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Inter- and intra-organizational conditions for supply chain integration with BIM

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ABSTRACT

Digitizing buildings via building information modelling (BIM) is increasingly gaining traction in the architecture, engineering and construction (AEC) sector. The plethora of BIM-based technologies affects both inter- and intra-organizational relations. Structured inter-organizational networks across tiers, such as supply chain (SC) partnerships were used to examine how BIM affects these changing relations across and within firms' boundaries. Empirical explorations around the interplay between BIM and SC partnering – as a proxy for supply chain management (SCM) philosophy – were deployed to assess their contribution to SC integration, and to investigate the functions of key actors in AEC. One young and one long-standing SC partnership were studied, and it was observed that the contractual arrangements had to be complemented by well-defined BIM scope, and communications across multiple tiers to built trust and support collaboration in the network. There were two types of BIM-enabled SC partnering: with emphasis on either transactions or relations, the former being merely operational whereas the latter strategic. These inter-organizational orientations of BIM-enabled SC partnering outlined further intra-organizational conditions for integration regarding functional division, business models and services offered. The study carries implications for BIM and SCM researchers, policy-makers and practitioners, and proposes strategies for SC integration by aligning intra- with inter-organizational relations.

KEYWORDS
building information modelling (BIM); collaboration; integration; supply chain; supply chain management; supply chain partnerships; trust

Introduction

The architecture, engineering and construction (AEC) industry has been deemed *unintegrated*, *i.e.* displaying lack of integration regarding its processes (Howard, Levitt, Paulson, Pohl, & Tatum, 1989), and *fragmented*, *i.e.* consisting of numerous small multidisciplinary firms (Briscoe & Dainty, 2005; Dainty, Millett, & Briscoe, 2001; Nam & Tatum, 1992). Whilst this multidisciplinarity facilitates expert input from various specialities, fragmentation induces network complexity (Briscoe & Dainty, 2005). To counterbalance this complexity, the AEC adopts innovative solutions for design practices and project teams. Digitizing building information through building information modelling (BIM) improves project performance (Bryde, Broquetas, & Volm, 2013), and affects collaboration and coordination (Dossick & Neff, 2010). Apart from design and construction, BIM also impacts the organizational structures. Sebastian (2011b) acknowledged that BIM changes the actors' roles. Whilst these changing roles appear highly interdependent (Jaradat, Whyte, & Luck, 2013), a better understanding of the impact of BIM on structured inter-organizational settings, such as partnerships, could open opportunities for supply chain (SC) integration.

BIM adoption and implementation have been previously associated with client- or demand-driven partnering structures for asset delivery, such as public–private partnerships (PPP) (Love, Liu, Matthews, Sing, & Smith, 2015; Porwal & Hewage, 2013). As PPPs represent project-specific delivery methods, they hardly extend across multiple tiers and beyond projects. However, supply chain management (SCM), being a procurement strategy, introduces the potential for deeper integration across tiers from a relational perspective (London & Kenley, 2001). Although SCM has emanated from logistics, it carries numerous interpretations. Here it is approached through the lens of SC partnerships, which include contractual relations across firms (Lambert, Emmelhainz, & Gardner, 1996). 'SC partnership' instead of simply 'partnership' is used to describe multiple dyadic partnerships among

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networks of firms, aiming to reduce their inter-organizational interfaces, across projects and beyond organizational barriers, through intense communications, jointly deployed operations and trust building (Lambert et al., 1996). Viewing SC partnerships as a proxy for SCM, BIM implementation was studied in BIM-enabled SC partnerships in the Netherlands. In this paper, SCM philosophy is seen as the theoretical lens for BIM implementation, which could provide fresh insights into inter- and intra-organizational relations, as one can truly comprehend BIM-based collaboration from inter-organizational studies. Across Europe, there is recent trend to revisit SCM, as, for example, in the UK, since government-sponsored reports called for SC integration through BIM (CIC, 2011), by reflecting older visions for increased collaboration, *e.g.* Egan's (1998), which anticipated SC integration from close collaboration. Similarly, collaboration is a key topic surrounding UK Level Two BIM, as shown in the UK BIM maturity wedge.

By analysing two cases, the paper explores collaboration in BIM-enabled SC partnerships. As it explores both first- (*e.g.* contractor, architects, engineers) and second-tier actors (*e.g.* subcontractors and suppliers), it enriches the discussions on SC integration. This study aims to explore inter- and intra-organizational relations in BIM-enabled SC partnerships, identify conditions and propose strategies for deepening SC integration in BIM-enabled SC partnerships. The paper begins by reviewing the theoretical interplay of BIM and SCM, and identifying the research gap. The next two sections describe the methods, based on empirical explorations, and present data and findings. The ensuing section mobilizes the relations and functions (findings) against scientific literature. The concluding section summarizes and outlines implications for relevant parties.

Theoretical basis and research gap

SCM and SC partnering

SCM is the management of networks of firms 'involved in the upstream and downstream flows of products, services, finances, and information from a source to a customer' (Mentzer et al., 2001, p. 4). As SCM has emerged from efforts to attain performance in logistics, there 'has been much debate about distinguishing' logistics from SCM (London & Kenley, 2001, p. 780). In construction, SCM and SC partnering are considered synonymous (Fernie & Thorpe, 2007). It also prevails that firms continue competing on price regardless of partnering (Fernie & Tennant, 2013) and that partnering requires more than pricing to be meaningful (Bresnen & Marshall, 2000). SCM and SC partnerships are also relational, as Christopher (2011, p. 217) considered SCM essentially network management and anticipated transformations in businesses by shifting the emphasis from inventories to information flows, and from transactions to relationships. Therefore, to achieve 'high-involvement' partnerships (Gadde & Dubois, 2010) and overcome opportunism, emphasizing on scope, joint vision and developing long-term relationships is essential (Briscoe & Dainty, 2005).

There are numerous frameworks of SCM and SC partnerships (*e.g.* Lambert et al., 1996; Tan, 2001; Mentzer et al., 2001). Mentzer et al. (2001) extracted essential activities from the past literature for successful implementation of SCM philosophy: mutual information, risks and rewards sharing, same goals, process integration, and long-term relationships. Tan (2001) described cultural change, trust, communication across tiers, suppliers' development and sharing common goals as key drivers for SCM. Lambert et al. (1996) proposed a framework for justifying and implementing SC partnerships that consisted of planning, joint operating controls, communications, risk and reward sharing, trust and commitment, contract style, scope, and investment as joint activities (components) for SC partnerships. These SC partnerships were formed by 'compelling reasons to partner' (drivers), such as cost and market advantages, and intra-firm characteristics (facilitators) that could support or hinder SC development, such as corporate compatibility, managerial philosophy and relational symmetry (Lambert et al., 1996).

