ALIGNING BIM ADOPTION WITH IMPLEMENTATION IN LOOSELY COUPLED CONSTRUCTION SYSTEMS

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ABSTRACT

Building Information Modelling (BIM) is considered an innovation for construction, with the potential to digitise various construction processes. Being an innovation, it affects and is affected by organisational aspects. At the same time, innovations are better observed at a project level. This study connects intra- and inter- organisational levels mobilised during BIM implementation. To explore the relation between BIM motivation and capabilities within firms and BIM implementation in projects, three case studies are analysed through the theoretical lens of loosely coupled systems. The results showed that despite the fact that the firms had strong external or internal BIM motivations and visions, at a network level, they rarely coordinated to support BIM implementation. To this end, the multi-actor networks of projects where firms were motivated by '*internal'* drivers (e.g. quality assurance) for adopting BIM implemented BIM in a more collaborative and flexible way. On the contrary, networks of firms that were driven to BIM to comply with '*external'* demand (e.g. macroscopic market pressures or client demand), were largely rigid and competitive during BIM implementation and did not allow for knowledge transfer. Drawing upon the empirical data other factors affecting mature BIM implementation and in need for further inter-organisational alignment were corporate compatibility, inter-firm knowledge mobility, and power dynamics among firms.

KEYWORDS

Loosely coupled systems, innovation, Building Information Modelling (BIM), BIM adoption, BIM implementation.

INTRODUCTION

The use of Building Information Modelling (BIM) is considered an innovation that in the last decade increasingly gains traction in Architecture, Engineering, and Construction (AEC) industry. Innovation is the introduction of new artefacts or processes (Abernathy and Clark, 1985). BIM domain entails a set of Information Technology (IT) tools for generating, managing, and sharing building information among project actors. The AEC industry has been also previously described as a 'loosely coupled system' (Dubois and Gadde, 2002), given that it is fragmented into various firms that collaborate or compete across the market. BIM could be considered an innovation for the AEC, as it brings new ways for innovative project delivery and deeply transforms the intra- and inter-organisational settings. Given that BIM qualifies as misaligned innovation among construction networks, probably those with strong relational stability and permeable boundaries would perform better in BIM implementation (Taylor and Levitt, 2007).

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Intra-firm decision-making on adopting BIM is the resultant of institutional forces, internal drivers, and external pressures (Kassem *et al.*, 2015). Currently, the use of BIM has been mandated or strongly recommended for governmental buildings from policy-makers in various European countries, such as the United Kingdom (UK), Germany, France, the Netherlands, and the Nordic countries. Such initiatives include quasi-contractual BIM documents among multi-disciplinary project actors, such as the pre-contract 'BIM Execution Plan' (CPIc, 2013) from the UK or the 'BIM Norm' issued by the Dutch Government Building Agency (GBA) (Rijksgebouwendienst, 2012), both of which are inspired from the Norwegian 'BIM Manual' (Statsbygg, 2011). As BIM implementation requires synergy among various multi-disciplinary actors, there is additional room for observing its implementation in projects. After all, projects are excellent vessels to implement and study innovation (Shenhar *et al.*, 1995), as any successful innovation relies on a sound project (Shenhar and Dvir, 2007). Thus, there are three levels of observing BIM: market (macro-), inter-organisational (meso-), and intra-organisational (micro-level). This paper attempts to link them, using the concept of loosely coupled systems to explore innovation adoption and diffusion.

Whereas the adoption of BIM is usually discussed at an intra-organisational level (Ahn *et al.*, 2015, Son *et al.*, 2015), the high interdependence among heterogeneous multi-actor networks also affect BIM adoption (e.g. drivers) and implementation (e.g. maturity). This paper sets up to explore the relation between intra-firm motivations (*heterogeneity* attributes) for adopting BIM innovation, and how innovation unfolded and was applied (implementation) in projects, at a network level (as *systemic* innovation), drawing upon empirical data and exploratory research of three multi-actor construction networks. Subsequently, the study attempts to link the intra- and inter-organisational levels of BIM, by confronting BIM motivations with BIM practice. The paper is organised as follows. First, the theoretical basis around innovation, BIM, and network view of BIM innovations is presented. Subsequently, the selected methodology and data collected are presented. The paper ends by interpreting and discussing (confronting) the empirical data against the literature, outlining implications for research, practice and policy and concluding with summary and future research.

THEORETICAL BACKGROUND

DIFFUSION OF INNOVATIONS IN CONSTRUCTION

Rogers' (2003) diffusion of innovations model is a popular model that describes the process by which innovations spread via communication channels across social systems over time. Some innovations spread relatively rapidly while other innovations spread slowly depending on (a) novelty, (b) compatibility with existing values, beliefs, and experiences, (c) ease to comprehend and adapt, (d) tangibility, and (e) testability (Rogers, 2003). Real-life phenomena do not unfold in a linear, but instead a highly complex, inter-related and complex manner. Similarly, innovation diffusion is multi-scalar and complex. Local networks' interactions (micro-level) trigger the emergence of global structures and behaviours (macro-level) (Rogers *et al.*, 2005). Given that even firms delivering similar services or products are highly heterogeneous; repetitive and heterogeneous *micro-scale* behaviours and adoption decision contribute to macro-scale phenomena, and diffusion (Ibid). The construction industry is largely project-based (Morris, 2004) and its projects are unique by displaying high demand and supply variability. Thus, also the projects upon which construction industry is organised upon are highly heterogeneous and complex. For Rogers *et al.* (2005) heterogeneity is central in the diffusion of innovations theory, and probably acknowledging the influence of heterogeneous institutional contexts in macro-scale phenomena is a promising way forward for grasping innovation in construction and particularly complex project networks.

HISTORY AND PRECURSORS BUILDING INFORMATION MODELLING

Projects are nexuses of processing information (Winch, 2002). Presently, BIM is considered the most representative information system in construction. BIM is not only a domain of digital artefacts, but has historical roots in the long process of structuring and standardising building information for construction projects (Laakso and Kiviniemi, 2012). Although the term BIM was introduced in 1992 (Van Nederveen and Tolman, 1992), its underlying principles are not entirely new for construction. BIM has evolved from efforts for structuring and consistently representing information and knowledge about building artefacts, which was a predominant line of thought in the 1970s (Eastman, 1999).

