

A SYSTEMIC BIM INNOVATION MODEL IN THE CONSTRUCTION SUPPLY CHAIN

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BIM innovation research has mainly focused on diffusion models of acceptance at the individual and organisational levels. However, BIM has the potential to bring together multiple organisations working collaboratively in a coordinated fashion. Realising this potential requires a study of BIM innovation at the inter-organisational level, which is considered to be systemic BIM innovation. Systemic BIM innovation and its effect in the construction supply chain have not been sufficiently investigated. The aim of this paper is to present a critical review of literature on the diffusion of BIM innovation in the construction industry. A conceptual model of systemic BIM innovation is developed and presented. The proposed model incorporates factors such as individual BIM acceptance, organisation's drivers of BIM usage, organisation's linkages, supply chain management challenges, and the role of context. It is found that variables facilitating systemic BIM innovation are interrelated at different analytical levels, and are shaped by the context. Directions for future research and empirical validation are presented.

Keywords: BIM, construction supply chain, diffusion model, inter-organisation, systemic innovation

INTRODUCTION

Research in information and communication technologies (ICTs) in construction, such as BIM, has investigated ICT adoption from perspectives such as enablers for technology uptake (Sargent *et al.*, 2012), alignment of technology with current work processes (Hartmann *et al.*, 2012), implementation constraints (Peansupap and Walker 2006), user resistance (Sargent *et al.*, 2012), and user technology acceptance (Howard *et al.*, 2017). As such, BIM adoption is usually approached at the individual level (Davies and Harty 2013), and the firm level (Peansupap and Walker 2006). It is argued that BIM unfolds its potential in complex inter-organisational settings, however, inter-organisational BIM studies are scant (Papadonikolaki *et al.*, 2017). The challenge is to make BIM work at an inter-organisational level in a temporary construction project-coalition in the context of various governance modes (Keast and Hampson 2007), procurement methods (Rose and Manley 2014), and top-down and middle-out BIM diffusion dynamics (Succar and Kassem 2015).

The innovation diffusion literature offers multiple names to the networks of agents in a social system interacting with technology, institutions and infrastructure to generate, diffuse, and utilise a technology. This concept has been labelled as systemic innovation (Bröring 2008), or system innovation (Geels 2002). Systemic innovations in the supply

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chain require multiple partners participating, adhering, modifying and adapting innovations in order to make them work (Chesbrough and Teece 1996).

In construction innovation research, Slaughter (1998) described system innovation as a set of complementary innovations working together to provide new attributes or functions of a system or facility. To achieve the greatest potential, the set of innovations requires implementation from the earliest stages, multiple firms working collaboratively, combined with organisational authority to ensure integration (Slaughter 1998). Taylor *et al.*, (2004) defined systemic innovation as innovations that reinforce an existing product but necessitate a change in the process that requires multiple firms to change their practice.

A systemic BIM innovation in this research is defined as the set of BIM-related innovations, including technology, process and organisational innovations, which requires multiple firms to change their practice simultaneously in order to reduce the asymmetry between the theoretical BIM potential and empirical results in projects. Systemic BIM innovation impacts the inter-organisational sphere in the construction supply chain. It requires high-level BIM applications, which have more barriers to adoption and less immediate benefits (Davies and Harty 2013). It is argued that challenges of the construction supply chain management are also challenges for the diffusion of a systemic BIM innovation. The resistance to innovation adoption is observed at organisational as well as individual levels (Singh 2014). Thus, systemic BIM innovation requires further attention to the effect of individual acceptance, organisation's drivers for technology uptake, inter-organisational linkages, and the role of the context.

The objectives of this review paper are to: (1) identify factors influencing the diffusion of systemic BIM innovation across the construction supply chain in a temporary project-coalition, and (2) develop and present a diffusion model of systemic BIM innovation. To achieve these objectives, a literature review was conducted and a systemic BIM innovation model was developed and presented. The model is discussed and directions for empirical validation are presented.