Concepts such as trust, scope, joint operations, contracts and communication recur among the frameworks of the scholars above. Lambert et al.'s (1996) framework additionally included intra-organizational aspects (facilitators) and was validated in a follow-up longitudinal study (Lambert, Knemeyer, & Gardner, 2004), where it was concluded that establishing contractual SC partnerships facilitates SCM philosophy. As this study focuses on BIM-based collaboration, this SC partnering framework (Lambert et al. 1996) was selected for being implementation focused and rich in intra-organizational insights (see research aim). However, this study approaches SCM from a network-based perspective rather than from a 'focal' firm perspective that past SC scholars held, as the SCs are networks with actors' interdependences. After all, Christopher (2011) also referred to 'supply chains' as 'networks'.

BIM and procurement

As construction is primarily organized in projects, projects are nexuses of processing information (Winch, 2004). Whereas BIM has recently proliferated as an integrated way to managing information, its integrative potential is still unfulfilled. Eastman, Teicholz, Sacks, and Liston (2008) defined BIM as an integrative technology with 'parametric intelligence' that alters the digital building representation process. BIM is a 'multifunctional set of instrumentalities for specific purposes that will increasingly be integrated' (Miettinen & Paavola, 2014, p. 86) and affects various actors across the AEC lifecycle, as policies, processes and technologies interact to generate a digital building design (Succar, Sher, & Williams, 2012). Thus, BIM is a domain of loosely coupled information technology (IT) systems for generating (authoring tools), controlling (model checking tools), and managing (planning tools) building information flows intra- and inter-organizationally, based on principles of information systems' interoperability.

Eastman et al. (2008, p. 10) advised that design–build (DB) procurement 'may provide an excellent opportunity to exploit BIM technology because a single entity is responsible for design and construction', as it is more time and cost efficient than design–bid–build. Holzer (2015) analysed opportunities for BIM under various procurement methods and concluded that integrated project delivery (IPD) is contractually appropriate, although it is not globally applicable (Holzer, 2015; Sebastian, 2011a). Kent and Becerik-Gerber (2010) corroborated that IPD-using BIM projects are sparse. Whereas all procurement routes could potentially support BIM (Eastman et al., 2008; Kuiper & Holzer, 2013), as procurement affects actors' involvement, it outlines SC integration. Therefore, procurement routes closer to relationship contracting would better support BIM (Kuiper & Holzer, 2013). This paper looks at BIM as IT (independent variable), which by affecting *processes* and *actors* influences SC integration regarding inter- and intra-organizational relations (dependent variables).

Synthesis of SC partnering and BIM for integration

Based on the above, both SCM and BIM aim at achieving integration. The lack of construction integration persists across its lifecycle and involved actors (Briscoe & Dainty, 2005; Fernie & Tennant, 2013; Nam & Tatum, 1992), due to the conflicting nature of demand and supply (Cox & Ireland, 2002). Integration pertains to both processes and actors, and regarding the latter as collaboration across tiers (Dulaimi, Ling, Ofori, & De Silva, 2002). For Dulaimi et al. (2002) strategies such as early involvement, risk and reward sharing, joint inter-firm operations, IT investment, and DB procurement boost integration. Correspondingly, the synergy between integrative management philosophies, *e.g.* SCM, and IT, *e.g.* BIM, could induce SC integration. The AEC deploys integration to improve the traditionally fragmented project-based procurement and information flows. Figure 1 schematically compares traditional with integrated approaches.

BIM implementation has been previously associated with partnering structures, *e.g.* PPPs, which increase the clients' involvement (Love et al., 2015), compared with DB. PPPs are usually supported by public bodies – also responsible for issuing BIM-related mandates – via institutional mechanisms. Although public bodies act as agents for change and support innovation (Taylor & Levitt, 2007), PPPs pertain to the demand rather than the supply side of the chain and have little influence on second-tier actors, *e.g.* subcontractors, suppliers. Similarly, Porwal and Hewage (2013, p. 204) having studied publicly funded construction projects, claimed that 'maturity and adoption of BIM depend mainly on the client or the owner'. Whereas most BIM studies mainly consider clients and contractors, this study focuses on the supply side of the SC to explore how BIM and SCM affect networks of construction tiers, from engineers to suppliers.

Although partnering is regarded a 'less formal predecessor' of IPD (Ilozor & Kelly, 2012), both IPD and PPPs are project-specific procurement methods. However, SC partnering is a procurement strategy beyond project barriers, which enables reusing information channels and relational components, such as long-term *commitment*

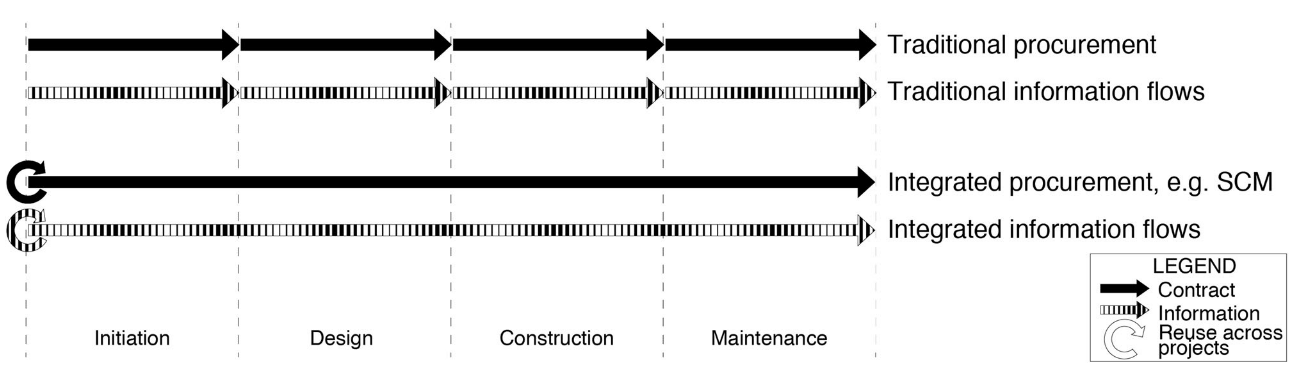

Figure 1. Schematic representation of traditional versus integrated procurement and information flows.

and *trust building*, across projects. There is much evidence that BIM improves the coordination of mechanical, engineering and plumbing (MEP) engineering, under conditions such as prior experience, early joint decision-making, and *joint planning* and *operations* (Ahn, Kwak, & Suk, 2015; Dossick & Neff, 2010; Wang & Leite, 2014). The BIM-based collaboration usually resembles concurrent engineering (Lee, 2014), which entails *intensive communication*. All *italicized* concepts above – joint planning, operations and communications – are components of Lambert et al.'s (1996) framework and could potentially support BIM. Thus, this framework is used as an analytical lens for identifying opportunities and conditions for SC integration with BIM, at an inter-organizational level and across multiple tiers.