In the United States of America (USA) initiatives in the mid-1980s for '*building product model'* definitions were developed for exchanging building information amongst Computer-Aided Design (CAD) applications (Ibid), replacing error-prone human interventions. Building product modelling advancements followed the long-standing debate on the computerisation and digitisation of construction (Eastman, 1999). Industry Foundation Classes (IFC) is probably the most popular and long-lived data exchange format for construction and is supported from BIM applications. Against widespread belief, BIM is not newly-found, but the evolution of efforts by industry consortia to structure building information (East and Smith, 2016) in building product models. Although BIM is an old concept, it could be still branded as an innovation for construction, as although its content is already known to lower-tiers actors of the supply chain, implementing it in projects from all actors is something entirely new and, thus, challenging. Additionally, BIM-related policy is also considered innovation. Its novelty lies at policies prescribing BIM-related contract addendums and workflows in project delivery.

BIM is a "*multifunctional set of instrumentalities for specific purposes*" (Miettinen and Paavola, 2014) and affects various actors across the construction lifecycle, while policies, processes, and technologies interact to generate a digital building design (Succar *et al.*, 2012). BIM is a domain of loosely coupled Information Technology (IT) systems for generating, controlling, and managing information flows intra- and inter-organisationally. Loose coupling in computer and system design entails components that are not constrained in same definitions, programming languages, environment (web or desktop) operating systems, or platform. Undoubtedly, BIM not only affects the representation of building product information, but also actors of multi-disciplinary project teams (Dossick and Neff, 2010, Bryde *et al.*, 2013). Thus, whereas it is a technological innovation, BIM has been linked not only to coordination of technological artefacts, but also complex socio-technical processes to align heterogeneous actors and information (Liu *et al.*, 2016) across projects, supply chains, and markets.

BIM AS A CONSTRUCTION INNOVATION

As BIM increasingly attracts interest from various industry players, it inevitably becomes object of high quality scientific research, which carries implications for Higher Education. Research on BIM currently takes place in three wide categories: (a) *adoption* of isolated firms (based on individual perceptions), (b) *implementation* in projects (based on case studies of projects, and (c) *diffusion* at a macro-level (focusing on distinct professions and countries). BIM adoption studies provide rich insights into intra-firm barriers and enablers. Son *et al.* (2015) analysed BIM adoption in architects in China using Technology Acceptance Models (TAM), and individual perceptions and mistrust were key barriers. Both relational and technical aspects shape the transformation of contractors in the USA for BIM adoption (Ahn *et al.*, 2015). As adoption relates to micro- and diffusion to macro-scale, implementation relates to an intermediate or meso-level. Similarly, technical and organisational BIM implementation studies offer a firm grasp of BIM advantages and shortcomings. Such studies identified benefits in design management (Elmualim and Gilder, 2014), project management, communication, and coordination improvement (Azhar, 2011), project performance (Bryde *et al.*, 2013), collaboration, and coordination (Dossick and Neff, 2010).

However, most BIM adoption or implementation studies, do not acknowledge innovation at a network level. BIM diffusion studies facilitate better understanding of how BIM innovation unfolds across contexts, and whether the innovation is evolutionary or revolutionary (Burns and Stalker, 1961). Succar and Kassem (2015) described BIM implementation as a '*three-phased approach'* that includes readiness, capability, and maturity that firms should develop to successfully use BIM. In projects with various BIM-using firms, implementation varies, as firms carry various BIM readiness, capability, and maturity levels, due to different disciplines and sizes (Succar *et al.*, 2012, Succar and Kassem, 2015) – that is heterogeneity. Succar and Kassem (2015) categorised BIM diffusion dynamics into *top-down*, *middle*-out, and *bottom-up*, depending on pressure, i.e. downwards, horizontal, or upwards, from government, large firms, or small firms respectively. To this end, supply chains and network-view of projects offer rich contextual examples to study BIM innovation.

NETWORK VIEW OF BIM INNOVATION

This paper looks at construction innovation and in particular of BIM, from a systems' perspective. Systems Thinking emerged soon after World War II and offered a constructivist approach to the positivism of operations management research (Klir, 2001). Klir (2001) defined a system as a set of things, *thing-hood*, and a set of relations among these things, *system-hood*. The term *system* is usually used interchangeably with the term *network*, however the latter, is a newer term than that mostly relates to the representation of a set of things (nodes) and a set of relations (links). The AEC has also been described as a 'loosely coupled system' (Dubois and Gadde, 2002). This study adopts Orton and Weick's (1990) dialectical definition of '*loosely coupled system'*. According to them, such a system is both closed and open to outside forces, as its constituent elements display both distinctiveness and responsiveness (Orton and Weick, 1990). To this end, 'loosely coupled system' is neither a 'managerial failure', nor needs to be transformed into a tight system, but instead entails tools for understanding and evaluating interpretative systems (Orton and Weick, 1990, p. 219). Conversely, a tight system would be static and possess neither distinctive nor responsiveness.

Based on the previous, looking at loosely coupled systems facilitates the understanding of "*fluidity, complexity, and social construction*" of organisational structures (Orton and Weick, 1990, p. 205). In the context of construction, indeed projects are extremely complex and inter-firm relations are fluid, by maintaining both distinctiveness and responsiveness. Chesbrough and Teece (1996) distinguish between autonomous and systemic innovations, as the former can be pursued independently by firms in a decentralised way, whereas the emerging inter-relations in the latter, suggest an additional need for control. As an innovation, BIM cannot be pursued in a decentralised manner (Eastman *et al.*, 2008) and it is considered a systemic innovation. For Brusoni and Prencipe (2001, p. 1022), "*systemic innovations can be realised only in combination with complementary innovations*". Indeed, changes in procurement and particularly integrated schemes such as Design-Build (DB) have been suggested as necessary for BIM (Eastman *et al.*, 2008). De Valence (2010) proposes that non-traditional procurement schemes, such as Build- Maintain with long-term engagements encourage innovation.

Brusoni and Prencipe (2001, p. 1028) suggest that varying cooperative agreements such as market-based, joint ventures, and strategic alliances need coordination and integration to safeguard the responsiveness needed in the loosely coupled system. In systemic innovations, there is an additional need for coordination, which is usually covered by highly integrated firms who can leverage their size. Such firms are called systems integrators and are both specialised in in-house activities and, keen to manage technological capabilities of other firms in the network (Brusoni and Prencipe, 2001, p. 1031). In similar spirit, Dhanaraj and Parkhe (2006, p. 661) discuss recruitment and brokering potential of *'hub firms'* in order to coordinate – or orchestrate – innovation in networks of firms. They recognised the focal role of the orchestration/hub firm – whose role resembles that of a system integrator – and the importance of three interdependent parameters among the multi-actor network: (a) knowledge mobility via formal and informal communication channels (Dhanaraj and Parkhe, 2006, p. 661), (b) innovation appropriability by capturing benefits from innovation via trust and mutuality (Ibid, p. 663), and (c) network stability through subtle leadership, recruitment and brokering activities (Ibid, p. 664). However, given the high actors' heterogeneity in construction networks, probably a less focal view would be a promising way forward to understand BIM innovation in multi-actor construction networks.

