UNDERSTANDING CONSTRUCTION AS A COMPLEX AND DYNAMIC SYSTEM: AN ADAPTIVE NETWORK APPROACH

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ABSTRACT

Construction can be characterised as a specific type of project industry, with specific features concerning the production, such as temporality, bounded location, and one-off products. The industry can be analogised as a nexus from which parties connect in temporary "project networks" bringing together numerous production factors needed for specific projects. In this paper, construction is viewed from an adaptive network perspective, bringing together various conceptual angles. The adaptive network approach is based on the emergence of flexible patterns in a quasi-structured manner. It attempts to assist in the control of fixed patterns whilst relying on self-regulation, which, in practice, often leads to chaos. In a construction environment, which differs from that of manufacturing, production systems need to be adaptive to changes from both inside and outside of the system, but need to reduce the inherent risk of chaos caused by the unstable nature of the production environment of construction. The management challenge for these types of production environments is to balance between a minimum level of predictability and controllability with a maximum level of flexibility and emergence. The adaptive network approach is discussed to be an appropriate model for the effective management of construction projects.

KEY WORDS

Adaptive network approach, construction, emergence, complexity, industrial dynamics

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INTRODUCTION

According to (Ball 1988), the main shortcoming of the traditional procurement system was that the main contractors utilise a "merchanting" system based on financial optimisation logic, where fixed costs are kept to the minimum and with extensive use of plant hire and subcontracting of the workforce. The resultant vertical disintegration has lead to the construction industry's fragmentation and the use of complex contractual arrangements. The tendency of main contractors for recourse to market forces in their strategic outlook has resulted in the malaise found in the industry, such as: low profitability; detrimental "boom & bust" cycles; widespread short-termism; endemic high cost and low productivity; and most important of all, client dissatisfaction. (Benhaim & Birchall 1999) claimed that main contractors – through the merchanting system – have damaged the flexible construction process to such an extent that the process based regulation mechanisms, i.e. the professional codes of practice and informal relations on site, have impacted on the effective application of contracts in operational situations. The authors also reflected that the current move towards greater integration (referring to partnering) could be interpreted by the voluntarist sociological approach of the collective-action theory. But by merely extending the traditional use of outsourcing or subcontracting could lead to the creation of cumbersome hierarchical structures consisting of several tiers of suppliers, forming complex supply chain networks. The weak co-ordination by traditional market contracts along with high levels of fragmentation poses numerous problems in the organisation of a supply network in construction projects.

There exists a need for supply chain concepts in construction to be able to cope with the organisational complexity and implicit structures of the industry. The network approach is presented here as an appropriate basis for analysis and configuration of governance of project coalitions and supply chain management in construction (Pryke 2002, 2003). This is achieved through an exploration of theoretical perspectives to industrial networks and complex adaptive systems, as a alternative methodology for the effective management of construction supply chains. The adaptive network approach could enable supply chains to be adaptive to changes from both inside and outside of the supply system.

INDUSTRIAL NETWORKS: THREE THEORETICAL PERSPECTIVES

Earlier studies by Vrijhoef and Tong (2004) showed the significance of industrial networks in the examination of the construction industry. It was inferred that inter-firm networks might be dynamic either because of changes to its composition, as members come and go, or due to adjustments of inter-relationships by existing members. Two generic types of industrial networks were found, based on distinct change processes. In the first type, relations are socially integrated and change is more a function of collective learning and social control, consistent with the neo-institutional perspective. In the second type, however, inter-firm relations are mostly competitive and change occurs mainly through the substitution of individual firms in the organisational population, consistent with the ecological perspective.

The neo-institutional perspective with regards to organisational analysis focuses on the social aspects of organisational behaviour, which includes inter-organisational relations. Success is seen as tightly integrated systems, although the mechanisms of integration may

vary widely. Dense networks may provide opportunities for co-operation through cognitive sharing, imitation, and regulation. Successful co-operation results from effective learning, both individually and collectively, and enhances the long-term viability of individual firms and the network as a whole. To the extent that all firms in the network draw on network-level resources, depending upon their particular position within the network and their connections to others, one would expect failure rates in the network to be relatively low.

