Formal and informal relations within BIM-enabled supply chain partnerships

Papadonikolaki, Eleni; Verbraeck, Alexander; Wamelink, Hans

DOI
10.1080/01446193.2017.1311020

Publication date
2017

Document Version
Final published version

Published in
Construction Management and Economics

CONSTRUCTION MANAGEMENT AND ECONOMICS, 2017
http://dx.doi.org/10.1080/01446193.2017.1311020

Formal and informal relations within BIM-enabled supply chain partnerships

Eleni Papadonikolaki[a], Alexander Verbraeck[b] and Hans Wamelink[c]

[a]Bartlett School of Construction and Project Management, University College London, London, UK; [b]Faculty of Technology, Policy and Management, Delft University of Technology, Delft, Netherlands; [c]Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, Netherlands

ABSTRACT

Supply chain management (SCM) and building information modelling (BIM) are innovations that focus on integration. Recent literature suggests performance benefits from combining these innovations. Within supply chain (SC) partnerships, that use BIM – hereinafter called BIM-enabled SC partnerships – various formal and informal dimensions influence the inter-organizational relations. To understand such partnerships, a mixed method approach featuring case studies and social networks analysis (SNA) was deployed. SNA was an analytic approach to explore the complex relations within two Dutch BIM-enabled projects. The inter-organizational relations were asymmetrical and formal in Case A, emphasizing transactions, whereas in Case B, they were asymmetrical and informal, emphasizing relations. The transactional-oriented partnership had greater control over contractual issues, but their formal relations were not sufficient for diffusing BIM-related knowledge across the chain. Conversely, the relational-oriented partnership engaged the partners in BIM by informal means, e.g. dense communication and BIM-related peer-learning across all tiers. Symmetric and jointly fostered formal and informal relations contribute to SC integration. The study extends the knowledge base of SCM and BIM, by offering real-world data on their combination. Besides providing new insights into SNA deployment for BIM-related research, it also offers a novel constructivist and inter-organizational perspective on the old concept of SCM.

ARTICLE HISTORY
Received 30 March 2016
Accepted 19 March 2017

KEYWORDS
Building information modelling (BIM); integration; social network analysis (SNA); supply chain management (SCM); supply chain partnerships

Introduction

The construction industry is employing various types of integration practices and technologies to manage its intrinsic complexities. Integration is seen both as an innovation per se and as a means to stimulate other innovations (Wamelink and Heintz 2015) and it pertains to either management approaches or technological means. Supply chain (SC) partnering implies strategic, long-term contractual relations and it deploys SC management (SCM) philosophy to integrate the material flows and subsequently information across firms (Gosling *et al*. 2015). Partnering entails "formal instrumental and informal developmental" aspects, throughout the inter-organizationally deployed behaviour, attitudes, values, practices, tools and techniques (Bresnen and Marshall 2000, p. 232). Likewise, innovative technologies, such as building information modelling (BIM), integrate information flows among multi-disciplinary teams by improving their collaboration (Eastman *et al*. 2008) and enhancing project control (Bryde *et al*. 2013). SCM and BIM-related innovations, and particularly involving suppliers in design, have been previously conceptually linked (van Nederveen *et al*. 2010, Nummelin *et al*. 2011). However, although contractual and managerial actions are needed to control digital innovation – and BIM – (Whyte and Lobo 2010), there exists little evidence of the impact of combining SCM with BIM. There is still room for exploring inter-organizational working with BIM, and particularly from a SCM perspective.

To explore the combination of SCM and BIM, the study draws upon the representation of inter-organizational construction networks as social networks (SN). SN analysis (SNA) becomes increasingly popular in construction research (Chinowsky *et al*. 2008, Larsen 2011, Pryke 2012), following on applications in other fields, such as social science and economics. Pryke (2004, 2005, 2012) analysed SC partnerships in a quantitative manner using SNA. However, the impact of integrative technologies such as BIM on inter-organizational networks remains unknown. In this paper, SNA is used as an "analytical language" (Pryke 2012, p. 13) to explore the inter-organizational impact of combining integrated managerial philosophies with technologies, i.e.

CONTACT Eleni Papadonikolaki E.Papadonikolaki@ucl.ac.uk

SCM with BIM, by analysing digital and contractual relations in two SC partnerships. The term "SC partnership" instead of "partnership" is used to describe a network of multiple dyadic partnerships that extend across multiple tiers.