DIFFUSION OF INNOVATION IN CONSTRUCTION

The innovation diffusion process has been investigated in the construction industry by a number of authors. Harty (2008) claimed that the complex context of innovation in construction, characterised by inter-organisational collaboration and project-based approach, can be studied through the sociology of technology approach. The concept of socio-technical systems was used to understand the social and organisational contexts in which innovation success can occur. These include actors and objects as mutual constituents when technology is used and negotiated in practice (Schweber and Harty 2010). Nevertheless, in a broader definition, a socio-technical system includes the cluster of technologies, regulation, user practices, infrastructure, cultural meaning and supply networks (Geels 2002). Sackey *et al.*, (2014) used the socio-technical approach in a BIM-enabled intra-organisational construction context and revealed how BIM can be aligned with concomitant work processes to maintain systems alignment.

Some other perspectives from the sociology of technology approach have also been investigated. Larsen (2005) presented cohesion, structural equivalence, and thresholds as dominant concepts in the diffusion process. Such concepts involve how individuals take up adoption based on peer's level of innovation. Larsen and Ballal (2005) identified six stages in the innovation diffusion process: awareness, interest, opinion, forming, decision-making, use and promote/impede. The research concluded that the innovation-decision

process cannot be seen without a specific context and actors initiate the innovation at any point in relation to cohesion, structural equivalence, and thresholds.

Larsen (2011) argued that awareness and influence are key concepts in the early stages of the innovation process. Linderoth (2010) suggested the actor network approach as a means to understand how to transfer knowledge and benefits from BIM adoption from one project with a constellation of firms to a consecutive project network with another constellation of firms. The perspectives of sociology of technology in construction have helped to understand technology diffusion across individuals who accept or reject a technology, organisations which negotiate in practice the use of technology, and organisations which are influenced by a more powerful firm. However, it is still unknown the effects of industrial contexts which can constraint or promote the use in the long-term. Linderoth (2010) highlighted that clients and regulation bodies are the actors believed to be the triggering point of BIM usage at an inter-organisational level and ultimately to an ecosystem level.

PREVIOUS MODELS ON SYSTEMIC INNOVATION

The underlying problem of inter-organisational analysis is the constantly changing constellation of firms working on different projects (Adriaanse *et al.*, 2010; Linderoth 2010). Winch (1998) represented the construction industry using a complex systems model composed of a superstructure (clients, regulators, and professional institutions), systems integrators (contractors, architects and engineers), and infrastructure (subcontractors and suppliers). The model highlights the system integrator at the design and construction phases as the innovation champion required to integrate innovation into a coherent whole. Taylor and Levitt (2004) found influential factors facilitating the diffusion of systemic innovation among trades: organisational variety, boundary strength, interdependence of tasks, and span. However, the unit of analysis is a construction project with downstream stakeholders, namely, contractors and trade contractors.

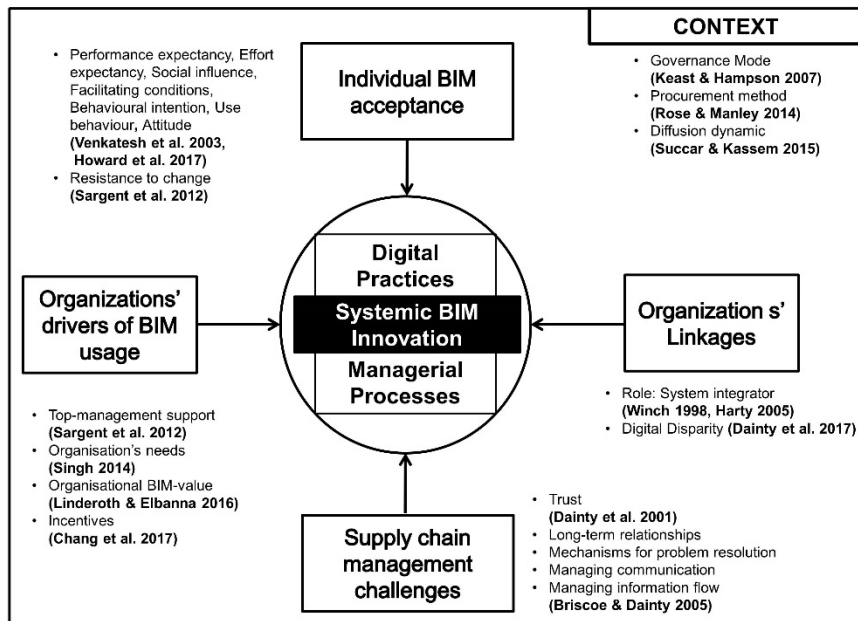
Adriaanse *et al.*, (2010) presented a model to explain the inter-organisational use of ICTs. The model showed that personal motivation, external drivers, knowledge and skills, and acting opportunities trigger the intention to use ICT, thus, the inter-organisational use of ICTs. However, these constructs are ingrained in the individual and organisational dimension of technology uptake. Moreover, BIM is defined as coordination and communication tool, leaving unexplored the process and inter-organisation changes required. Singh (2014) described three types of systemic innovation-related needs to analyse diffusion of innovations: need to innovate, need for the innovation and need for the diffusion of the innovation. Nevertheless, these needs are explained from an intra-organisational perspective in various context settings such as project complexity, client's requirement, and firm's leadership. There is a lack of understanding of how the needs of a given organisation interrelate with the needs of other firms. Mahamadu *et al.*, (2014) catalogued technological, organisational and environmental determinants to understand BIM acceptance in the construction supply chain. The focus is on user acceptance that plays a major role in BIM implementation in the supply chain context.