Actors' heterogeneity is characterised by six attributes: (a) goals, (b) knowledge bases, (c) capabilities and competences, (d) perceptions, (e) power and position, and (f) cultures (Corsaro *et al.*, 2012). There is additional room for studying BIM as a systemic innovation, through the lens of loosely couple systems from a non-focal (decentralised or distributed) perspective. To this end, this study is agnostic concerning which actor would act as systems integrator. The paper looks at BIM adoption and implementation from an inter-firm (network) perspective and poses the question: *How do intra-firm decisions about BIM adoption influence the* *implementation of BIM innovation from multi-actor networks in projects?* Figure 1 illustrates the theoretical framework linking the key themes of the paper.

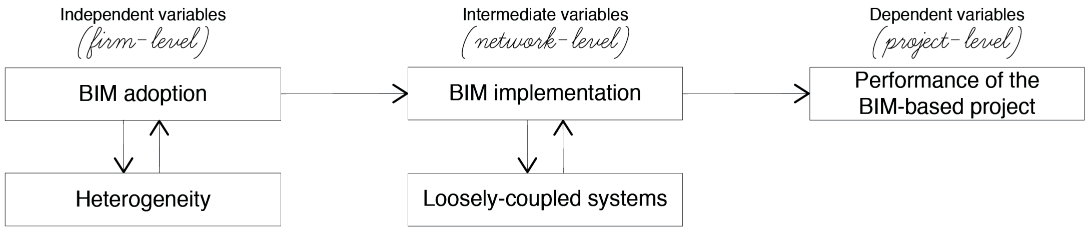

Figure 1: Theoretical framework of the study, linking the various levels (firm-, network-, and project-level) and the theoretical lenses (actors' heterogeneity and loosely coupled systems).

METHODOLOGY

RESEARCH METHODOLOGY AND RATIONALE

The study follows an interpretative approach and attempts to explore the relation between BIM adoption and implementation by using inter-organisational perspectives of various actors regarding BIM. Drawing upon Orton and Weick's (1990, p. 219) dialectical definition of 'loosely coupled system', case studies would be a suitable methodology to "*preserve dialectical interpretation*" and offer insights into the processes. The study took place in the Netherlands, where BIM has gained a lot of traction the last decade. The idiosyncrasy of the Dutch market could potentially allow for generalisation. As Dutch firms are keen to collaborate (Winch, 2002, p. 25) and seek consensus, any lessons-learned from this small market could reflect trends to other construction markets in North-Western Europe. After all, the Dutch BIM level of maturity is well-advanced, without been subjected to mandatory policies from the Dutch GBA (Kassem *et al.*, 2015), but from 'bottom-up' initiatives (Berlo and Papadonikolaki, 2016).

The research method was case study, to allow for an analysis of phenomena in "*real-life context*" (Yin, 1984). Three cases (projects) were selected from a larger pool of cases for being representative of the Dutch construction market. Namely, all cases included both multi-functional and housing typology, which is the dominant building project type in the Netherlands. Case A was a very prestigious project, because it featured a complex design of 3 (irregular shaped) volumes organised around a public square with access to a canal and featuring an underground basement. Case B was also a prestigious project, and quite unique as it concerned 12-floor housing towers over a pre-existing shopping arcade constructed in the late 1980s. This project (phase B) followed the construction of another housing tower a couple years ago (phase A). Case C was a rather mainstream project for the Dutch construction market. Namely, it featured 44 apartments organised in two rectangular volumes in a densely populated area in the Netherlands.

The sample was considered diverse, as the participating firms were of varying sizes, e.g. Small-Medium Enterprises (SME) and large firms. The firms that participated in the projects (cases) were simultaneously engaged in long-standing supply chain partnerships (alliances) and this ensured access to multi-disciplinary interviewees and facilitated a network-view of the study. In all three cases, the point of entry of the researcher was the contractors' firms. The researcher was not affiliated with any of the participating firms. The cases (projects) were studied over a period of 18 months, during Definitive Design phase, Pre-Construction phase, and the first stages of Construction. Table 1 includes some descriptive characteristics about the projects and Table 2 data sources about the cases and details about interviewees.

Table 1: Key characteristics of the projects and the case interviewees.

	Case A	Case B	Case C
Typology	Multi-functional	Housing (multiple phases)	Housing
Size	Retail, offices, and 255 apartments	83 apartments	44 apartments
Morphology	3 volumes, public square, and parking	1 tower above shopping arcade	2 volumes
Duration	6 years (delays in initiation)	2 years (phase B)	2 years
Completion	April 2016	February 2017	November 2015

Table 2: Interviewees (primary data sources) of the case studies.

Case A		Case B		Case C	
Firm (size)	**Function**	**Firm (size)**	**Function**	**Firm (size)**	**Function**
Facility Mgt[1]*	Project Mgr[2]	Contractor*	Project Leader	Client**	Tender Mgr
Contractor*	Site Eng[3]		Site Eng	Contractor**	BIM Director
	BIM Manager	Architect**	Lead Architect		Tender Mgr
	BIM Coordinator		BIM Modeller		BIM Mgr
Architect**	Director	Structural Eng**	Lead Eng		Project Mgr
	BIM Modeller	Mechanical Eng**	Tender Mgr	Architect**	Lead Architect
Structural Eng**	Director		Site Eng		BIM Architect
	BIM Modeller		BIM Modeller	Structural Eng*	Lead Eng
Mechanical Eng*	Project Leader	Sub-contractor*	Project Leader	Mechanical Eng*	Lead Eng
Supplier*	Tender Mgr	Supplier**	Director	-	-
	BIM Eng		BIM Modeller	-	-

[1] Management, [2] Manager, [3] Engineer
* Large firm, ** Small- Medium Enterprise (SME)

DATA COLLECTION AND ANALYSIS

The primary data of the study were interviews with various actors per project from both supply and demand sides of the supply chain, as well from multiple tiers, e.g. first-tier: client, contractor, architect, engineers, and second-tier: sub-contractors and suppliers. Interviews were held at three study phases: (a) beginning of the study, b2) project progression, and (c) study validation, after the preliminary case analysis took place. Accordingly, the interview questions revolved around (1) the motivation of the firms for adopting BIM, (2) their perceived benefits and challenges during its implementation process, and (3) the project's performance. As usually cases study methods "*incorporate a number of data gathering measures*" (Berg, 2001, p. 225), the research also included secondary data for triangulation and credibility (Miles and Huberman, 1994, p. 266). Meetings observations, 'living labs', document (physical and digital) inspection, site and firm visits, and press coverage from online resources attempted to complement the analysis of BIM implementation with additional sources and triangulate the findings.

