisible work visible: Using social network analysis to support strategic collaboration. California management review, 44 (2), pp. 25-46.
Dainty, A., Moore, D., and Murray, M. (2007) Communication in construction: Theory and practice. London: Taylor and Francis Group.
Denicol, J., Davies, A., & Krystallis, I. (2020) What Are the Causes and Cures of Poor Megaproject Performance. A Systematic Literature Review and Research Agenda. Project Management Journal, 51(3), 328-345.
Dubois, A., & Gadde, L. E. (2002) The construction industry as a loosely coupled system: implications for productivity and innovation. Construction management & economics, 20 (7), pp. 621-631.
Englehardt, C. S., & Simmons, P. R. (2002) Organizational flexibility for a changing world. Leadership & Organization Development Journal, 23 (3), pp. 113-121.

Fabianski, C. J. C. (2017) Complex Partnership for the delivery of Urban Rail Infrastructure Project (URIP): How Culture matters for the treatment of Risk and Uncertainty, PhD Dissertation, University College London.

Ford, R. (2008) Complex Adaptive Systems and Improvisation Theory: Toward Framing a Model to enable Continuous Change. Journal of Change Management, 8 (3-4), pp. 173–198.

Fuhse, J., & Mützel, S. (2011) Tackling connections, structure, and meaning in networks: quantitative and qualitative methods in sociological network research. Quality & quantity, 45 (5), pp. 1067-1089.

Garfinkel, H., Lynch, M., & Livingston, E. (1981) I. 1? The Work of a Discovering Science Construed with Materials from the Optically Discovered Pulsar. Philosophy of the social sciences, 11 (2), pp. 131-158.

Gaventa, J. (2006) Finding the spaces for change: a power analysis. IDS bulletin, 37 (6), pp. 23-33.

Geraldi, J. G., Lee-Kelley, L., & Kutsch, E. (2010) The Titanic sunk, so what? Project manager response to unexpected events. International Journal of Project Management, 28 (6), pp. 547-558.

Geraldi, J. G. (2008) The balance between order and chaos in multi-project firms: A conceptual model. International Journal of Project Management, 26 (4), pp. 348-356.

Gershenson, C. (2007) Design and control of self-organizing systems. Mexico: CopIt Arxives.

Gherardi, S. and Nicolini, D. (2000) To transfer is to transform: The circulation of safety knowledge, Organization, Vol.7 no.2, pp. 329–348.

Gkeredakis, E. (2008). An "articulation" perspective on coordination of project work: the case of a complex construction. The University of Liverpool, Management School Abstract. Organization Learning, Knowledge and Capabilities Conference pp. 1–16.

Glass, J., Bygballe, L. E., & Hall, D. (2020) Call for Papers Transforming Construction: The multi-scale challenges of changing and innovating in construction. Place: University College London: London, UK.

Goddard, S. E. (2009). Brokering change: networks and entrepreneurs in international politics. International Theory, 1 (2), pp. 249-281.

Grove, E., Dainty, A., Thomson, D., & Thorpe, T. (2018) Becoming collaborative: a study of intra-organisational relational dynamics. Journal of Financial Management of Property and Construction, 23 (1), pp.6-23.

Hamilton, A. (1997) Management by projects: achieving success in a changing world. London: Thomas Telford.

Handy, C. B. (1994) The Empty Raincoat: Making Sense of the Future. Place: Arrow Business Books.

Hastings, C. (1998) The Virtual Project Team-part 3. Project Manager Today, 10, pp. 26-29.

Heylighen, F. (2011) Rationality, complexity and self-organization. Emergence: Complexity and Organization, 13 (1-2), pp. 133–145.

Heylighen, F. (2013) Self-organization in communicating groups: The emergence of coordination, shared references and collective intelligence. Understanding Complex Systems, pp. 117–149. Place: Springer Berlin Heidelberg.

Higgin, G., & Jessop, N. (1965). Communication in the building industry. London: Tavistock Institute.

Jackson, M. O. (2010) Social and economic networks. Place: Princeton university press.

Jarzabkowski, P., Mohrman, S. A., & Scherer, A. G. (2010) Organization studies as applied science: The generation and use of academic knowledge about organizations (introduction to the special issue). Organization Studies, 31 (9-10), pp. 1189-207.

Kania, E., Radziszewska-Zielina, E., & Śladowski, G. (2020) Communication and Information Flow in Polish Construction Projects. Sustainability, 12 (21), 9182.

Lewin, R., & Regine, B. (2000) The Soul at Work: Listen, respond, let go: Embracing complexity science for business success. New York: Simon & Schuster.