Two projects in the Netherlands were used as in-depth cross-sectional studies of BIM-enabled SC partnering – that is SC partnerships with BIM-enabled information exchange. The study compared formal and informal relations among the actors. Formal aspects entail contracts, hierarchies or agreements for online collaboration, whereas informal aspects entail actors' interactions that often circumvent these formal procedures (De Bruijn and Ten Heuvelhof 2008, p. 9, Klijn 2008). The formal relations where analysed via SNA (Pryke 2004, 2005, 2012). In Egan's Report (1998), day-to-day communication and knowledge sharing are deemed informal relations. Previous work has suggested the need for aligning contractual (formal) and organizational arrangements with digitisation, such as BIM, to control "mutual knowledge sharing" (informal) across firms (Whyte and Lobo 2010, p. 565). *Also, Taylor and Levitt (2007) claimed that networks with strong relational stability and permeable boundaries – such as the SC partnerships – would easily overcome challenges of misaligned innovations – such as BIM. Correspondingly, there is room for a better understanding of how SCM philosophy and BIM technology interact.* This study aimed at exploring, analysing and understanding the formal and informal relations that unfold among actors engaged in BIM-enabled SC partnerships and the influence of choices about formal or informal relations on the longevity and performance of the SC partnership. This study is also needed for adding to the knowledge base about BIM-based inter-organizational work and BIM functionalities, which is sparse.

The paper is structured as follows. The ensuing background section highlights the research gap, presents the conceptual model and introduces the research questions. Next, the methodological justification, underlying philosophical paradigm and methods to answer these questions follow. Subsequently, the results underlining various formal and informal relations are presented. The results are discussed and confronted to relevant literature. The study concludes with outlining suggestions for reducing the asymmetries between formal and informal relations, and implications for relevant parties.

Theoretical background and research gap

Innovations aiming at integration in construction

Integration has been considered an antidote to fragmentation in construction. Integration refers to integration of actors or integration across project phases (Howard *et al*. 1989). Regarding actors, integration refers to project-based teams (Baiden *et al*. 2006) or inter-organizational teams, beyond organizational boundaries. The latter relates to partnering as an approach to integrating project partners at the supply side, e.g. contractor and suppliers, or demand side, e.g. contractor and client, of the chain. Integration has been seen as the overarching goal of SCM (Vrijhoef 2011). SCM philosophy aims among others at minimizing the interfaces between various partners and their operations (Vrijhoef and Koskela 2000). In literature from the United Kingdom (UK), SCM has been viewed as a hindrance to competitiveness and free market (Fernie and Tennant 2013). Pryke (2012) considered SCM, partnering and work clusters as "governance modifiers" attached to traditional contracts, following on Egan's Report (1998) who envisaged a less contractually formal and more collaborative industry. Whereas SCM has been traditionally linked to performance tracking and input–output methodologies – the transactional view – informal inter-organizational relations among project partners are also present in SCM (London and Kenley 2001) – the relational view. For Leuschner *et al*. (2013), SC integration relates to either "operational" or "relational" integration among various actors.

Apart from focusing on inter-organizational relationships, integration has also been linked to information flows of design and construction. After all construction projects are nexuses of processing information (Winch 2005) and managing information flow is an intrinsic part of managing construction projects. Correspondingly, integration refers to various construction phases. Dulaimi *et al*. (2002) recognized the integration in the procurement processes, e.g. design-build (DB) delivery, and the integration between design and production as equally important to advancing the industry. Therefore, given that DB procurement not only reduces the interfaces between design and realization, but also outlines risk allocation and involvement by key project actors, integration across phases may induce SC integration and vice versa. Apart from merely contractual means to integration, Howard *et al*. (1989) suggested that computer-aided means instigate integration across phases, by integrating the information flows among various disciplines. Dulaimi *et al*. (2002) emphasized the need for various actors – from designers to suppliers – to adopt compatible information systems (IS) to exchange information and integrate the design and construction processes. Undoubtedly, BIM could potentially carry out this function. However, a case should be made to differentiate BIM from just "digital objects" (Whyte and Lobo 2010), given that BIM not only allows for various actors to work digitally using their preferred IS but also affects project coordination through the exchange of largely compatible information flows, which are reusable across phases and manageable, via open data standards such as Industry Foundation Classes (IFC), currently the most long-lived (Amor 2015). In this study, BIM is defined as a domain of technologies for generating, sharing and managing consistent information among actors, based on the principles of IS' interoperability.

Table 1. Scientific literature on BIM adoption and implementation across various actors.