Methods

Research rationale

To complement inter-organizational research on BIM, building on SCM literature through Lambert et al.'s (1996) framework could offer additional inter-organizational insights into BIM. Also, inter-organizational studies allow for indirect validation by including multiple perspectives. Figure 2 presents the conceptual framework, focusing on processual and actor-related aspects of BIM-enabled SC partnerships. The study explores the following questions:

- How do inter-organizational relations unfold in BIM-enabled SC partnerships? (RQ1)
- How do intra-organizational conditions contribute to integration of BIM-enabled SC partnerships? (RQ2)

To answer these questions and explore various actors' perceptions of BIM-enabled SC partnerships, case methods were selected because they provide in-depth analysis of phenomena in 'real-life context' (Yin, 1984). The combination of SCM and BIM could offer insights into other inter-organizational BIM settings. Whereas the cases were exploratory, Bengtsson and Hertting (2014, p. 2) claimed that case findings are generalizable when 'expectations about similar patterns … in similar contexts', *i.e.* similar inter-organizational BIM settings, exist. Here, the empirical material 'is seen as a potential dialogue partner' (Alvesson & Kärreman, 2007, p. 1279), discussing SC integration in existing BIM-enabled SC partnerships.

The study occurred in the Netherlands, where both BIM and SCM concepts flourish. SC partnerships in the Dutch AEC have replaced traditional procurement (Vrijhoef, 2011) by using short documents to prescribe inter-firm relations, *i.e.* SC 'framework agreements' (Pryke, 2002). These partnerships are based on long-standing pre-existing relations that aim at increasing process and product quality. BIM adoption in the Netherlands is quite balanced by presenting a proportional mix of mandatory and suggestive documents (Kassem, Succar, & Dawood, 2015). The Dutch AEC is proactive regarding BIM-related initiatives, *e.g.* by developing BIM assessment tools after popular industry demand (Sebastian & van Berlo, 2010), or undertaking initiatives to standardize the exchange of BIM-generated information (Berlo & Papadonikolaki, 2016). The latter is evidence that the Netherlands is an appropriate research setting by displaying a ubiquitous consensus-seeking culture that fosters close inter-firm collaboration. This consensus-seeking culture would be ideal to investigate integration, which is a resurfaced hot topic in AEC.

Case study selection

The empirical research context concerns two cases of multi-actor networks organized in partnerships developing BIM-based projects. The partnerships provided a structured research setting by facilitating data collection through unimpeded access to data. Two projects (one per case) were analysed as snapshots of 'interaction episodes', governed by past experiences and future expectations (Gadde & Dubois, 2010). They were selected from a larger pool of BIM-using partnerships, and were representative because:

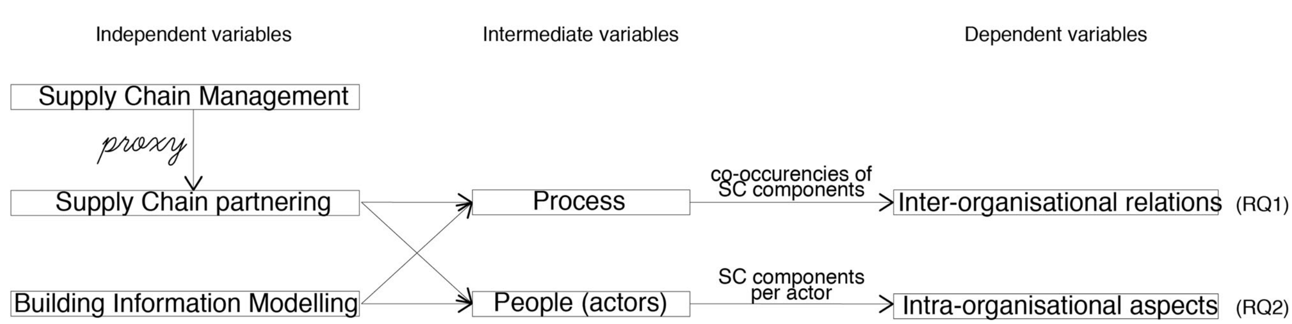

Figure 2. Conceptual framework of the study presenting the relation between key topics and research questions.

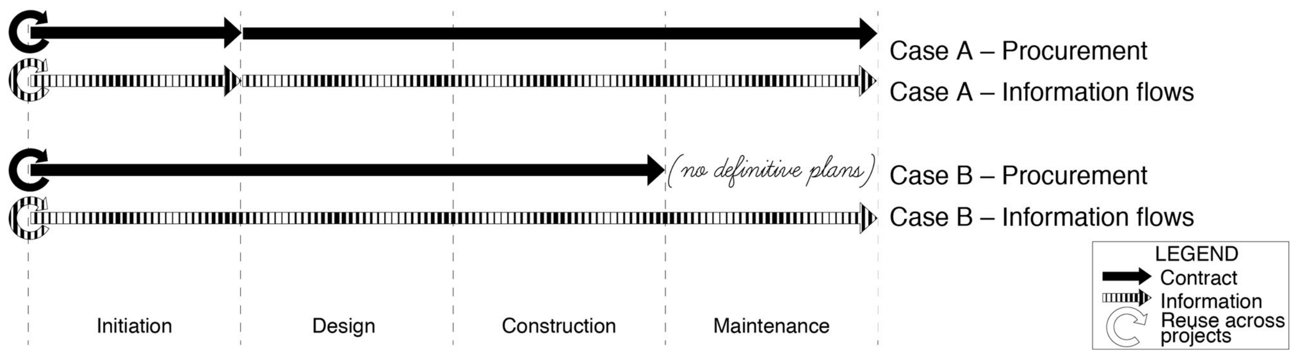

Figure 3. Key features of the cases' procurement strategy and information flows.

- various company sizes participated, such as multinational corporations, large, and small and medium-sized enterprises (SMEs)
- they used SC frameworks agreements and had long-term scope
- they used open standards, *i.e.* industry foundation classes (IFCs), which allowed using various BIM applications
- they used common data environments (CDEs) to share information

Despite the similarities, the two cases were different because they had diverse partnering status; case B was an older partnership than case A. The firms in case A had previously collaborated in three projects, whereas the firms in case B had collaborated in more than 15 projects. According to Eisenhardt and Graebner (2007), sampling cases with extreme features offers distinct patterns of the studied phenomenon. Through these differences, the cases offer a rich evidence base of BIM-enabled SC partnerships and potentially support generalization. Figure 3 schematically represents the differences between the cases.

Case study design

The study focused on inter-firm relations by devoting equal time to all partners, rather than concentrating on 'focal' firms. The study deployed interviews to place an emphasis on the incongruent actors' interpretations, and as cases 'incorporate a number of data gathering measures' (Berg, 2001, p. 225), for triangulation and credibility (Miles & Huberman, 1994, p. 266) the contractual inter-firm relations were also analysed. Whereas the data were collected per firm, to ensure grounded understanding and avoid biases (Eisenhardt & Graebner, 2007), employees from various hierarchical levels were interviewed, from top management to modellers. Within engineering firms, three functions were interviewed: project/tender manager, lead engineer and modeller. In smaller firms, these functions were merged. Interviewing various functions per firm contributed to acquiring additional intra-organizational perspectives. Table 1 describes the interviewees and Table 2 their contractual relations.