The primary data (interviews) were analysed using systematic thematic analysis, following the themes identified in the 'Theoretical background' section, around motivation for BIM adoption and an inter-organisational perspective. The interviews were recorded (audio) and then transcribed and translated (from Dutch). Both descriptive and '*in vivo'* coding was used to analyse the data. The secondary data were used to represent and analyse the BIM implementation process at project- and inter-organisational levels and triangulate (support, challenge or enrich) the insights into BIM implementation. The two sets of data sources were subsequently confronted to identify gaps between the motivation for BIM adoption and the actual BIM implementation, by building on metrics of BIM maturity. These metrics include evaluation of the BIM-based collaboration process, which is seen as both prerequisite and indicator of BIM Level Two maturity in the United Kingdom (UK).

FINDINGS

BIM ADOPTION MOTIVATIONS

Given that the cases were approached as systems (or networks) of actors organised around projects, a systematic approach to analyse the three cases was followed. Accordingly, the actors from each case were interviewed separately about their intra-firm motivations for adopting BIM (see again Table 2). To ensure internal data validity, additional perspectives from various hierarchical levels of the firms were received. In some instances, this approach was an opportunity to identify incongruent perceptions and motivations about BIM adoption and implementation within the boundaries of the same firm. Overall, the data showed that BIM is indeed regarded as a novelty for the Built Environment from key actors but for varying reasons.

In Case A, almost all actors adopted BIM driven from market demand (external driver). In the contractor's firm, it was recently decided "*that all projects must go in principle in BIM because that is the future. We must*" (Case A- Contractor-BIM Coordinator). However, at this particular project, BIM was simply a contract requirement from the client (demand). This decision had cascading effects to the other project actors. In the structural engineering firm, they acknowledged that "*BIM improves the process, but the advantage of BIM is for the contractor*" (Case A-Structural-Director) and they admitted that they "*switched to BIM because of the demand*" (Case A- Structural-BIM modeller). According to the mechanical engineers the BIM benefits were: "*in the automation process around it that makes it very clear to all parties (...) and yes, its (BIM) adoption came from the market*" (Case A-Mechanical-Project Lead). The suppliers stated that they "*were looking on how to do it (design) with 3D. The client started asking us for BIM. This was decisive for us working with BIM. This is the bigger influence of why we did it. But we also see benefits for our process*" (Case A-Supplier-BIM Engineer). However, the architects' decision to adopting BIM was driven by different motivation. Case's A BIM Modeller in the architect's firm shared the following: "*we were already relatively early engaged with BIM in our office, with discovering the capabilities of the software. One of the bosses, even from his studies, began with software development,* *so he has always some kind of had for love or interest in that and (...) we go along with it to see if it offers added value or not*".

Most of Case B actors were more strategic concerning BIM adoption decision-making. At least three of the main actors adopted BIM to improve their businesses and not to comply with market (or client) demand. In this project, BIM was not required by the client. For the contractor's firm: "*the most important aspect is the consistency of BIM, which we share with all our partners towards the execution*" (Case B-Contractor-Site Engineer). Similarly, the architects acknowledged that "*for us it is not become more expensive to model BIM than using 2D drawing, because our quality level has gone up*" (Case B-Architect-Lead Architect). Probably the firm of the structural engineers presented the most organic approach to BIM adoption. The shared that: "*with us in 2007 there was the main motivation to step to 3D design and BIM from the 2D design because we ourselves saw benefits. It was obviously a new development. And we ourselves have discovered that there's a future in it, but we also saw from our own work benefits to better understand constructions*" (Case B-Structural-Lead Engineer). In the mechanical engineers' and the sub-contractor's firms, it was therefore stated that BIM "*was requested from the market"* (Case B-Mechanical-Director). The Project Leader of the sub-contractor shared that: "*BIM is what the contractor demanded. They said, we are going to do this and our suppliers must join*" (Case B-Sub-contractor-Project Leader). For the suppliers, the traction that BIM gained the recent years was only a catalyst for adopting it. They explained that: "*four years ago we switched to 3D models. To go along with modernity. The customer can better see what he gets. The errors can be discovered quickly*" (Case B-Supplier-BIM Modeller) and "*BIM is better for clients and goes with the times. Customer dema*nd" (Case B-Supplier-Director).

Finally, Case C actors also held incongruent positions as to what led their decision to adopt BIM. The client's firm admitted that although they do not use BIM, they respond to the general market demand. The client shared that: "*we want our partners to, for the quality of products we buy from the firms*" (Case C-Client-Tender Manager). In the contractor's firm, they recognised that "*do BIM even if it is not a client requirement*" (BIM Director). According to the Tender Manager of Case's C contractor: "*BIM is the business of the future; it is efficient and eliminates extra costs*". The contractor firm has founded a 'BIM Center' to disseminate BIM knowledge across various firm subsidiaries. In a similar spirit, the architects' firm stated that "*BIM is very important for quality management (...) not all firms have realised what it can do to their firms*" (Case C- Architect-BIM Architect). However, again the structural engineering and mechanical engineering firms were simply responding to the market demand for BIM implementation in projects.

According to the data analysis, there were three main motivations for BIM adoption across the firms: (1) intra-firm strategy, (2) project-based requirements, and (3) market or client demand. First, intra- firm strategy pertained to the internal decisions across the various firms to adopt BIM as a way to modernise their information management and computer-aided design infrastructure (all cases). Second, the project-based requirements were short-term requirements that were project-specific and usually related to the clients' demand to adopt BIM (Case A). Finally, general market demand stemming from institutional and industry prescriptions was a long-term motivation that would contribute to the competitive advantage of the firms and factored to the decision of firms to adopt BIM (all cases). From these three motivations, the first could be codified as *'internal'*, whereas the other two as *'external'*. Table 3 assigns the *'internal'* and *'external'* motivations codes to the various actors participating in the projects (cases).