In contrast to the neo-institutional focus on the social quality of inter-firm relations, and the micro-processes linking environments and organisations, the ecological model emphasizes resource competition and focuses on external selection forces fuelling the competitive struggle (Hannan & Freeman 1989). The resultant scenario as a result of selection pressures is that the less effective organisations are eventually driven out of the population and an element of inertia within organisations appears to hinder the capacity to react to changes in order to keep pace with environmental turbulences. Strong network embeddedness is therefore a liability, limiting firms' adaptability in volatile environments. High firm mortality rates would be interpreted from this perspective as an indicator of network vitality only if founding rates are high as well,

The neo-institutional and ecological perspectives thus offer different interpretations of the dynamism and flexibility linked to industrial networks. From the neo-institutional perspective, network flexibility is the outcome of existing firms continuously learning, through networks, new competencies and adjusting old ones. Successful inter-firm networks are socially dense and evolve through collective learning. From the ecological perspective, network flexibility reflects the continuous re-composition of networks with a different mix of specialized firms. Relations are competitive, changing mainly through the differential selection of firms.

The complexity theory perspective adds to these perspectives from a viewpoint of organic growth. The complexity theory originates from evolution science and biology viewing organizational systems as organic systems dominated by intrinsic disorder and chaos, evolution according to certain basic rules and dynamical self-organization (Lewin 1999). Anderson (1999) presents four basic elements of complex adaptive system: agents with schemata, self-organizing open systems receiving energy from outside, co-evolution on the edge of chaos and system evolution based on recombination. This view is based on the notion of agents (individuals, groups or coalitions of groups) in a system behaving according to certain "cognitive structures", and influencing each other. The system is therefore self-organising, but needs to import energy to maintain the self-organized state. Agents co-evolve with each other according to a dynamic equilibrium and power laws lying keeping the co-evolution of agents on the edge of chaos. The system evolves over time because of new entry, exit or transformation of agents, and the evolution of the connections between agents. Anderson et al. (1999) observe measures taken to increase the level of control of complex organizational systems by simplification and modeling. The challenge of control here is living between too much order and too much disorder. Disorder and complexity can be reduced by standard policies and procedures (codification and institutions) or absorbing complexity by building a relational network. By taking measures the system can be manipulated in order to increase interdependencies between actors (i.e. agents) and policies, to encourage search behavior and goal sharing. Tighter synchronization between actions,

recombination of partial solutions and team production must encourage cooperation and interaction between actors reducing the level of chaos and establishing the dynamic equilibrium of the system. The theories presented indicate the importance of viewing projects as complex adaptive systems.

COMPLEX ADAPTIVE SYSTEMS

The different perspectives offered by the neo-institutional and organisational ecology models present a basic dilemma for industrial organisations between internality and externality, competition and co-operation, evolution and control. In his view of a "new economy" Langlois (2002) observes the rise of a more ecological industrial model, and a shift from internal to external capabilities. The "vanishing hand" argument proposed by Langlois is based on a society that is getting ever more volatile, variable and diverse. The increasing speed of societal and technological developments demands increased dynamic capabilities and responsiveness of industrial systems. Langlois argues that 'largely vertically integrated firms are becoming less significant and are joining richer mix organisational forms'. Less vertically integrated and centrally coordinated firm, yet interlinked and extended, being able to respond to ever faster changing circumstances, will become a larger part of the industrial landscape. However, in their explanation of complex organisational dynamics, Dooley and Van de Ven (1999) propose that the observation of "chaotic organisational dynamics" may indicate the implicit presence of control and structure instead of the lack of it. In a changing organisational system though, this is another form of control that was present previously.

In his analysis and design model of complex adaptive systems (CAS) of organisational change, Dooley (1997) states that such systems are dominated by concept, including chaos, random behaviour, internal and external dependence and organic growth (evolution). Their development is characterised by structural change and continuous evolution of apparent chaos and interaction with the (turbulent) environment and self-organisation (Morel & Ramanujam 1999). When the system reaches the "edge of chaos", it spontaneously self-organises into new structures. Design of complex adaptive organisations must be a balance of convergent and divergent forces, and is organic rather that linear (Dooley 1997). Designing should be interpreted more as conditioning and channelling a development, i.e. "evolutionary design" (Langlois 1998). In a way, a CAS could be described as a "living system" in contrast to a "planned system" (Towill 1996).

INDUSTRIAL NETWORKS AS COMPLEX ADAPTIVE SYSTEMS

Powell (1990) criticised the argument that hybrid modes of governance can be arrayed in a continuum with market transactions at one end and hierarchy (i.e. vertically integrated firm) at the other end. Powell states that a hybrid mode of organization is a form of governance that is distinctly different from market and hierarchy. He used the term network to classify such ties between firms. Networks are more flexible and complex than hierarchies (Powell 1990).