Lizardo, O., & Pirkey, M. F. (2014) How organizational theory can help network theorizing: Linking structure and dynamics via cross-level analogies. In Contemporary Perspectives on Organizational Social Networks pp. 33-56. Place: Emerald Group Publishing Limited.
Loosemore, M. (1998) Social network analysis: using a quantitative tool within an interpretative context to explore the management of construction crises. Engineering, Construction and Architectural Management, 5 (4), 315-326.
Magoon, A. J. (1977) Constructivist approaches in educational research. Review of educational research, 47 (4), pp. 651-693.
McMillan, E. (2006). Complexity, Organizations and Change: An Essential Introduction. London: Routledge.
Middleton, D. (1996) Talking work: Argument, common knowledge and improvisation in multidisciplinary teams. In: Engeström, Y., and Middleton, D. (Eds.) Cognition and Communication at Work, pp. 233-256, Cambridge: Cambridge University Press.
Mitleton-Kelly, E. (2003) Ten principles of complexity and enabling infrastructures. In: Mitleton-Kelly, E. (Eds.), Complex systems and evolutionary perspectives on organisations: The application of complexity theory to organisations, pp. 23-50, Oxford: Pergamon, Elsevier Science.
Morgan, G. (2006) Images of Organization. Place: SAGE Publications.
Mulgan, G. (1998) Connexity: Responsibility, freedom, business and power in the new century. London: Vintage.
Newman, M. E. (2001) The structure of scientific collaboration networks. Proceedings of the national academy of sciences, 98 (2), pp. 404-409.
Nowakowska-Cicio, M. (2020) An assessment of a network approach in a project-based organization–a case study of a global engineering service provider. Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, 64 (10), pp. 69-87.
Padalkar, M., & Gopinath, S. (2016) Are complexity and uncertainty distinct concepts in project management? A taxonomical examination from literature. International Journal of Project Management, 34 (4), pp. 688-700.
Pascale, R. T., Millemann, M., & Gioja, L. (2000) Surfing the Edge of Chaos: The Laws of Nature and the New Laws of Business, Vol. 41. Place: Three Rivers Press.
Pasian, M. B. (Eds.). (2015) Designs, methods and practices for research of project management, Place: Gower Publishing, Ltd.
Pedler, M., Burgoyne, J., & Boydell, T. (1996) The learning company: A strategy for sustainable development (2nd Edition). Maidenhead: McGraw-Hill.
Pietroforte, R. (1997) Communication and governance in the building process. Construction Management & Economics, 15 (1), pp. 71-82.
Powell, W. W., White, D. R., Koput, K. W., & Owen-Smith, J. (2005) Network dynamics and field evolution: The growth of interorganizational collaboration in the life sciences. American journal of sociology, 110 (4), pp. 1132-1205.
Prell, C. (2012) Social network analysis: History, theory and methodology. Sage.
Priesmeyer, H. R. (1992) Organizations and chaos: Defining the methods of nonlinear management. Westport, CT: Quorum Books.
Pryke, S. (2012). Social network analysis in construction. Supply Chain Management (Vol. 1). Oxford: John Wiley & Sons, Ltd.
Pryke, S. (2017) Managing networks in project-based organisations, Place: John Wiley & Sons.
Pryke, S., Badi, S., Almadhoob, H., Soundararaj, B., & Addyman, S. (2018) Self-organizing networks in complex infrastructure projects. Project management journal, 49 (2), pp.18-41.Ruan, X., Ochieng, D., Price, A. and Egbu, C. (2013) Time for a real shift to relations: appraisal of social network analysis applications in the UK construction industry. Australasian Journal of Construction Economics and Building, 13(1), pp. 92-106
Pryke, S., Badi, S., & Bygballe, L. (2017) Editorial for the special issue on social networks in construction. Construction management and economics, 35 (8-9), pp. 445-454.
Pryke, S., & Smyth, H. (2006). The management of complex projects: A relationship approach. Oxford: Blackwell.