Table 3: Motivations for BIM adoption across the case studies. Descriptive and in vivo (italicized) codes and codification (interpretation) into internal (I) or external(E).

Case A		**Case B**		**Case C**	
Firm	**BIM motivation**	**Firm**	**BIM motivation**	**Firm**	**BIM motivation**
Facility Mgt[1]	Demand (E)	Contractor	*Consistency* (I)	Client	*Quality* (E)
Contractor	*Obligation* (E)	Architect	*Quality* (I)	Contractor	*Business* (I)
Architect	*Interest* (I)	Structural Eng	*Future* (I)	Architect	*Quality* (I)
Structural Eng[2]	*Demand* (E)	Mechanical Eng	*Market* (E)	Structural Eng	Demand (E)
Mechanical Eng	*Market* (E)	Sub-contractor	*Demand* (E)	Mechanical Eng	Demand (E)
Supplier	Client (E)	Supplier	Quality (I) and *Demand* (E)	-	-

[1] Management, [2] Engineer

BIM IMPLEMENTATION IN PROJECTS

Drawing upon the above, BIM adoption depended on various internal or external intra-organisational motives (firm-level). However, BIM implementation was a collective inter-organisational exercise (network-level) in applying the technologies that fall under the umbrella of BIM. Given that BIM has been approached as a domain of technologies, processes, and other functionalities in this paper, Table 4 summarises key aspects of BIM implementation in the three projects (cases), as derived from document analysis and meeting observations. Similar to the various motivations for adopting BIM across the participating firms, there were various ways that BIM implementation took place across the studied cases.

Table 4: Deployed BIM-based functionalities (artefacts, processes, and structures) among the three cases.

BIM implementation feature	**Case A**	**Case B**	**Case C**
BIM as a requirement	Yes	No	No
BIM-savvy partners' selection	Yes	No	Yes
BIM-related meetings	Pre-scheduled	On-demand	On-demand
Co-location practices	Predefined	On-demand	Ad-hoc
Use of Common Data Environment	Yes	No (extranet)	No (extranet)
Use of BIM protocol	Project-defined	Project-defined	Firm-based
Model checking tools	Yes	Yes	No
Information exchange file type	Native, IFC	CAD/PDF, Native, IFC	CAD/PDF, Native
Deliverable file type(s)	CAD/PDF, IFC (as-built)	CAD/PDF, IFC	CAD/PDF

Following the study's theoretical framework, BIM implementation in the three cases was explored by content analysis of the interviews around three areas: (a) communication channels, (b) trust, and (c) network stability activities (Dhanaraj and Parkhe, 2006, p. 661). In Case A, BIM capabilities were a decisive factor for the quality of *communications.* Case's A Design coordinator from the contractor stated: "*simply each party there is differently able to BIM. And that is sometimes difficult.*

(...) The communication was always difficult". However, for some actors, the BIM-based collaboration was not participatory, but formal and top-down instead. The BIM Engineer of Case's A supplier shared that: "we *have not gone in clash sessions. The contractor has done it themselves and then send us the findings to us. Sometimes we sit with some specific suppliers in the table and discuss, but more often we receive a mail or phone call. (...) This process is exactly the same with other contractors*". Naturally, this communication had repercussions for *trust*. For the Design coordinator of the contractor "*the collaboration and how one must work with BIM and the expectations of each other should be well-pronounced, in order to trust each other*". According to Case's A Mechanical Engineer's Project Leader, due to BIM they needed "*also a trust bond to build with the contractor (...) a bit of mutual trust towards each other*". Regarding *network stability* activities, there were various approaches and not a clear vision for the BIM network. One the one hand, the Architect admitted that: "we *do not really have a role distribution within the office. Everyone does it all (...) we do not really work with terms like BIM manager*", the structural engineers "*only work in BIM when the architect or the installer in BIM work too*" (Case A-Structural-BIM Modeller) and the mechanical engineers "*always choose a contract not initially parties*" (Case A-Mechanical-Project Leader). On the other hand, the suppliers were more strategic in BIM adoption. They shared that "*with other contractors we also use BIM. But not all their partners can do it with BIM. (...) We need permanent contact persons to have in the partners (otherwise) you cannot good BIM do without the supply chain*" (Case A-Supplier-BIM Engineer). From the above, in Case A, the network struggled to align communication with trust and were not strategic in network formation for BIM implementation.

For Case B, the contractor ensured with formal and informal approaches that the BIM *communications* run smoothly. Case's B Site Engineer from the contractor argued that: "*we make appointments in advance. We have a BIM kickoff-meeting, here we go with all our partners to agree how we are going to provide, what sessions we're going to get to keep our noses in the same direction, in order to BIM*". The architects also contributed in times in good communications. They explained that: "*we also sometimes took the role as runners as architects. That is not always good, but we did that because we were busy to meet the application deadlines*" (Case B-Architect-Lead Architect). This was seconded by the Tender Manager of the Mechanical engineering firm who shared: "*all partners sit around the table to highly structure on a daily basis what needs to be done to make everything run smoothly so that the costs of failure are the least*". The sub-contractor acknowledged that because of the dense communications they "*get more knowledge of the problems of other parties*" (Case B-Sub-contractor-Project Leader). Undoubtedly, this would in turn benefit *trust*. The architect admitted that there is a lack of trust towards their profession and shared that: "*our customers and clients have not yet confidence in the construction industry, because, of the mistrust. (...) So if we are then open about what we want to make, then we get another discussion*" (Case B-Architect-Lead Architect). For the contractor, all these formal and informal communications were beneficial for knowledge externalities. The contractor's Site Engineer explained the benefits of long-term relations and BIM use from their partners as follows: "*we look in the 'kitchen' of other contractors. (...) This is why we have also an open BIM structure, so that we do not impose how our partners should work*". And also there existed trusting and long-term relations, such as with the structural engineers, who consider themselves the contractor's "*house builder*" (Case B-Structural-Lead Engineer). All the above contributed to a more *stable network*, although there were both opponents and proponents of out-sourcing BIM services. For example, the Mechanical Engineering firm shared that: "*I think we are fairly neat because we do not out-source*" (Case B-Mechanical-Tender Manager), whereas the sub-contractor firm has adopted the opposite strategy. The Project Leader of Case's B sub-contractor shared: "*we have permanent BIM drafting company that we actually do all the work together. We sit together in one office so we have two separate companies, but we do it all together*". Therefore, in Case B, the good communications and trust in the network supported the heterogeneous decisions about BIM adoption and implementation.