In this perspective, industrial networks are adaptive systems with a minimum level of control and vertical integration, and a maximum level of flexibility and connectivity. Yet again, the dilemma between control and evolution arises. In addition, from the focal firm's point of view, the manner and extent of configuring and controlling the network is dependent

on various factors that include the type of product and the level of influence and power of the focal firm (Cox 1999, Cox et al. 2001, Lamming et al. 2000, Zheng et al. 2001).

CONTROL VERSUS EMERGENCE, STRUCTURING OR EVOLUTION, AND EMBEDDEDNESS

Compared with markets, networks provide potential for flexible integration, learning and exchange of information. Networks are particularly suitable when there is a need for flexible production control (Håkansson 1992). Sturgeon (2002) proposes the modular production network as a model of industrial organisation with high levels of outsourcing, interaction and flexibility. When observing supply networks as complex adaptive systems, there is a need to be a balance between control and emergence of the network. Control detracts from innovation and flexibility. Emergence decreases predictability and manageability of operations (Choi et al. 2001).

Alternatively, it is a question of engineering (formal structuring) or evolution (informal structuring) of inter-organisational cooperative relationships and processes, and the extent to which this is possible and effective (Bresnen & Marshall 2002). The engineering approach implies the possibility to structure and control inter-organisational arrangements in a relatively linear manner, and presupposes more clear business objectives (signification), power relations among partners (domination), and joint market opportunities (legitimation) (Smith Ring & Van de Ven 1998; Sydow & Windeler 1998). Instead, the evolution approach is aimed at finding or creating common values, based on equality and reciprocity, and "organic growth" of inter-organisational cooperation (Axelrod 1984), including education and socialization processes (Lehtinen 2001). The evolution as well as the engineering approach aims at a more integrated network structure. Through "social engineering", including trust building, intensified information exchange and interaction, and joint problem solving arrangements, inter-firm relations get socially as well as structurally more embedded (Uzzi 1997).

COMBINING COMPLEX ADAPTIVE SYSTEMS WITH ADAPTIVE NETWORKS

There is growing realisation of the importance of managing both the physical and social relationships within and between firms in response to adapting to growing market complexity. This approach highlights a shift from closed to open systems thinking and the importance of interacting with the environment, as firm survival is dependent on its ability to adapt to markets. This systems approach attempts to analyse a subsystem in a wider context by coordinating a connected network of companies (Christopher 1992). The solutions generated often have important consequences for the whole supply chain and may results in the strategic alignment of sub-units in order to allow for seamless co-ordination along the supply chain. Although good at describing and modelling the flow of information and materials, the increased complexity in terms of human interaction in network forms of organisation makes general systems theory incomplete. Rigby et al. (2000) argue that inter-firm agility can not be fully understood by utilising simple unidirectional cause and effect that is favoured by general systems theory. The reason being that such an approach does not take into account the more subjective aspects of human interaction. It is also naive to envisage relationships in networks as being trusted, fair and reciprocal. Instead, it would be more realistic to conceptualise social processes and networks as full of tensions and contradictions,

governed by a dialectic of control which can only to some extent be tamed by an appropriate governance structure that is based on a process of permanent reproduction (Sydow & Windeler 1998). The portrayal of industrial networks as complex adaptive systems has significant implications to the study of construction projects.

ADAPTIVE NETWORK PARADIGM APPLIED TO CONSTRUCTION

The construction industry is a specific type of project industry. As a consequence, relations between firms are mostly maintained for the duration of projects only. In addition, construction projects have often a large scope, long lead-times, and involve many parties and stakeholders. Supply chains are not merely directed towards "classical goals" such as minimising transaction costs, but also towards enhancing the transfer of expertise and information on planning, design, construction and maintenance between parties, and ultimately towards striving for joint value maximisation. Construction supply chains often lack integration due to the many different firms involved in the production of a built object. Therefore the industry is often blamed for being fragmented (Latham 1994). More centralised governance mechanisms have been proposed in the industry to relieve the fragmentation, reduce costs as well as increase value (Voordijk et al. 2000). The emergence of more centralised forms of organising supply chains would imply a shift to more hierarchical, vertically integrated structures. Co-operation and integration between supplying, constructing, and designing parties in networks would make it possible to present a total product with quality guarantees to the market.