Pryke, S.D. and Ouwerkerk, E. (2003) Post completion risk transfer audits: an analytical risk management tool using social network analysis. Proceedings of 2003 Construction and Building Research Conference of the RICS Research Foundation (COBRA 2003).
Saha, B., Mandal, A., Tripathy, S. B., & Mukherjee, D. (2015) Complex networks, communities and clustering: A survey. arXiv preprint arXiv:1503.06277.
Salancik, G. R. (1995) Wanted: A good network theory of organization. Administrative Science Quarterly, 40 (2), pp. 345-49.
Sandberg, J., & Tsoukas, H. (2011) Grasping the logic of practice: Theorizing through practical rationality. Academy of management review, 36 (2), pp. 338-360.
Saynisch, M. (2010) Beyond frontiers of traditional project management: An approach to evolutionary, self-organizational principles and the complexity theory—results of the research program. Project Management Journal, 41 (2), pp. 21-37.
Schipper, D., & Spekkink, W. (2015) Balancing the Quantitative and Qualitative Aspects of Social Network Analysis to Study Complex Social Systems. Complexity, Governance & Networks, 2 (1), pp. 5-22.
Scott, J. (2017) Social network analysis (4th Edition). London: Sage.
Senge, P. (1990) The Leader's New Work: Building Learning Organizations. Sloan Management Review. incomplete
Silvius, G., & Karayaz, G. (2018) Developing Organizational Maturity for Effective Project Management. Place: IGI Global.
Simmel, G. (1908) In Soziologie: Untersuchungen über die Formen der Vergesellschaftung, 1. Aufl., [Online]. Available at: http://socio.ch/sim/soziologie/index.htm; Berlin: Duncker & Humblot Verlag). [Accessed on: 20th November 2019]. Note: This work was originally published in 1908 but translated into English under Simmel, G. (2009).
Smyth, H. J., & Morris, P. W. (2007) An epistemological evaluation of research into projects and their management: Methodological issues. International journal of project management, 25(4), pp. 423-436.
Stacey, R. D. (1996) Complexity and Creativity in Organizations. Place: Berrett-Koehler.
Stacey, R. (2003) Complex Responsive Processes in Organizations: Learning and Knowledge Creation. Place: Routledge.
Stacey, R. D. (2007). Strategic Management and Organisational Dynamics: The Challenge of Complexity to Ways of Thinking about Organisations. Financial Times, Place: Prentice Hall.
Stacey, R. (2012) Tools and techniques of leadership and management: Meeting the challenge of complexity. New York, NY: Routledge.
Stacey, R. D., Griffin, D., & Shaw, P. (2000) Complexity and Management: Fad Or Radical Challenge to Systems Thinking? London, UK: Psychology Press.
Steen, J., DeFillippi, R., Sydow, J., Pryke, S., & Michelfelder, I. (2018) Projects and networks: understanding resource flows and governance of temporary organizations with quantitative and qualitative research methods. Project Management Journal, 49 (2), pp. 3-17.
Styhre, A. (2008) The role of social capital in knowledge sharing: The case of a specialist rock construction company. Construction Management & Economics. 26. pp. 941-951. 10.1080/01446190802259035.
Tavistock Institute (1966) Independence and Uncertainty – A study of the Building Industry. London: Tavistock Publications,
Taylor, Frederick, W. (1911) The principles of scientific management. New York & London: Harper Brothers.
Transport for London (2014) Innovative Contractor Engagement Report. [Online]. Available at: https://www.secbe.org.uk/content/panels/Report%20-%20Innovative%20Contractor%20Engagement%20Procurement%20Model%20-%20Bank%20Station%20Capacity%20Upgrade-6d5f2a.pdf [Accessed on: 04th July 2017].
Tsoukas, H., & Chia, R. (2002) On organizational becoming: Rethinking organizational change. Organization science, 13(5), pp. 567-582.

Wagner, A., & Fell, D. A. (2001). The small world inside large metabolic networks. Proceedings of the Royal Society of London. Series B: Biological Sciences, 268(1478), 1803-1810.

Wasserman, S., & Faust, K. (1994) Social network analysis: Methods and applications. Place: Cambridge university press.

Watts, D. J., & Strogatz, S. H. (1998) Collective dynamics of 'small-world'networks. Nature, 393 (6684), pp. 440.

Watts, D.J. (1999) Networks, dynamics, and the small-world phenomenon. American Journal of Sociology, 105 (2), pp. 493–527.

Weick, K. E. (1976). Educational organizations as loosely coupled systems. Administrative science quarterly, pp. 1-19.

Wild, A. (2002) The unmanageability of construction and the theoretical psycho-social dynamics of projects. Engineering Construction and Architectural Management, 9 (4), pp. 345-351.

Winch, G. (2002) Managing Construction Projects: An Information Processing Approach. Place: Wiley.

Winter, M., Smith, C., Morris, P., & Cicmil, S. (2006) Directions for future research in project management: The main findings of a UK government-funded research network. International journal of project management, 24 (8), pp. 638-649.

Yang, Q., Yang, N., Browning, T. R., Jiang, B., & Yao, T. (2019) Clustering product development project organization from the perspective of social network analysis. IEEE transactions on Engineering Management, 69(6), 2482-2496

Zheng, X., Le, Y., Chan, A. P., Hu, Y., & Li, Y. (2016) Review of the application of social network analysis (SNA) in construction project management research. International journal of project management, 34 (7), pp. 1214-1225.