SYSTEMIC BIM INNOVATION MODEL

The resistance to innovation adoption is observed at organisational as well as individual levels (Singh 2014). Several theoretical insights were found in the literature which help to construct a diffusion model at the inter-organisational level. The literature suggests that a systemic BIM innovation model should include: (1) BIM acceptance at the individual level; (2) organisational drivers of BIM usage; (3) inter-organisational linkages

between firms; (4) supply chain management challenges; and (5) the role of the context. The elements of the literature review were combined into a Systemic BIM Innovation Model, as shown in Figure 1.

Figure 1: First Version of the Systemic BIM innovation model



Individual BIM acceptance

Most researchers investigating user's technology acceptance have utilised the Unified Theory of Technology Acceptance (UTAUT) to explain the acceptance and use of various ICT's in the construction industry (Davies and Harty 2013; Howard *et al.*, 2017) The model developed by Venkatesh *et al.*, (2003) predicts factors influencing the behavioural intention and the intention to use of information systems. Behavioural intention is affected by performance expectancy, effort expectancy and social influence, whereas intention to use is driven by behavioural intention and facilitating conditions. The model has been modified to explain ICT appropriation in the construction industry. Sargent *et al.*, (2012) included resistance to change to understand the individual intention to use an ICT, whereas Howard *et al.*, (2017) found attitude as a construct that correlates to the behavioural intention to use BIM. Improper ICT adoption and misalignment between construction project's problems and BIM implementation may lead to user resistance at the top-management and user levels, thus, negatively affecting the diffusion process.

Organisation's drivers of BIM usage

A top-down approach of BIM usage within a large organisation implies that top managers are convinced that their organisation-related problems might be solved by proper use of BIM. As such, managers use it as a strategic platform to overcome problems during the design, construction and operation of building projects. Sargent *et al.*, (2012) argued that top-management support plays a crucial role in determining the failure or success of technology implementation.

Singh (2014) presented ICT innovation-related needs to understand why organisations make adoption decisions: (i) some organisations seek innovations to stay ahead of the competition (need to innovate), (ii) organisations need to improve their efficiency and manage complex projects (need for the innovation), (iii) some organisations need to drive and facilitate change as a social responsibility (need for the diffusion of the innovation).

These needs are intrinsically related to organisational ICT-value. In the inter-organisational perspective, a basic condition for value creation is the existence of firms willing to form cooperative clusters and co-create value in a thoughtful way. However, lack of incentives constrains organisation's willingness. Furthermore, firms are more focused on their own processes and ICT return of investment (Linderoth and Elbanna 2016). Economic incentives are also found in the literature as drivers of organisation's BIM uptake and inter-firm collaboration, particularly in high collaborative environments such as Integrated Project Delivery (Chang *et al.*, 2017).

Organisation's linkages

Pryke (2005) contended that all organisations are social networks, thus, projects should be analysed in terms of networks of relationships, and classified according project coalition roles. A similar view is shared by Linderoth (2010) who stated that a new network of actors with new experiences will shape roles and relationships in the network. BIM will delegate new roles and competencies such as an increased need for collaboration, for example, subcontractors could soon assume a more decisive role in the design process (Papadonikolaki *et al.*, 2016). Harty (2008) claimed that there is a strong systems integrator needed to steer and manage innovation processes. This gravitating force can be defined as 'relatively bounded' which aligns various participants and reconcile potential conflicts. This relatively bounded force can be seen as a prominent role in the innovation process and has inter-organisational effects in a number of spheres of influence.