Focus	Goal	Scientific literature	Research method
Architect	BIM adoption drivers	Son *et al*. (2015)	Survey using the technology acceptance model (TAM)
	Factors affecting BIM adoption	Ding *et al*. (2015)	Survey using structural equation model
Facility owner	Framework to realize benefits from BIM investment	Love *et al*. (2014)	Conceptual model based on resource-based view
	Assessment of BIM competency	Giel and Issa (2016)	Delphi method from various maturity matrices
	BIM benefits and challenges	Korpela *et al*. (2015)	Survey using cultural historical activity theory
Contractor	Transformation strategies for BIM adoption	Ahn *et al*. (2015)	Literature review and interviews
Supplier	BIM acceptance model	Mahamadu *et al*. (2014)	Unified Theory of Acceptance and Use of Technology (UTAUT) and Technology–Organizational-Environmental (TOE)
Installations engineers	Collaboration with BIM	Dossick and Neff (2010)	Ethnographic observations and interviews
Designers & engineers	Governance of BIM implementation	Rezgui *et al*. (2013)	Interviews with industry participants and focus group meetings
	Responsibility for adopting BIM innovation	Elmualim and Gilder (2014)	Literature review and questionnaire survey
Engineers & contractors	BIM adoption decisions	Gu and London (2010)	Interviews with focus groups
Multi-actors (incl. suppliers)	Adoption and benefits from BIM	Eadie *et al*. (2013)	Online questionnaire

BIM adoption has not been extensively studied from an inter-organizational or SC perspective, but rather from the perspective of isolated actors. Table 1 presents scientific literature from peer-reviewed journals on BIM adoption and implementation of various actors. Most BIM-related studies have been focusing exclusively and separately on designers, owners or contractors, neglecting the perspectives of second-tier actors, e.g. subcontractors and suppliers. Surprisingly, there is a lot of emphasis on the benefits of BIM for facility management (FM), despite the paradox that there are immense technical challenges for BIM/FM application (Korpela *et al*. 2015). Looking at literature on BIM adoption from management and engineering journals, such as Automation in Construction, Construction Management and Economics, Journal of Management in Engineering, and conference papers from the Association of Researchers in Construction Management, most studies neglect the impact that one party's decision to adopt technology (BIM) has on the other actors. However, as Higgin and Jessop (1965) suggested, the construction industry features not only interdependent tasks but also interdependent actors' decision-making.

As a consequence, studying relatively stable construction networks could open opportunities to explore the impact of these interdependent processes and tasks stemming from deciding to adopt innovations (Taylor and Levitt 2007), such as BIM. As SC partnerships are long-term and pre-structured networks, they are stable. The above peer-reviewed studies explored BIM technology by isolating actors but ignored the relations to their complementary disciplines across all tiers, such as suppliers. These single-actor studies usually overlook BIM implementation within inter-organizational environments and particularly contractually defined SC partnerships. From a multi-actor network perspective, Klijn (2008) suggested that analysing the actors' network is crucial to further assess the influence of institutional structures – here of BIM adoption – upon inter-organizational networks. Thus, analysing networks of BIM-using actors could offer fresh insights into emerging relations during BIM implementation.

Social networks analysis in construction

Following the example of Pryke (2012), this study deployed SNA to represent and understand the relations emerging from SCM and SC partnerships that use BIM. The roots of SNA are found in sociometry, according to Granovetter (1973, p. 1360). Sociometry is a quantitative method to analyse the social interactions of a set of people via sociograms, i.e. graphs visualizing their social interactions and inter-relationships, created by social psychologist Moreno (1960). Wasserman and Faust (1994) defined Social Network as "social structure" of actors (nodes) connected by one or more relations (ties), such as friendship or alliance. The ties are either non-directional, and thus symmetric, or directional, and thus non-symmetric; symmetry reveals whether a relation is mutual (Wasserman and Faust 1994, pp. 149–150). Apart from structural metrics to describe networks, there are also mathematically founded SNA metrics, e.g. the centrality concept for understanding communication patterns in small groups by Bavelas (1950, p. 727). Graph theory has provided SNA first with a vocabulary to "label and denote many social structure properties", and second with the mathematical operations to prove theorems about the social structures (Wasserman and Faust 1994, p. 93). Scott (2012, p. 63) called Graph theory the "mathematical language" for SNA. Among key concepts of graph theory adopted for SNA are network density and degree centrality. Freeman (1978) specified the social implications of SN centralities. The betweenness, degree and closeness centrality of nodes represent control, activity and independence, respectively (Freeman 1978, p. 226).

Table 2. Taxonomy of studies applying SNA regarding the focus and the modelled entity.