In Case C, the *communications* were organised in a top-down manner, essentially via the contractor. They explained that they have been using their "*BIM Center to train the sub-contractors and suppliers (...) and perform analyses and coordinate the BIM models from all our suppliers*" (Case C-contractor-BIM director). The suppliers and sub-contractors would only use an extranet for data drops to exchange information. However, because in this project, not all available BIM functionalities for collaboration were used, the various actors did not have a lot of interaction. This naturally, had implications for *trust* and *stability* in the network. According to the architects: "*our BIM collaboration methodology that we have to develop it all the time (...) because all the partners are also changing their methodology*" (Case C-Architect-BIM Architect). These ad-hoc communication patterns, caused mistrust in the project team. The contractor admitted that they were trying to control mistrust by direct confrontation: "*we always asked them how they stand and if they were ready to show us all the cards*" (Case C-Contractor-Tender Manager). With regard to *network stability* activities, the contractor was trying to select project partners based on BIM-savviness. Essentially, they shared that: "*we get our suppliers to enter our BIM contract (protocol)*" (Case C-Contractor-BIM Director). This was in accordance with the intentions of the client who stated: "*we require that our partners use BIM to improve the design and minimise the design faults (...) because we have a culture of young people and innovation in order to offer excellent services*" (Case C-Client-Tender Manager). However, these visions were not supported by any formal or informal structures, neither were they democratised across the rest of the supply chain.

PERFORMANCE OF BIM-BASED PROJECTS

The three studied projects were ongoing during the data collection phase and have since been completed. Drawing upon the interviews during the projects' progression as well after the validation sessions of the preliminary findings with the case participants, insights into the projects' performance were obtained. The validation sessions aimed at grasping the final thoughts of key projects participants about the outcomes of the projects. As opposed to the initial interviews, the validation sessions were collective interviews, featuring key project participants, in the form of 'living labs'. They were an opportunity for reflection on their engagement in the project and particularly from a BIM perspective. These sessions took place only for Case A and Case B, and not in Case C, because the interviewees were unavailable as they have since moved to new firms.

The project of *Case A* was completed in good order and in time. However, not all initial aspirations for the project were fulfilled, probably because there were incongruent BIM motivations (external or internal) within the construction network. For example, they did not manage to optimise and control the logistics in site using BIM-based methods, as they were planning to at the beginning. Regarding their aspiration to deliver 'as-built' BIM models to the facility management organisation, this took place as planned, but they still face challenges into streamlining this information for facility maintenance. Regarding their BIM-based collaboration, they contractor firm admitted that '*the communication was not very good'*. Overall, their varying firm sizes and BIM capabilities were a limitation for executing this project, e.g. the architect's firm was understaffed to manage the complexity of this prestigious and unique project for the Dutch construction market.

Case B project was also completed in time. As the building design was part of a larger project, the project team was awarded the project to continue in the next phase (Phase C). The project team members perceived this as a recognition of their successful performance. The fact that the developer contracted the same team (supply chain partnership) was considered an indication that the project progressed well and that their compatible BIM motivations were effective. The third tower of the project is currently under development and includes another (similar) housing tower over the same shopping arcade. Additionally, there are also new discussions of a project fourth phase to be expanded to a neighboring site with a tower consisting of more storeys and more apartments, 107 (phase D). Regarding, their BIM-based collaboration, the project actors admitted that they have improved their BIM capabilities immensely through these repetitive projects. However, they stressed that although the design was similar, they design preparation was the opposite of 'copy-paste', as with the advent of BIM-related technologies, they were continuously amending their BIM technology implementation and collaboration.

Case C project was also delivered in-time with no delays, similarly to the other two cases. However, it was not possible to evaluate the performance of this case's practices, as the contractor's organisation became insolvent in the meantime. Afterwards, the contractor firm re-evaluated their strategic objectives and priorities, which among others, featured the application of lean methodologies, BIM, and supply chain management, and underwent major restructuring in personnel. Essentially all the interviewees from the contractors' firm have since moved to different positions. Therefore, although the project was completed satisfactorily, there was no opportunity to reflect on the future of Case C's BIM network and the outcomes of this BIM-based collaboration remain largely inconclusive. This is naturally a limitation, but also probably an indication of the projects' performance.

DISCUSSION

BIM INNOVATION FROM MICRO- TO MACRO-LEVEL

As mentioned above, the AEC industry behaves as a 'loosely coupled system' (Dubois and Gadde, 2002), given that it is fragmented into various collaborating or competing firms. For systems thinking, a loosely coupled system is a system in which its actors have or use little or no shared knowledge, understanding, and visions with the other multi-disciplinary actors – that is distinctiveness. In a sense, also the varying functionalities of BIM make it a loosely couple system. Indeed, throughout the three studied cases, the actors were complying to varying external or internal drivers when deciding to adopt BIM innovation. These drivers ranged from matching market demand (macro-level), what Bossink (2004) refers to as '*environmental pressure'* (Case A-external) to business growth aspirations (Case C-external) to increasing quality (Case B-internal) (micro-level) (see Table 3). However, loosely coupled systems are also potentially useful for diffusion, as they are responsive (Orton and Weick, 1990). Among the three cases, Case B could be considered more responsive than Case A and Case C, as they did not have rigid BIM-based partner selection criteria, instead they were flexible regarding meetings and co-location practices (see Table 4). Instead, whereas in Case A, the BIM implementation practices followed were consistent with firms' 'external' BIM adoption drivers, they were far too rigid and did not allow for systems' responsiveness, e.g. by partner development practices. In Case C, the again consistent firms' 'external' BIM adoption motivations were not supported by any collaboration structure for BIM implementation (see Table 4). To increase the performance of the AEC, various construction researchers *"prescribe either more competition or more cooperation to increase the performance of the industry as a whole"* (Dubois and Gadde, 2002). Indeed, Case A and Case B were more collaborative, whereas Case C displayed more competitive attitude to BIM implementation.