The interviews were semi-structured, had consistent preparation and data handling, and were administered

Table 1. Interviewed firms and employees for cases A and B and the size of the firms shown in parentheses.

Case A			Case B		
Firm	**Role/position**	**BIM user**	**Firm**	**Role/position**	**BIM user**
Contractor (MNC[a])	Site engineer	×	Contractor (L)	Site engineer	×
Contractor	BIM manager	×	Architect (SME)	Project architect	×
Contractor	Design coordinator	×	Architect	BIM modeller	×
Architect (SME[b])	All-around architect	×	Structural engineer (SME)	Lead engineer	×
Structural engineer (SME)	Director		MEP engineers (SME)	Tender manager	
Structural engineer	BIM modeller	×	MEP engineers	Site engineer	×
Mechanical engineer (L)[c]	Project leader	×	MEP engineers	BIM modeller	×
Supplier A1 (L)	Tender manager		Subcontractor (L)	Project leader	
Supplier A1	BIM engineer	×	Supplier B1 (SME)	Director	
			Supplier B1	BIM modeller	×

Notes: [a]Multinational corporation.
[b]Small- to medium-sized enterprise.
[c]Large firm (>250 employees).

by the first author, who was not affiliated to the firms. The questions were about the motivation and implementation (enablers, barriers) of BIM-enabled SC partnerships, and the interviewees' functions. The interviewees conversed in Dutch and agreed their input to be used anonymously for research. Four research assistants attended and recorded all interviews with permission, and afterwards transcribed and translated them. The data analysis had two parts: (1) quantitative, which outlined recurring topics inductively (Krippendorff, 2013); and (2) qualitative, which discussed them. The transcripts were analysed – or 'coded' (Miles & Huberman, 1994, p. 56) – for data reduction (Miles & Huberman, 1994, p. 12) with qualitative analysis software (atlas.ti), using protocol coding derived from Lambert et al.'s (1996) framework. With protocol coding, second-cycle coding was redundant, as the themes were pre-developed (Saldanā, 2009, p. 149). Because the study focuses on understanding and not theorizing anew, using protocol coding harmonized the data analysis to the study's conceptual framework (Figure 2) (Saldanā, 2009, p. 49). According to Boyatzis (1998, p. 99), as new raw data are available, using existing codes could 'establish levels of an independent variable', as less interpretative codes are also 'theorising act' (Miles & Huberman, 1994, p. 57).

The data were analysed using descriptive coding and co-occurrence frequencies. Co-occurrence is the event where two constructs intertwine in the narratives. First, co-occurrence was used to discover conceptual interrelations (He, 1999) among SC components. Co-word analysis shows how constructs co-exist, evolve over time (Ronda-Pupo & Guerras-Martin, 2012) and practically relate (RQ1). Second, co-occurrence was used to understand the relation between SC components and actors, and explore intra-organizational conditions (RQ2). To counterbalance the limitations of co-word metrics, which are innately quantitative and simplistic (He, 1999), in the ensuing section key findings from this analysis are tabulated and then discussed around the interviewees' narratives to facilitate comparison and reflection between cases and data.

Data analysis and findings

Case description

Case A was a multifunctional building complex consisting of three volumes with 255 residential units, offices and commercial spaces. The project is prestigious for the partnership; however, although the contractor had agreed 'that all projects go in BIM because it is the future. In this project BIM was simply an obligation, a contract requirement' (case A, design coordinator). The contractor, client, heating and energy firms, and facility manager formed an SC partnership in the form of a so-called UAV-GC (in English: uniform administrative requirements for integrated contracts) multi-party contract for 20 years, which is similar but involves more financial agreements than design–build–maintain procurement. UAV-GC contracts have long-term scope and generate reusable information across projects. BIM was applied from preliminary design until pre-construction and will be used for maintenance (Figure 3).

Case B concerns a housing tower with 83 housing units over a pre-existing building and high technical complexity. This project is crucial for the longevity of the chain, as for some of the firms it was their first residential undertaking: 'we really did not dare to do it in a traditional way [without BIM]; it was really a conscious decision' (case B, architect-project architect). The contractor had SC contracts with the architect, structural engineer, steel subcontractor and suppliers, *e.g.* windows, cladding, roof. BIM was applied from initiation until construction, and 'as-built' BIM will be delivered (Figure 3). The main difference between the cases was the partnership type, as case A was a new partnership involving a multi-party contract, dating back three years, with many one-off collaborations, but case B was a mature long-standing partnership based on multiple dyadic contracts, dating back more than 10 years (Table 2). Both partnerships started implementing BIM in 2013.

Whereas both partnerships were long-term, these relations were manifested differently throughout the interviews. Lambert et al.'s (1996) framework was used, first, to present the (dis)similarities between the cases and, second, to highlight the compatibilities of BIM and SC partnering. Table 3 compares the co-occurrences of the SC partnership components across the cases to identify interrelations among SC components (RQ1). Table 4 presents the frequencies of SC components across the narratives of various actors to identify intra-organizational aspects in BIM-enabled SC partnerships (RQ2). These descriptive metrics were not used for statistical analysis, but to underline the differences between the cases and to guide the analysis and discussions on the interplay between BIM and SCM. According to Krippendorff (2013), developing co-occurrence frequency tables does not produce findings per se, but facilitates the summary of data and identification of 'inductive themes'.

Case analysis

Components of SC partnerships and BIM

In case A, Table 3 suggests three pairs of highly discussed topics: scope/contracts, operations/planning and

Table 2. Types of contractual relationships among the interviewed firms.

	Case A						Case B					
Relations	**Architect**	**Structural engineer**	**Contractor**	**Mechanical engineer**	**Supplier**		**Architect**	**Structural engineer**	**Contractor**	**Subcontractor**	**MEP**	**Supplier**
Architect	n.a.					Architect	n.a.					
Structural engineer	–	n.a.				Structural engineer	–	n.a.				
Contractor	T	P	n.a.			Contractor	P	P	n.a.			
Mechanical engineer	T	T	M	n.a.		Subcontractor	–	–	P	n.a.		
Supplier	–	–	P	T	n.a.	MEP	–	–	P	–	n.a.	
–	–	–	–	–	–	Supplier	–	–	P	–	–	n.a.

Note: – = No contractual relation, T = tender, P = partnership, M = multiparty contract.

Table 3. Co-occurrence frequency of the supply chain (SC) partnership components from Lambert et al. (1996) in the cases.

	Case A								Case B							
SC partnership components	**Planning**	**Joint operating controls**	**Communications**	**Risk/ reward sharing**	**Trust and commitment**	**Contract style**	**Scope**	**Investment**	**Planning**	**Joint operating controls**	**Communications**	**Risk/ reward sharing**	**Trust and commitment**	**Contract style**	**Scope**	**Investment**
Planning	0								0							
Joint operating controls	**16**	0							9	0						
Communications	4	**27**	0						7	**35**	0					
Risk/reward sharing	2	3	3	0					2	2	7	0				
Trust and commitment	0	4	**13**	5	0				1	5	**12**	**8**	0			
Contract style	1	0	7	8	6	0			1	2	3	5	5	0		
Scope	3	6	6	5	4	**11**	0		**11**	4	4	0	3	4	0	
Investment	0	0	2	1	0	0	2	0	1	1	3	0	0	0	0	0

Note: bold entries emphasize concepts with higher frequency

Table 4. Co-occurrence frequency of the supply chain (SC) partnership components from Lambert et al. (1996) across cases and actors.