Technological disparities are also key elements to understand organisation's linkages. The term digital divide (Van Dijk 2006) refers to the gaps in access and usage of ICTs. Appropriate technology uptake requires material access (hardware and software), mental access (digital experience and interest), skills access (digital skills) and usage access (use opportunities). Large companies are in the position to use BIM due to previous experience, investment opportunities, and power. However, small and medium enterprises (SMEs) might have the usage access (e.g. a contract) but lack of the skills, material and mental access. This digital disparity makes BIM uptake in these companies an important barrier to deploy the innovation across the supply chain (Dainty *et al.*, 2017). As a consequence, some stakeholders are not in the ability to adopt new tools and processes when required.

Supply chain management challenges

To unfold a systemic innovation it is crucial to unveil systemic problems that hinder the development of a specific technology development (Wieczorek and Hekkert 2012). Such problems are rooted in the network of supply chains. Bröring (2008) argued that the more systemic the innovation, the more centralised supply chain coordination should be. Nevertheless, systemic innovation is not possible in a fragmented industry (Dubois and Gadde 2002; Taylor and Levitt 2004).

A number of authors have identified problems in the management of supply chains. Thorpe *et al.*, (2003) suggested that having preferred subcontractors is actually a disadvantage. By contrast, Dainty *et al.*, (2001) claimed that main contractors tend to work with similar subcontractors and suppliers across projects. This suggests that it is possible to integrate the construction supply chain in subsequent projects when learning loops and improvements are made. However, there are factors that hinder subcontractors' integration and performance such as poor feedback and late payments made by the contractor. In this context, better achievements are hindered by decreased trust in upstream tiers and adversarial relationships in downstream tiers (Dainty *et al.*, 2001). To

address the main barriers to full deployment in supply chain management, Briscoe and Dainty (2005) identified key attributes deemed to be the most important for the successful integration of the supply chain. Such drivers are managing communication and information flows, mechanisms for problem resolution, and establishing long-term relationships.

Context

Existing research recognises the critical role played by the context in the diffusion of systemic innovations (Larsen and Ballal 2005; Harty 2008; Linderoth 2010; Sackey *et al.*, 2014). The context in which the technology is deployed has direct influence in its rate of adoption. Rose and Manley (2014) catalogued contextual determinants which influence the decision to adopt innovative products. This research argues that systemic BIM innovation within a project-based coalition is shaped by client's decision on the procurement method, the governance mode and the diffusion dynamics.

Governance modes appear to be an important contribution to the field of context of innovation networks as they configure the behaviour of project teams and the BIM diffusion process at the inter-organisational level. Keast and Hampson (2007) identified hierarchy, market and networks as different governance modes that directly affect the process and of the diffusion of innovations. In the hierarchical model, an authority integrates and regulates relationships between actors. By contrast, in the market mode, organisations are regulated by demand and supply by means of contracts. The network governance is underpinned by relational aspects such as reciprocity, trust and mutual benefit.

These governance modes lead to specific procurement methods and diffusion dynamics. The hierarchy mode is closely related to the top-down approach (Winch 1998; Succar and Kassem 2015) in which all stakeholders within the circle of influence of the authority are regulated. The market mode is related to a more natural diffusion of innovation in which a large organisation or industry association exert pressure to small organisations further down the supply chain, and upwards to regulatory bodies and governments, namely, the middle-out approach (Succar and Kassem 2015). Finally, the network mode of governance resembles supply chain partnerships in which inter-organisational teams integrates beyond organisational boundaries in a long-term perspective (Papadonikolaki *et al.*, 2017). Active clients have been identified as positive influential factors for the diffusion (Rose and Manley 2014) as they are able to decide the scope of innovations since the early stages of a project.