On an industry scale, Dubois and Gadde (2002) distinguish tight (contractual) couplings in projects and loose couplings in the permanent network within the industry. The industry is therefore considered as a "loosely coupled system". The pattern of couplings influences productivity, innovation and the behaviour of firms. In terms of organisational behaviour, cultural and human issues, such as trust and learning, have been indicated as major implications on construction supply chains (e.g. Love et al. 2002). The network approach would therefore not only improve the performance of construction supply chains, but also the socio-organisational basis of the inter-firm relationships within the supply chain.

THE EXTENDED ENTERPRISE AND THE VIRTUAL ORGANIZATION AS GOVERNANCE MECHANISMS FOR ADAPTIVE NETWORKS IN CONSTRUCTION

Karlsson (2003) observes that contemporary industrial organization and production strategies increasingly put emphasis on the operations that are external to traditional organisational environments, and managing operations in an external network. Karlsson calls this the shift from an enterprise to an "extraprise". This concept is close to the extended enterprise (O'Neill & Sackett 1994) and the virtual corporation (Davidow & Malone 1992). The extended enterprise and the virtual corporation are similar concepts aimed at the establishment of partnerships between firms to achieve joint business success. According to Browne and Zhang (1999), the difference lies in the dynamism and temporality of the virtual corporation, and the stability and longer-term focus of the extended enterprise. The emergence of the concepts of the extended enterprise and the virtual corporation has raised the question of what co-ordination mechanisms keep these enterprises together.

The idea of the extended enterprise and virtual organisations in construction has first been discussed by Eccles (1981) by observing a construction project as a "quasi-firm" with strong linkages between firms involved in the project as if it were one firm delivering one built object to the end customer. Two important issues impact the idea of extended enterprises and virtual corporations in the construction supply chain: the division and allocation of the many specialised operations and tasks among the many specialist firms, and the strong project focus of construction. As described above, this is particularly an issue in the construction industry because of the prominence of SMEs. Compared with the models of extended enterprises in manufacturing (O'Neill & Sackett 1994), the model for construction must be able to cope with the relative high level of fragmentation and temporality of construction projects, or the model should propagate the recurrence of inter-firm cooperation in different projects (Kornelius & Wamelink 1998).

Since supply chains in construction are dominated by fragmentation and a general lack of integration, application of the concepts of the extended enterprise and the virtual corporation to construction supply chains implies a higher level of integration between firms. In order to achieve higher levels of supply chain integration, Dainty et al. (2001) observe the need to facilitate inter-firm relationships, achieve mutual benefits and build trust at key interfaces in the supply chain (client/contractor, consultant/contractor, contractor/subcontractors, subcontractor/suppliers etc.). It is crucial to take away the ingrained barriers of traditional relationships and the adversarial culture in construction practice, and instead, introduce a change management framework to facilitate the implementation of supply chain management at an operational level (Dainty et al. 2001).

COLLABORATIVE GROUPING AND INTEGRATION OF ACTIVITIES

At the operational level networks can be achieved by grouping of activities in an extended/virtual enterprise setting. Wu and Sun (2002) propose a model of merging, grouping and interlinking core activities, irrespective of the party in the supply chain executing the activities. The links between the activities predefine the interfaces, interaction and communication between the parties. Nicolini et al. (2001) add the concept of clusters to the integration of activities in construction projects. Activities are first integrated to activity clusters and then made up into subsystems of the entire product structure. In terms of the extended enterprise within the supply chain Bitici et al. (2003) propose the integration of all activities in an extended business process encompassing all parties in the supply chain (i.e. value system) to create and sustain competitive advantage in a collaborative system (i.e. the extended enterprise).

DEVELOPMENT OF ADAPTIVE NETWORKS AND FLEXIBLE SUPPLY CHAINS IN CONSTRUCTION

The development of adaptive networks as organisational structures in the construction industry is highly dependent on the environment. Shirazi et al. (1996) argue that relative complex environments in construction lead to greater decentralisation of authority, particularly by delegation. Technological complexity, uncertainty and distributed expertise among parties cause great numbers of specialists involved in the project, leading to greater project complexity. In terms of development of adaptive networks, this calls for a flexible

supply chain organisation including the following six supply chain flexibility components: operations system flexibility, market flexibility, logistics flexibility, supply flexibility, organisational flexibility and information systems flexibility (Duclos et al. 2003). Based on these components, flexibility measures must be put in place across the firms in the supply chain in two flexibility dimensions: resource flexibility and coordination flexibility. Tendering and procurement mechanisms must be aimed at selection of best available resources and competencies, to be able to build a group of firms that operate in a network (Palaneeswaran et al. 2001). The group of firms is lead by a supply chain of network broker.