Focus	Node	Tie (Link)	Scientific literature	SNA metric used
Intra-organizational	Employees	Awareness (informal)	Larsen (2011)	Network density
	Employees	Physical communication (formal and informal), also inter-organizational focus	El-Sheikh and Pryke (2010)	Degree centrality, closeness centrality
	Employees	Physical communication (informal), also project-based focus	Loosemore (1998)	Degree, betweenness and closeness centrality
Project-based	Employees	Physical communication (informal)	Chinowsky *et al*. (2008)	Betweenness centrality
	Employees	Physical communication (informal)	Alsamadani *et al*. (2013)	Network density, degree and betweenness centrality
	Employees	Digital communication (formal)	Hossain and Wu (2009) and Hossain (2009)	Network density, degree, betweenness and closeness centrality
	Firms	Hierarchical leadership (formal)	Solis *et al*. (2012)	Network density, centrality and structural equivalence
	Firms	Physical communication (informal)	Wambeke *et al*. (2011)	Degree and eigenvector centrality
	Firms	Physical (informal), digital communication (formal)	Thorpe and Mead (2001)	Degree centrality
	Firms	Knowledge (informal)	Chinowsky *et al*. (2010)	Network density
	Firms	Knowledge (informal)	Ruan *et al*. (2012)	Network density, degree, betweenness and closeness centrality
Inter-organizational	Employees	Physical communication (informal)	Pryke *et al*. (2011)	Network density, actor (degree) centrality and tie strength
	Employees	Financial incentive (formal)	Pryke and Pearson (2006)	Degree centrality
	Firms	Physical communication (informal)	Pryke (2004, 2005)	Degree centrality
	Firms	Performance incentives and contracts (formal)	Pryke (2005)	Network density, degree centrality
	Firms	Contracts (formal)	Park *et al*. (2011)	Network density, degree centrality
	Firms	Contracts (formal)	Chowdhury *et al*. (2011)	Degree, betweenness, closeness and eigenvector centrality
	Firms	Contracts (formal)	Sedita and Apa (2015)	Network density, average path length, betweenness and closeness centrality
	Firms	Contracts (formal)	Liu *et al*. (2015)	Degree distribution, average path length, and clustering co-efficient

According to Freeman (1978, p. 238), these metrics are networks' structural attributes and their interpretation greatly depends on context and respective theoretical starting points. These metrics have been prevalent among construction management researchers that use SNA.

SNA is a popular approach in construction management research. It has often been applied with a project-based focus, as construction projects consist of essentially "unstable networks that get re-initiated for each project" (Chinowsky *et al*. 2008, p. 806, Chinowsky *et al*. 2010, p. 453). The unit of analysis is either isolated social actors, that is social network, or firms, that is organizational network (ON). SNA was used by Thorpe and Mead (2001) to analyse communication among project teams from different firms and compare it to their use of project-specific websites (PSWS). Among their most interesting findings, it was observed that project teams circumvented traditional communication channels and hierarchy to speed up communication (Thorpe and Mead 2001). Chinowsky *et al*. (2010) used SNA to study information exchange in construction firms to reveal the relation between the actors' and the firm's performance. Other SNA studies focused on informal aspects, such as knowledge, trust and awareness (Morton *et al*. 2006, Chinowsky *et al*. 2008, Larsen 2011). Pryke (2002, 2004, 2005, 2012) applied SNA to analyse inter-organizational transactions as to information exchange, performance incentives, and contractual relationships, and revealed dependences between innovative procurement, new roles and communication patterns. These studies have demonstrated the applicability of SNA in inter-organizational settings to analyse formal and informal relations simultaneously. Table 2 summarizes and categorizes influential studies in SNA in construction, from peer-reviewed journals, such as the Journal of Construction Engineering and Management (JCEM), Construction Management and Economics (CME), and the International Journal of Project Management (IJPM). They are categorized as to their focus, nodes and ties analysed, to show the variety of research goals and methods for SNA in construction. After studying an initial sample of 42 publications, those in Table 2 were selected due to their affinity to SN-related and construction project organization concepts and this paper's scope.

Surprisingly, in Table 2, most studies contain data on physical communication collected retrospectively via interviews, questionnaires and surveys from participants (Table 2). Such data collection methods could further allow for "impression management and retrospective sense-making" (Eisenhardt and Graebner 2007). There are only a few studies (Hossain 2009, Hossain and Wu 2009) that measured actors' interactions using tangible data sources, such as interactions over digital means. Guo *et al*. (2013) also underlined the need for investigating the actor's interactions on digitally enabled infrastructures, rather than by analysing data collected via surveys. Charalambous *et al*. (2013), in an effort to demonstrate the redundancy of email-based communication in BIM-based projects, used SNA to represent the distribution of actions among project actors using online platforms. Data collection for SNA from online platforms minimizes informants' biases.