	Case A					Case B					
SC partnership components discussed in the context of the BIM-enabled SC partnership	**Architect**	**Structural engineer**	**Contractor**	**Mechanical engineer**	**Supplier**	**Architect**	**Structural engineer**	**Contractor**	**Subcontractor**	**MEP**	**Supplier**
Planning	6	0	8	5	7	7	3	5	8	10	0
Joint operating controls	9	8	21	9	12	9	12	11	13	15	7
Communications	12	21	18	12	18	15	17	14	14	27	9
Risk/reward sharing	9	3	20	8	6	6	4	5	13	7	1
Trust and commitment	2	9	10	6	9	5	6	9	20	11	1
Contract style	8	5	33	9	11	6	9	4	12	8	3
Scope	2	4	19	4	7	6	9	6	3	6	1
Investment	5	6	6	3	3	2	6	6	7	5	6

communication/trust (see the bold numerals in Table 3, case A). First, the SC components of *scope*, *contract style* and *risk/reward sharing* co-occurred with strategic BIM decisions. For the contractor 'BIM was simply an obligation from the client' (contractor-design coordinator). The partners admitted that 'if the contractor does not ask BIM we do not use it' (structural engineer-BIM modeller). Although the contractual relations across the partnership were clearly defined, the BIM-related agreements and scope were vague:

> the BIM protocol that we made at the beginning of the project had not been regulated. … Thus, the responsibilities and role partitioning had been not yet fixed. (contractor-design coordinator)

Concerning the adoption of BIM and SCM partnering, the contractor admitted that 'adopting a BIM strategy is less risky cost-wisely than adopting a SCM contractual strategy' (contractor-design coordinator). However, the suppliers saw SC partnering as an opportunity 'to have SC relations with more companies' as they 'receive predictable amount of work from the contractor' (supplier-tender manager). Thus, case A was scope-aware, but rarely surpassed contractual prescriptions.

Second, the concepts of *joint operating controls* and *planning* co-occurred intensively. The partners were struggling to align their planning and joint operations with BIM implementation (Table 3, case A). The contractor stated that:

> if you have a BIM project you must have in fact firstly a design in BIM, and then your subcontractors would develop (their work) in BIM (contractor-design coordinator)

which did not happen in case A, as the technical design started with delay. The mechanical engineer admitted that 'BIM design was not finished … but we just needed to build because we had to meet the schedule' (mechanical engineer-project leader). They coordinated their activities by compartmentalizing problems:

> It depends a bit on what needs to be changed and which party is responsible for adapting. … It can take up to two weeks before a specific issue is completely processed. (architect-all-around architect)

This shows that due to lack of truly joint operations the project was behind schedule.

Third, the concepts of *communications* and *trust and commitment* co-occurred (Table 3, case A). There were both formal and informal inter-firm communications. The contractor encouraged 'that we go to find out among ourselves and that we contact the architect to sort things out' (structural engineer-BIM modeller), but again the partners would 'directly contact the engineers but then inform the contractor' (architect-all-around architect), which reveals that trust was not equally disseminated. Communications extended beyond project requirements:

> the partners have asked us to guide and educate them. … Our BIM knowledge has increased considerably, and we spend time with our subcontractors to solve BIM export problems physically together. (contractor-design coordinator)

As the firms interacted, BIM implementation was supported from long-term relations:

> We need to have permanent contact persons in the partners' firms, so this is where the SC partnership and BIM are intertwined. I think that you cannot do good BIM without a SC partnership. (supplier-BIM modeller)

In case B, the interplay between BIM and SCM unfolded around the clusters of contracts/risks, scope/planning and communications/joint operations/trust (see the bold numerals in Table 3, case B). First, the components of *contract style* and *risk/reward sharing* co-occurred, but less than in case A. The firms had long partnering history; they were 'developed by this, only back then it was called differently' (MEP engineers-site engineer) and 'are quite used to enter into a SC partnership' (MEP engineers-tender manager). Their business transactions evolved due to BIM:

> We used to have simple tendering assignments but not anymore. Nowadays it's very easy to receive the BIM model and find it out. The BIM model is like what the tender proposal was back then. (subcontractor-project leader)

However, 'as everyone is responsible for their own part, the contractor controls less, which is risky' because 'one chain partner is better in BIM than the other' (architect-project architect). Therefore, BIM had an impact on both project briefing processes and risks.

Second, the concepts of *planning* and *scope* frequently co-occurred (Table 3, case B). The interviewees discussed how to align partnering with project scope and how BIM affected their planning: 'we agreed in advance at which stage what BIM information was going to be delivered' (contractor-site engineer). From agreeing on BIM scope, they received 'earlier insights into where the bottlenecks really are in the process. So forward-thinking is far important in BIM' (architect-project architect). 'The innovation of BIM-ing lies in process control … you can make sure to keep your planning agreements' (architect-project architect). The concepts of *planning* and *scope* were also connected to the discussions about levels of detail: 'It's important that you have clear goals in advance; if you would later use the BIM model to manage the building or not' (structural engineer).

Third, the concepts of *communications*, *trust and commitment*, and *joint operating controls* co-occurred (Table 3, case B). The partnership's BIM-based operations were combined with co-locations: 'Sometimes it's better just to sit jointly at the table because of the non-verbal communication' (MEP engineers-site engineer). Their communication was also very open, due to their pre-existing relations: 'in partnership we do not always have to agree with each other' (subcontractor-project leader). However, a shift had to take place while investing in BIM, given that:

> it is very difficult for people because they have to think outside their comfort zone, that they are so used to it for years. … With the new information possibilities of BIM, it's easier to exchange information. (contractor-site engineer)

as well as coordinate projects and the supply chain. Overall, BIM was not a costly investment: 'for us it is not more expensive to model 3D than 2D drawing; our quality level has gone up' (architect-project architect); however, it required investment in time, *e.g.* earlier discussions: 'we now work with each other at an early stage in the process … and that's actually a whole mentality change' (structural engineer).

Key actors in BIM-enabled SC partnerships

Whilst the two cases displayed different approaches for developing and implementing BIM-enabled SC partnerships, no major mismatches were observed across their actors (Table 4). Overall, the case A contractor governed *planning*, *communications*, and *joint operating controls*. In case B, these components were equally discussed among actors. In both cases, the contractor held most long-term partnering contracts. The contractor was seen as the 'spider in the web' (case B, MEP engineers-site engineer) who might have had 'some yearly contracts but the larger part was bought traditionally' (case A, contractor-design coordinator). In both contractors, top management had decided on adopting BIM. However, in case B, the top management's commercial decisions did not align with firm capacity:

> the commercial guys, who sit on the second floor above, sell a very nice project to a customer, then we will set a date and go. And that is for us, of course, enormous time pressure, to make the right decisions. (case B, contractor-site engineer)

To support BIM implementation, the contractors were responsible for ensuring *joint operations*, by facilitating co-locations. They spent 'time on the subcontractors to solve BIM export-problems physically together' (case A, contractor-design coordinator), or 'sit down together in an IT-prepared space, everyone with their own laptop … to do their own thing so we can have design sessions together easily' (case A, contractor-site engineer).