Undoubtedly, the implementation of BIM immensely impacts collaborative design and engineering. Kvan (2000) highlighted that collaborative design also behaves as a 'loosely coupled system,' which is quite time-consuming task and requires relation management among the involved actors. De Valence (2010, p. 54) puts forward the idea that "*the best way to increase innovation lies in the methods and systems used to procure building and construction projects*". Therefore, given that the construction industry is rather fragmented and multi-disciplinary – that is distinctiveness – enabling structures, such as relation management and special procurement routes to ensure the system's responsiveness are needed in loosely coupled systems. With regard to the adoption of innovations such as BIM, aligning innovation adoption decision-making with BIM implementation not only enables it, but instigates closer collaboration among the various multi-disciplinary actors. While BIM adoption is an internal firm-level decision, the type of BIM adoption motivation, whether is it external or internal, predisposes the way that the supply chain implements BIM and outlines the coordination. Therefore, encouraging key AEC actors (micro-level) to adopt innovations such as BIM in a long-term perspective that induces relational stability could actively support the coordination of BIM work (meso-level) and BIM diffusion (macro-level).

BIM PROJECTS AS LOOSELY COUPLED SYSTEMS

Cross-case comparison of BIM innovation adoption and implementation

Naturally, as the sample of the studied cases was limited, no definitive associations could be made between BIM adoption motives and the level (maturity) of BIM implementation. However, consistent patterns emerged on the relation between team composition and BIM adoption motives of the supply chain and the level of BIM implementation. Namely, wherever the contractor had adopted BIM as a part of their 'internal' vision, BIM implementation was more sophisticated by including various functionalities, and flexible by enabling collaborative work (Case B). On the contrary, in cases were the contractor was simply complying with the growing market demand for BIM adoption (Case A and Case B), without actively supporting it, the level of BIM implementation was more ad-hoc (Case C). At the same time, firms where the BIM visions were not well-diffused across all hierarchical levels (see Case A and Case C contractor firms), would display inconsistent behaviours during BIM implementation (Case C). Thus, it can be stated that the composition of the BIM-pushing actors in the chain outlines or even predicts the level (maturity) of sophistication that BIM would be applied with. Among these three cases, the contractor might qualify as the BIM innovation change agent.

The implementation of BIM unfolded in varying ways. On one hand, Case A and Case B displayed sophisticated approaches to BIM implementation, by utilising various BIM functionalities and relying on interoperable BIM tools and the exchange of open standards as prescribed from UK BIM Level 2 (GCCG, 2011) (Table 4). At the same time, the firms operating in these two cases had generally compatible BIM adoption motivations: Case A adopted BIM due to largely 'external' drivers, whereas Case B adopted BIM driven from 'internal' motivations. On the other hand, Case C displayed less sophisticated or ad-hoc BIM implementation approaches, by combining digital and paper-based deliverables in hybrid practices (Harty and Whyte, 2010) (see Table 4). Similarly, the firms of Case C were responding to both 'external' and 'internal' BIM adoption motivations and probably this complicated the BIM implementation process.

Structure and organisation of construction networks

Loosely couple systems is a useful lens to understand both specialisation – through in-house capabilities – and integration – through out-sourcing activities – of technological knowledge (Brusoni and Prencipe, 2001). Dhanaraj and Parkhe (2006) recognised the importance of three interdependent parameters for innovation in networks: (a) knowledge mobility via formal and informal communication channels, (b) innovation appropriability, and (c) network stability through subtle leadership, recruitment and brokering activities. First, with regard to *communication*, the firms that deployed various formal and informal communication channels performed better in managing BIM innovation (Case A and Case B). These outlets ranged from meetings, use of digital artefacts, and communication over online means (see Table 4). However, among the two cases, Case B additionally supported communication with informal and relational approaches that enriched and supported the implementation of BIM innovation (see the quotations of Case A-Contractor-Design coordinator and Case B-Mechanical-Tender Manager). After all, proactive and informal inter-firm communications across multiple tiers, beyond contractual prescriptions could support supply chain integration in the long-term (Papadonikolaki and Wamelink, 2017). Besides, Brusoni and Prencipe (2001, p. 1033) claimed that as loosely coupled systems are pervasive *"they will become even more important in future, as the continuing growth and specialisation of knowledge production will make firms' external knowledge relations even more important"*, essentially knowledge externalities. Indeed, '*knowledge externalities'* could facilitate the adoption and implementation of innovations (de Valence, 2010).

As *appropriability* entails the capturing the benefits from innovation via trust and mutuality, it first relates to the notions of investment and ownership of innovations.

For example, across the cases, firms used knowledge externalities to improve and develop their own BIM implementation process (see the quotation of Case B-Contractor-Site Engineer). However, although across the three cases, the contractor of Case C had made a rather large investment in a 'BIM Center' but did not further disseminate BIM knowledge across their partners and was not appropriated by them. On the contrary, the contractors in Case A and Case B were keen to share BIM knowledge with other firms, although they had not performed a large investment in BIM. Allowing the project partners to appropriate the benefits of knowledge might be an incentive to engage a larger part of the construction supply chain with innovation (de Valence, 2010). Similarly, Baddeley and Chang (2015) after identifying factors affecting the uptake of BIM, concluded that emphasising on collaboration benefits and group-work is probably more important than any traditional financial incentives.

According to Dhanaraj and Parkhe (2006), all knowledge mobility (via formal and informal communications), appropriability of innovation, and *network stability* are interdependent. Indeed, from the empirical data, BIM was a partner selection criterion in Case A and Case C (see Table 4), and BIM-savviness affected the composition of the project team via recruitment mechanisms. However, in Case B there were both firms that our-sourced and delivered in-house BIM capabilities, but this did not necessarily hinder knowledge mobility and the network remained stable. This is in support of Brusoni and Prencipe (2001, p. 1027) that *"maintaining capabilities wider than the range of activities actually performed in-house is, under some circumstances, a necessary condition to effectively manage external relationships in the presence of technological change".* To this end, the compatibility of BIM adoption motivations and the knowledge mobility in Case B contributed more to innovation success and lead to a stable (loosely coupled) system. Dhanaraj and Parkhe (2006, p. 666) had previously suggested the theoretical and practical merits of testing the causalities between innovation output and network stability, and according to Case B; the former led to the latter. On the contrary, in Case A and Case C, any recruitment and network stabilising activities did not manage to contribute to positive innovation outcomes.