INTER-ORGANISATIONAL LEARNING

In order that an Adaptive Network approach can be implemented successfully, a closer focus on inter-organisational (between organisations) learning processes must be made. This extension to the traditional intra-organisational (within organisations) learning has developed in the past 10 years as a result of inter-organisational collaborative entities like joint ventures, strategic alliances and networks. Up to now, the literature has concentrated primarily on studying the requirements for successful learning between organisations with the help of such conceptual notions as transparency and receptivity, experiential similarity and diversity, and inter-organisational trust (Larsson et al. 1998).

Less attention has been devoted, however, to the empirical examination of the way inter-organisational collaborative constellations actually learn as unique learning entities by producing inter-organisational standard operating procedures, routines and other ''inter-organisational rules'' that, it can be assumed, will differ to some extent from the experiential rules of the individual organisations that constitute the formal collaborations (Holmqvist 2003). This is particularly pertinent for the construction industry and the same author has also observed that within inter-organisational learning processes the source of dominance often shifted, and authority remained vague, thus making any consistent or continuous control of learning processes unlikely. Intra-organisational learning processes appeared to generate much exploitative learning that created reliability in experience, whilst inter-organisational learning appeared to generate more explorative learning that maintained variety in experience. Both intra- and inter-organisational learning will be required to maintain both control and flexibility to the adaptive network approach. Additionally, this approach allows for the early detection of "weak signals" that could prove invaluable to the development and improved learning of the network. Such signals would otherwise be invisible to traditional forms of management.

CONCLUSIONS

This paper presents an adaptive industrial network perspective based on emergence as well as control of inter-firm patterns in the management of construction supply chains. Production systems in a construction environment need to be adaptive to changes from both inside and outside of the system and must be observed as complex adaptive systems. The management challenge of adaptive networks is to balance between a minimum level of predictability and controllability, with a maximum level of flexibility and emergence.

This has been considered by incorporating the more established ideas of industrial networks with those of complex adaptive systems. The neo-institutional and ecological

perspectives may appear to be conflicting. The first emphasises cooperation and learning, whilst the latter on competition and natural selection. In fact the difference is mainly due to focus and the level of analysis. Depending on what practices are considered appropriate, institutional forces may either retard or encourage change. Industrial networks that combine cooperative and competitive processes, as well as social integration can either lead to change and innovation, or to inertia and path dependence.

The governance mechanism of adaptive networks was also found to promote connectivity of inter-firm concepts such as the extended enterprise and virtual corporations. The adaptive network approach was found to be an appropriate model for the effective management of construction supply chains. Application of these concepts must be aimed at collaborative grouping of resources, along with integration and coordination of activities in the supply chain, conducted in a flexible yet effective manner. The adaptive nature of this approach allows for the detection of weak signals through an ecological perspective, which contribute towards both intra- and inter-organisational learning. The resultant improvement to the understanding of the network provides better predictability in terms of more effective collaborations.

At present the production environment in the construction industry is mainly organised in separate projects involving relatively large number of independent firms. Therefore relatively high levels of emergence and fragmentation, disorder and chaos dominate construction. However from the complex adaptive systems concept, it is argued that a balance between control and emergence, integration and fragmentation, chaos and order should be established. Thus, in construction, this would imply a development towards more control and integration, by bringing in contractors, subcontractors and suppliers at the design stage. In terms of networks and supply chains, this means introduction of more "network orchestration", more centralised governance of supply chains and more "stabilised" production environments, and longer-term inter-firm collaboration. It implies also changing power regimes in the supply chain, changing division of roles and loss of autonomy. The focal firm in the supply chain, e.g. the main contractor or project developer, must act as the "supply chain broker", and the supply chain as "one firm". Competition in the construction industry may then shift from competition between individual firms toward competition between supply chains. The next step is to conduct further research with the use of case studies in order to identify whether the adaptive network approach has practical applications in construction projects. In particular, it will be interesting to examine advantages and implications (e.g. motivation and capabilities of firms) when applying more centralised and longer-term inter-firm arrangements and shared business strategies between multiple firms in construction supply chains, vis-à-vis the current fragmented nature of the industry containing a high level of SMEs and specialists.

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