They also maintained and managed *communications* over the CDE: 'they have always said "hey there's a new model and that you should download just because it also affects you … "' (case A, supplier-BIM modeller).

In both cases, the architects were responsible for delivering the initial BIM model of the project, *e.g.* 'you draw based on what was supplied by the architect' (case B, MEP engineers-site engineer) and 'we see the model of the architect as form and space within which we must operate' (case B, contractor-site engineer). Their additional role was facilitating *communications* across all tiers: 'our real role is good collaboration and making clear agreements about it' (case B, architect-project architect) (Table 4). However, the communications in case B were across all tiers: 'in that sense the communication goes all ways. It is not only that we give information, but we also need a lot of the suppliers' (case B, architect-project architect), whereas, in case A, the supplier stated: 'we did not have contact with the architect' (case A, supplier-BIM modeller).

The structural and mechanical engineers emphasized less on *communications*, and focused more on *planning* and *joint operating controls*. No significant differences were observed regarding their functions across the cases (Table 4). The subcontractors and suppliers displayed enhanced roles, associated with *planning*, *joint operating controls* and *scope*, because of BIM-enabled SC partnering: 'we have more expectations when we look at the work earlier, and we judge accordingly' (case A, supplier-tender manager). Both engineers and suppliers extensively associated *risk/reward sharing* to *scope* and *planning* and particularly:

> our work is riskier mainly because we begin earlier with the project. We start work on the drawings and then the offer comes. More responsibilities go along with it. (case A, supplier-tender manager)

Moreover, they acknowledged the importance of *joint operations* and *planning* for BIM: 'And now we try with BIM to shape the process earlier together, to then have fewer errors in the process' (case B, structural engineer) and 'we have first to make a design together and then go see what it costs' (case B, subcontractor-project leader).

From the above narratives, the actors develop different roles in BIM-enabled SC partnerships. The contractors acted as the coordinators of the joint operations and the architects as initiators of the BIM model and enablers of communication across tiers. The rest engineers and suppliers were more interested in aligning joint BIM-work with project planning (Table 4).

Discussion

Inter-organizational relations in BIM-enabled SC partnerships

The two cases displayed similarities as to partnering drivers and facilitators and dissimilarities as to partnering implementation. For both cases, sharing past history was an internal 'cultural' driver to deepen their inter-firm relations (see narratives on *trust and commitment*, *contract*). Moreover, both cases illustrated that adopting BIM was an external (environmental) factor, as clients contractually required it (case A) or top management adopted it due to market demands (case B). The latter corroborates evidence from literature that BIM becomes a partner selection criterion (Mahamadu, Mahdjoubi, & Booth, 2014). Thus, the decision-making on adopting BIM and SC partnering were compatible across the cases. This paper presented new evidence of IT penetrating into lower construction tiers, contrary to existing data from literatures (Akintoye, McIntosh, & Fitzgerald, 2000; Briscoe & Dainty, 2005) (see suppliers' and subcontractor's quotations). The authors concur with Kuiper and Holzer (2013) that not only BIM but also past efforts to reduce fragmentation instigate relational and contractual shifts in construction. In keeping with controversies about the effectiveness of IPD (Holzer, 2015; Sebastian, 2011a), and as the sophisticated 'multi-party' contract of case A did not integrate the SC further, simpler long-term dyadic relations (case B) can also support BIM implementation.

Despite the afore-mentioned similarities, the cases presented two contrasting types of BIM-enabled SC partnerships. Their contrasting features could be labelled dichotomies, as they present dilemmas with clear advantages and disadvantages for managers to choose between (McGrath, 1981; Smith & Lewis, 2011). The cases differentiated regarding Lambert et al.'s (1996) components, such as *planning* and *communication* (Table 3). For case A, *planning* was more associated to *joint operating controls* as opposed to case B, where *planning* was discussed through the lens of project and SC *scope*. This dichotomy relates to discussions over operational (case A) versus strategic (case B) perspectives of SCM (Green, Fernie, & Weller, 2005) and to what extent the SC visions penetrate into the work floor (Tan, Kannan, & Handfield, 1998). The fact that case A partnership was less strategic is supported by the quotation that adopting BIM was less risky than SC partnering (contractor-design coordinator), which suggests that engaging in SC partnering entailed higher uncertainty to them than financially investing in BIM. Accordingly, case A viewed *planning* as result of *joint operations* (operational SCM) and the narratives focused on improving efficiency, which is the perspective of SCM that 'dominates the literature' (Green et al., 2005). Adversely, in case B, *planning* was strongly related to *scope* (strategic SCM) and conceptually linked to commercial decisions and 'dynamics of competitive positioning' (Green et al., 2005). Hence, case A was essentially operational, whereas case B strategic SC partnership. Further research could investigate causalities between these types of SC partnering to identify whether they express maturity, and which particulars of BIM implementation could serve as maturity determinants.

Another dichotomy between the cases pertains to *communications*. In case A, *communications* were seen as a consequence of *trust* as opposed to the co-occurrence in case B between *joint operating controls* and *communications* (see Table 3 and *communications* narratives). This dichotomy resonates with Bresnen and Marshall (2000, p. 232) that:

> there is a division between those who see partnering as an informal and organic development and those who regard it as something more formal that can be actively engineered

as outlined in narratives from case B (informal) and case A (formal) respectively. For Green et al. (2005), trust was considered a prerequisite of mutually interdependent relationships (see case A quotations), while the SC partners of case B had previously worked proactively to build trust, and retain communication channels that could support BIM implementation beyond organizational boundaries (case B). The cross, case analysis revealed dichotomies that could apply to other BIM-enabled inter-organizational settings, with or without contractually binding agreements. From the cross, case comparison, the following dichotomies around inter-organizational relations unfolded (answer to RQ1):

- Operational (case A) or strategic (case B) *planning*
- Formal (case A) or informal (case B) *communications*
- Prerequisite (case A) or pre-existing (case B) *trust*

Whilst construction is generally deemed slow in technology absorption (Davies & Harty, 2013), there are encouraging notes that firms actively engage in BIM. Drawing upon the framework of Lambert et al. (1996), the partnerships focused on time investment for joint BIM learning during the project, rather than investment in tangible assets, such as acquiring technology or hiring specialized personnel. Such proactive behaviour towards developing their partners could not only facilitate relationship management, but also encourage innovation (Cox & Ireland, 2002). Regarding the timing of BIM adoption, no disruption effects were observed in the older partnership (case B), because BIM implementation used pre-existing communication channels, while the 'newer' case A had to implement both digital and relational changes simultaneously. Taylor and Levitt (2007) stated that networks with strong relational stability and permeable boundaries would perform better when faced with misaligned innovations. Likewise, case B SC partnership, which is a stable network, could perform better regarding BIM adoption, which is at the moment a misaligned innovation.