Actors' heterogeneity

The various actors of the three cases studied unsurprisingly held rather diverse opinions and behaviors around BIM adoption and implementation. Even among disciplines, their motivations and behaviours differed (heterogeneity). Indeed, even firms delivering similar services or products are highly heterogeneous. Actors' heterogeneity is characterised by six attributes: goals, knowledge bases, capabilities and competences, perceptions, power and position, and cultures (Corsaro *et al.*, 2012). Drawing upon the empirical data, the case projects' outcomes were influenced by various internal or external drivers for BIM adoption, as well as diverse behaviours during BIM implementation. Given the limited number of cases, no repetitive behaviours across disciplines were observed, but instead, between pairs of actors. First, the relation between client and contractor was decisive for the adoption of BIM innovation (Case A and Case C). This partly supports Porwal and Hewage (2013, p. 204) who having studied publicly funded construction projects, claimed that "*maturity and adoption of BIM depend mainly on the client or the owner*". At the same time, also the relation between the architect and the structural engineer and architect was critical, as these two disciplines are very important for the coordination and organisation of BIM work during the design phases (BIM implementation). After all, primarily architects and subsequently engineers lead the generation of BIM-based information (Papadonikolaki *et al.*, 2017). According to the empirical data, in cases where the architect and the structural engineer followed compatible BIM adoption drivers, communications and project outcomes were better (Case B).

Although this paper did not hold a focal view of construction and innovation and was largely agnostic in terms of the disciplines' dynamics, some observations about innovation leaders and change agents could be drawn upon the empirical data. After all, "*a central characteristic of loosely coupled networks is an in-house capability for systems integration*" (Brusoni and Prencipe, 2001, p. 1033). Accordingly, the actors of the two afore-described pairs could qualify as 'orchestrators' of innovation, depending on the procurement routes and essentially their involvement. For example, a DB contract may provide the opportunity that the contractor plays a 'systems integrator' role, following clients' prescriptions (Case C). In more traditionally procured projects, the relation between architect and structural engineer might be proven appropriate to manage the implementation of BIM innovation. However, as Dhanaraj and Parkhe (2006, p. 666), categorising actors into '*orchestrators'* and '*peripheral'* "*may be an oversimplification, particularly in settings of high-density networks or small networks"*. In turn, the previous suggests that there is additional room for exploring and understanding power dynamics in BIM-based projects.

RESEARCH IMPLICATIONS

Implications for practice

This study carries implications for practitioners, as it has displayed an interdependence between the types of BIM adoption motivation – external or internal – and the maturity/level that BIM innovation is implemented in projects. Accordingly, although actors in loosely coupled construction systems may appropriate innovation, the stability and performance of the network also depends on knowledge mobility within the network via formal and informal communication channels. Similarly, the corporate compatibility of BIM adoption drivers affects network stability by recruitment of BIM-savvy partners and through decision-making on delivering in-house or out-sourcing BIM services. These relations might support policy-makers in their decision-making about pushing BIM innovation across the industry. To this end, strict mandates for BIM adoption might hinder the effectiveness of BIM implementation, for not supporting the exploration of various BIM-related adoption strategies by actors. Conversely, an incremental adoption of BIM functionalities and structures, such as file exchange formats, quasi-contractual means, platforms, and online data environments could increase BIM-based project outcomes. At an inter-organisational level, some propositions for networks that would engage in BIM implementation could be to: (a) align intra-organisational BIM adoption motivations with inter-organisational BIM implementation process to make use of most BIM-related functionalities, and (b) revisit and re-evaluate the relations between key actors of the supply chain: e.g. client-contractor and architect-structural engineer.

Theoretical contribution

This research contributes to existing literature and knowledge base about BIM as an innovation, by exploring its adoption and implementation through the lens of loosely coupled systems. First, it explored the BIM adoption motivations as an innovation at a firm level and discovered that these may depend on internal or external drivers. However, as innovations are usually observed in projects (Shenhar et al., 1995), they do not only depend on one firm. Accordingly, it unveiled a relation between intra-firm BIM adoption drivers and BIM implementation levels and put forward the proposition that in projects teams with compatible BIM adoption drivers, the implementation of the innovation is both sophisticated – by including various functionalities – and flexible – enabling collaborative work. This study also revisited the concept of 'loosely coupled systems' and offered new data to the framework of Dhanaraj and Parkhe (2006) on communication structures, appropriability, and network stability activities of BIM-using construction networks. Finally, the study added to the knowledge base of BIM research – currently a hot topic – by offering new empirical data on BIM adoption and implementation from a network perspective.

Research limitations

This study took place in the Netherlands, and although there are rich contextual insights into collaborating networks in BIM innovation, the research does not allow for full generalisation. The Dutch construction market was a relevant locale to test newly introduced innovations, such as the adoption and implementation of BIM. Whereas the market is small, it has a high rate of BIM adoption, supply chain partnering agreements, and possibilities for second-hand, or '*external'* BIM knowledge, also known as '*knowledge externalities'*. The Dutch construction industry has been proven quite interdependent across policy and practice when it comes to adopting innovation (Bossink, 2004). The overall applied consensus-seeking and collaborative culture of Dutch construction firms (Dorée, 2004), could be considered apart from a research limitation, a promising way forward for informing BIM-related policy-makers about how BIM adoption and implementation unfolds in practice. Accordingly, in the future, a cross-cultural case sampling might shed more light on the complex socio-technical phenomenon of BIM adoption and implementation, which increasingly gains traction in other countries. At the same time, given that the functionalities of BIM are continuously in a transition, a longitudinal study might also increase the understanding of how BIM innovation unfolds within AEC networks.

CONCLUSIONS

This paper has sought to further refine our understanding of the relation between BIM innovation adoption and its implementation through the theoretical lens of loosely coupled systems. After analysing three cases of supply chains engaged in Dutch construction projects, the empirical data displayed an interdependence between BIM adoption drivers (external or internal from macro- or micro-levels) and sophistication or maturity of BIM implementation, as to the use of varying functionalities. In a sense, Case B which featured firms with internal BIM adoption drivers delivered better project outcomes than Case C. Moreover, causalities between the compatibility of BIM visions across construction firms and networks with project outcomes were observed. Essentially, both Case A and Case B, which were more uniform as to their BIM adoption drivers (external and internal respectively) had more consistent project outcomes than Case C, which was characterised by incongruent BIM adoption visions among the actors. There is room for further alignment of BIM visions across firms. Finally, the study added to the knowledge base of innovation in loosely coupled systems and particularly BIM innovation and shed new light on the relation between formal and informal communication channels that support appropriability of innovation from actors, regardless any recruitment activities that can only structurally affect the composition of construction networks.

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