DISCUSSION OF THE MODEL

The variables in the model appear to be dynamic, interrelated, and shaped by the context. When individual and organisational acceptance is analysed, a paradox is uncovered. According to (Jacobsson *et al.*, 2017), the central elements in construction are time and action, thus, immediate results in time and cost. Although some literature suggests a high return of BIM investments (Azhar 2011), it is also observed that top-management may not be fully convinced to invest in BIM due to lack of performance metrics and tangible results in the short-term. Thus, organisation's facilitating conditions decline and users at the operational level do not perceive strategic interest in adopting BIM. Individual acceptance at operational level triggers organisational decisions at the top level and vice versa.

At the organisational level, there seems to be a misalignment between a firm's strategic objectives and BIM use as means to achieve such objectives. When escalated to the inter-

organisational level, mismatches between each firms' objectives impede the diffusion of systemic BIM innovation. Inter-organisational BIM will work if win-win relationships between firms are set. For example, the rebar supplier might use BIM to improve the pre-fabrication process, and the constructor can use the same model to improve quality assurance. As such, both organisations benefit from BIM. It is also argued that systemic BIM innovation might exploit a high-level of implementation to realise the theoretical potential advantage of BIM and the highest level of collaboration (e.g. design simulation or prefabrication). Thus, client's demands, project's size and their complexity are variables for organisation's drivers of BIM usage, as noted by Singh (2014).

Organisation's linkages also impact systemic BIM innovation. A concurrent topic found in the literature is the necessity to steer innovations through innovation champions (Winch 1998), relative boundedness (Harty 2008), or power (Schweber and Harty 2010). The systemic integrator, as a role in the systemic BIM innovation, steers the innovation process, aligns objectives and overcomes individuals' and organisations' resistance. However, the impact of one big company choosing BIM on other firms it is still unknown (Papadonikolaki *et al.*, 2017) in temporary project-coalitions. In this context, digital disparities seem to be a significant barrier within inter-organisational relationships, especially when small and medium enterprises are forced to engage in BIM processes. Long-term relationships are fundamental to achieve a systemic BIM innovation. With short-term focus, firms in the project-coalition lack of incentives to diffuse knowledge and innovation, thus, hindering collaboration (Jacobsson *et al.*, 2017). This is particularly a challenge when it is observed the nature of industry as temporary project-networks.

The context shapes the innovation diffusion process. An interplay is found between the client, the procurement method, the diffusion dynamic and the power. The client stands out as one of the most powerful institutional actors (Jacobsson *et al.*, 2017). It is the client who select early in the project the procurement method and in turn, the level of supply chain integration (Briscoe *et al.*, 2004). In a top-down approach, the client would decide BIM use with a compatible procurement method and an experienced team. On the other hand, if the client does not promote BIM, other powerful actor, such as the contractor, might demand its use, exerting pressure to the downstream supply chain (Jacobsson *et al.*, 2017) in a middle-out approach (Succar and Kassem 2015). The client's procurement approach might hinder BIM use and engagement of key stakeholders. If long-term relationships in the client-supply side are required, changes to the traditional approach are deemed as necessary (Briscoe *et al.*, 2004).

CONCLUSIONS

BIM at the inter-organisational level is labelled systemic BIM innovation. This requires a set of BIM innovations (e.g. technology, process and organisational innovations) to be deployed simultaneously by firms in a temporary project-coalition. Drawn from the literature, the systemic BIM innovation model is identified to have five dimensions for inter-organisational BIM uptake. These dimensions are (1) BIM acceptance at the individual level; (2) organisational drivers of BIM usage; (3) inter-organisational linkages between firms; (4) supply chain management challenges; and (5) the role of the context. The model includes factors in different interrelated analytical levels, namely, the individual, the organisation, and the supply chain. It is the context which shapes all levels of analysis, as noted by (Jacobsson *et al.*, 2017), who contends that context shapes individual interpretative frames of a technology, and implicitly organisational drivers for BIM usage. However, the question remains how actors give meaning and make sense of BIM applications. The interplay between the client, the procurement method, the

dynamics of technology diffusion, and power shapes the way BIM innovations are perceived by firms. Moreover, the challenge remains of investigating what are the contextual determinants for systemic BIM innovation. Finally, the proposed model would serve as a framework for future research with detailed case studies to obtain larger datasets and confirm all variables in the model and their relationships, in both the public and the private sectors in the UK and overseas.

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