Intra-organizational conditions of BIM-enabled SC partnerships

The contractors provided CDE for online information exchange, 'IT prepared space' for co-locations and design coordination, occasional BIM training to their partners (case A), and also featured dedicated BIM departments, an observation in keeping with the work of Ahn et al. (2015). However, although the contractors held most long-term partnerships (Table 2), they were not necessarily the 'centre' of BIM-based collaboration. The contractors – through their commercial decisions – influenced their partners' BIM adoption and investment, an evidence against Porwal and Hewage (2013) who claimed that BIM maturity and adoption mainly depend on clients. Ackoff (1970) and Mintzberg, Lambe, Brian Quinn, and Ghoshal (1996) divided corporate planning into strategic, tactical, and operational levels and addressed the danger of detaching top management from tactical decisions and work floor operations (Mintzberg et al., 1996). The contractors presented such detachment; as despite displaying 'top management support' (Mentzer et al., 2001) for SC partnering and BIM, there was apparently an incongruence in understanding and planning BIM-based projects between senior and middle management (see contractors' narratives).

In both cases, architects and structural engineers were either desired (case A) or already keen (case B) to engage in informal communications with multiple tiers (Table 4). However, the two architectural firms had different mentalities, probably given their contractual position in the partnerships (Table 2), as case A architect was tendered, whereas case B architect was long-term partner. Informal and across all tiers communication could, accordingly, facilitate both implementation and alignment of BIM with SC partnering. Interestingly, both the architect and structural engineer from case B considered collaboration part of their role, which implies a cultural shift towards a more proactive and collaborative AEC. There were usually two BIM-related roles: a project leader/engineer, who might or might not be familiar with BIM and a BIM modeller/engineer (Table 1). Again, in smaller firms these functions were merged (case A). The MEP engineers, whose design coordination with BIM has been researched in multiple studies, given their tasks' complexity (Dossick & Neff, 2010; Wang & Leite, 2014), usually had three intra-firm functions: tender manager, project engineer, and BIM modeller (Table 1). Additionally, the cases presented both unintegrated (case A) and integrated (case B) MEP-services firms, which could be evidence of a shift in increasing integration in AEC, by forming multidisciplinary firms (Dulaimi et al., 2002). Such integrated professional services subsequently absorb inter-organizational tensions intra-organizationally.

The suppliers and subcontractors saw their involvement in BIM-enabled SC partnerships as an opportunity to engage earlier in design coordination (see suppliers' narratives), which accordingly supports integration (Dulaimi et al., 2002). The suppliers and subcontractors had similar BIM-related functional divisions to the engineers and contractors respectively. BIM implementation across the partnership induced transformations into firms' strategic IT investment, as some adopted BIM intra-organizationally (case A), whereas others outsourced BIM implementation in BIM-drafting companies (case B, subcontractor). Outsourcing BIM could potentially activate further inter-organizational challenges, as it transfers intra-firm communications externally.

Table 5 summarizes the afore-mentioned intra-organizational conditions of BIM-enabled SC partnership (answer to RQ2). These intra-organizational decisions, culture and strategies enable or hinder inter-organizational collaboration (Bresnen & Marshall, 2000). Also, Lambert et al. (1996) considered corporate compatibility across firms' top management philosophies as a catalyst for SC integration. Note that the cases displayed intra-organizational aspects that contribute to both integrated and unintegrated practices. Among the conditions that clearly differentiated the integrative potential of the cases are (1) corporate compatibility of BIM and SCM visions (*e.g.* in firms' business plan), and (2) whether the services offered per firm were integrated, *e.g.* MEP firms, or not. Further research could work towards identifying weights that these aspects have on SC integration.

Theoretical contribution and proposed strategies for SC integration

The study examined the combination of BIM and SCM by reflecting on their real-world interplay and

Table 5. Intra-organizational conditions that could influence the BIM-enabled supply chain (SC) partnership and the case where they were observed shown in parentheses.

Intra-firm conditions	Disintegrated (case observed)	Integrated (case observed)
Motivation for BIM/SCM adoption	External (A, B)	Internal (A, B)
Intra-firm structure	Rigid hierarchy (A, B)	Horizontal structure (A, B)
BIM/SCM vision into firms' business plan	Occasionally applied vision (A)	Incorporated vision (B)
Intra-firm BIM-related functions	Three BIM-related functions (B)	One all-around function (A)
Services offered per firm	Specialized services (A)	Integrated (*e.g.* MEP firms) (B)
BIM implementation by the firm	Out-sourcing to external firm (B)	In-house BIM implementation (A)

considering SC partnering a proxy for SCM. As decision-making is usually divided into strategic, tactical, and operational (Ackoff, 1970; Mintzberg et al., 1996), these levels affect the inter- and intra-organizational relations. The firms should not only align intra-organizationally and operationally but also inter-organizationally and strategically with BIM. Whilst human agency and intra-organizational conflict are largely absent in SCM implementation (Green et al., 2005), this study also investigated intra-organizational conditions. Figure 4 summarizes inter- and intra-organizational relations unfolding in BIM-enabled SC partnerships (RQ1, RQ2).

The paper contributed to theory through new, network-based insights into the 'old' concept of SCM – as opposed to the 'focal-firm' perspective, which has dominated the SCM literature. It also investigated the relevance of SCM philosophy in the 'digital era' through BIM implementation. As co-word analysis presents the evolution of concepts through time (Ronda-Pupo & Guerras-Martin, 2012), here, co-word analysis offered a better understanding of strengths, weaknesses and interactions among components of Lambert et al.'s (1996) framework, required for effective implementation of BIM-enabled SC partnering (Table 3).

Whilst this study resonates with London and Kenley (2001) regarding two main SCM thinking schools: performance-oriented (case A) and relational (case B), perhaps the proposed strategies for integration do not have to be binary. After all, 'seemingly opposed viewpoints can inform one another' (Poole & Van de Ven, 1989, p. 566) as *organizational paradoxes*. Thus managing paradoxical tensions might be a way forward for BIM-enabled SC partnerships, *e.g.* by focusing on *both* operational *and* strategic planning or encouraging *both* formal *and* informal interactions. Paradoxical management seeks to simultaneously adopt competing demands – such as the dichotomies presented in the first subsection of the discussion – and fosters innovation and longevity (Lewis, 2000). Drawing upon the empirical findings, some inter-organizational strategies for integration are:

- extending *joint operating controls* to include co-developed scope and agreements
- balancing strategic (SC scope) and operational (BIM joint operations) *planning*
- proactive informal *communications* across multiple tiers, beyond contractual prescriptions
- enabling *trust and commitment* by investing in partners' development via BIM learning

Another research contribution was adding to the evidence base of SC integration and long-term partnering, including second-tier suppliers. The balanced engagement in SCM from both large firms and SMEs (Table 1), sheds new light on alleged mistrust across SMEs (Dainty et al., 2001). Although most SCM studies

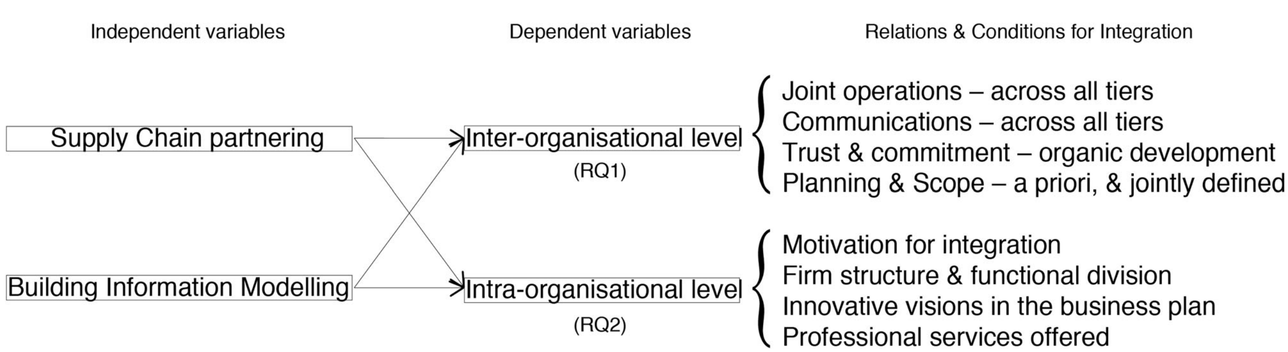

Figure 4. Observed inter- and intra-organizational relations and conditions in the BIM-enabled SC partnerships of cases A and B.

do not focus on intra-firm conditions, this study held intra-organizational sensitivities and proposed further intra-organizational strategies for AEC actors (contractors, architects, engineers, and suppliers) to support the previous inter-organizational strategies. Drawing upon those strategies and Table 5, additional efforts across all hierarchical levels within AEC firms for supporting integration intra-organizationally include:

- partnering across firms with compatible BIM visions and *scope*
- increased intra-firm *communications* across all hierarchical levels to fine-tune the *planning* of BIM-based projects
- intensive *joint operations* between architects and structural engineers, whose input is paramount for the initial BIM model
- evaluation of trade-offs between *integrated* MEP-engineering firms and *specialized* mechanical or electrical firms
- decision-making on incorporating or outsourcing BIM-related services

Limitations and further research

The study focused on BIM-enabled SC partnerships only in the Netherlands. Because the Dutch construction market is of *corporatist type system* (Winch, 2002, p. 25) the local firms are keen to engage in communications across all ties and form alliances and partnerships. As the efforts to eliminate risks and uncertainties are according to Dorée (2004) 'engrained in Dutch culture', the findings might relate to other north-western European countries. However, because Dutch firms feature a relatively 'flat' or horizontal organizational structure, the intra-organizational findings should be interpreted with caution.

Similarly, as only two cases were studied, the rich contextual insights and their resulted interpretations cannot be fully generalized. Given that the sample was small, the co-occurrence coefficient index was insignificant (Garcia, 2011) for statistical inferences. Interpreting this coefficient would be only meaningful with a sizable data set larger than the existing nineteen respondents, and probably from additional cases. Therefore, the study used the co-occurrences to identify' inductive themes' (Krippendorff, 2013) and delved deeper into the dichotomies and nuances of transactional and relational SC partnerships.

Analysing inter- and intra-organizational relations in BIM-enabled SC partnerships could contribute to further diffusing the SCM concept and potentially enriching the insights into inter-organizational BIM implementation. Given that this study focused on the supply side of the chain, further research may address the impact that clients, owners, and facility managers have on inter-organizational relations (within or without a partnering scheme) to explore the inter-organizational ramifications from the demand side.

Conclusions

Defining appropriate inter-organizational structures to support BIM implementation is a highly discussed topic across industry, policy, and academia. After analysing two BIM-enabled SC partnerships, three main dichotomies were revealed between: (1) operational and strategic approaches to BIM *planning*, (2) formal and informal *communications* around BIM work and (3) prerequisite and pre-existing *trust* between case A and B respectively (answer to RQ1; Figure 4). These dichotomies unfolded around the two partnerships might imply not only different maturity levels, but also need for adopting paradoxical management and continuously dealing with such competing demands. The study contributes to theory by offering new inter-organizational insights into BIM implementation through the lens of SCM philosophy, and particularly regarding strategic and operational means such as contracts and standards to support BIM-based collaboration. As the multi-party contract from case A (similar to IPD) did not facilitate further SC integration, contractual relations cannot instigate relational management without pre-existing trust and cultural alignment around IT adoption (case B). To further strengthen BIM-based collaboration, jointly agreed explicit scope and co-developed BIM-related agreements are preeminent to support the joint BIM operations. The study added to the knowledge base of BIM implementation, presented new evidence of BIM penetrating into lower construction tiers, and delineated strategies for effective BIM collaboration, which could support policy-makers' informed decision-making. Unravelling the ambiguity around UK Level Two BIM, this paper has presented real-world evidence of what the proclaimed 'collaboration' entails beyond tools: joint operations, contractual arrangements, time investment for joint BIM learning and trust-building (inter-organizational strategies). The later carries societal implications by outlining a necessary 'cultural shift' accompanying the 'digital shift' in construction, beyond opportunism and contingent behaviour.

The paper's contribution to SCM literature is based on holding *network-based* (exceeding across multiple tiers) rather than the '*focal*' *firm-based* view of the SCs, and developing intra-organizational sensitivities for SC integration. Future researchers could built upon these approaches to study SC collaboration with or without BIM implementation. Whereas the study focused on multi-actor construction networks, additional intra-organizational insights into the businesses of engineers, contractors, and suppliers were obtained, regarding the decision-making for BIM and SC partnering adoption, such as visions' corporate compatibility, inter-organizational synergy, and services offered (answer to RQ2; Figure 4). Surprisingly, various actors held a highly collaborative aptitude regardless their contracts. Diffusing BIM knowledge at all intra-firm hierarchical levels, from top management to work floor, and deciding on the incorporation or not of BIM into firms' business models call for re-evaluating functional division (intra-organizational strategies). The dichotomies between strategic and operational orientation of the cases suggest that deciding and defining BIM scope strategically and further disseminating it across all tiers is crucial for coordinating BIM-based projects. Likewise, BIM adoption could play a role in rationalizing and enriching the information flows among contractually bound SC partnerships, by joint agreements and inter-firm learning. Whilst SCM is an old concept in AEC, studying its interplay with BIM could contribute to SC integration. Likewise, relationally stable SC partnerships could promote the diffusion of BIM and digital innovations.

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