Table 2 shows that both formal and informal ties have been studied by using SNA. However, formal aspects, such as contractual relations, or financial and performance incentives, which are inherently tangible, are most suitable for analytical research methods such as SNA. Exceptions are also possible, as Buskens (2002) used SNA to evaluate trust and explore the structure of simplified networks where all actors were equally important. In Egan's Report (1998), contracts and other project documentation are "formal" relations pertaining to management and organization, whereas day-to-day communications pertain to "informal" aspects of management and organization. However, some contractual relations could be also classified as informal, such as long-term relations (Pryke 2012, p. 177). Similarly, whereas information exchanges are classified as "informal" relations, as they are implicitly and not explicitly contractually defined (Pryke 2012, p. 146), the information exchanges are not necessarily only informal (Pryke 2012, p. 17). In the context of BIM, where BIM learning and trust are informal aspects, the interactions over online platforms, such as PSWS, also known as common data environment (CDE), are formal collaborative relations, as they are explicitly prescribed in BIM execution plans.

Research gap and conceptual model

As shown in Table 1, there are few studies addressing BIM from an inter-organizational – or SC related – perspective focusing on a construction network across multiple tiers, from designers to suppliers. Simultaneously, SNA is a fruitful analytical method to analyse SC relations (Table 2) as multi-actor networks and not as hierarchical contracts, which are more rigid, uniform and unilateral (De Bruijn and Ten Heuvelhof 2008, p. 10). SNA studies could shed light on various formal and informal relations in BIM-enabled SC partnerships. BIM has been indirectly linked to the SCM philosophy by various researchers. van Nederveen *et al*. (2010) envisaged the need for including all construction actors in decision-making, e.g. suppliers and client, so as to play a more dominant role in design processes. BIM and SCM could be combined for design management, site management and cost management (Nummelin *et al*. 2011). However, there is sparse and contradicting evidence on the impact of combining SCM an BIM on inter-organizational performance. For example, whereas Navendren *et al*. (2014) observed a lack of SC integration, as some UK manufacturers were not convinced of the value of BIM investment, Dike and Kapogiannis (2014) reported on the "collapse of the traditional adversarial culture inherent in the UK construction" and indicated that early BIM adoption could facilitate inter-firm trust.

In the United Kingdom, the "intelligent" information flow, derived from BIM models, has been previously considered an enabler for SC integration (Cic 2011). Undoubtedly, as BIM has not yet reached a high level of maturity at an industry level (Kassem *et al*. 2015), its implementation entails a set of interdependent activities similar to the concept of "clusters" of multi-disciplinary teams operating in a non-hierarchical manner, e.g. "technology clusters" (Gray 1996). Governing such technology and work clusters is problematic for the industry, as those are incompatible with the "standard dyadic forms of contract in use alongside various partnering arrangements" (Pryke 2012, p. 60). Hence, a SN analytical approach for representing and understanding multi-disciplinary clusters, such as BIM-enabled SC partnerships, is needed for exploring the combination of BIM and SCM. After all, Whyte and Lobo (2010, p. 557) previously suggested that partnering and innovative contractual settings could provide an interesting setting to explore the implications of digital objects, such as BIM, for innovation and project coordination. To this extent, SNA is the vessel for analysing the combination of BIM with SC partnerships (independent variables) and especially exploring choices between their formal and informal aspects and their impact on SC performance (dependent variables).

Alongside formal agreements and top management's support, informal aspects of collaboration such as communication, consensus, culture, knowledge transfer and attitude to change, also play a role in integrating the multi-actor network (intermediate variables), which are not necessarily accompanied by formal structures. There is a need for investigating informal dimensions of BIM-enabled SC partnering, as although BIM carries the potential to transform inter-organizational collaboration (Dossick and Neff 2010), it cannot completely replace other IS (formal), such as email, databases and web-based platforms (Demian and Walters 2014). These informal BIM dimensions add to the complexity of formal relations and affect the chain's performance. Figure 1 illustrates the conceptual model of this study.

Based on the above, this study seeks to examine the relationships between formal and informal ties by asking the following Research Questions (RQ):

- (RQ1) What formal and informal relations of firms in BIM-enabled SC partnerships can be distinguished?
- (RQ2) How do choices about formal and informal relations of BIM-enabled SC partnering affect the performance of the SC partnership?

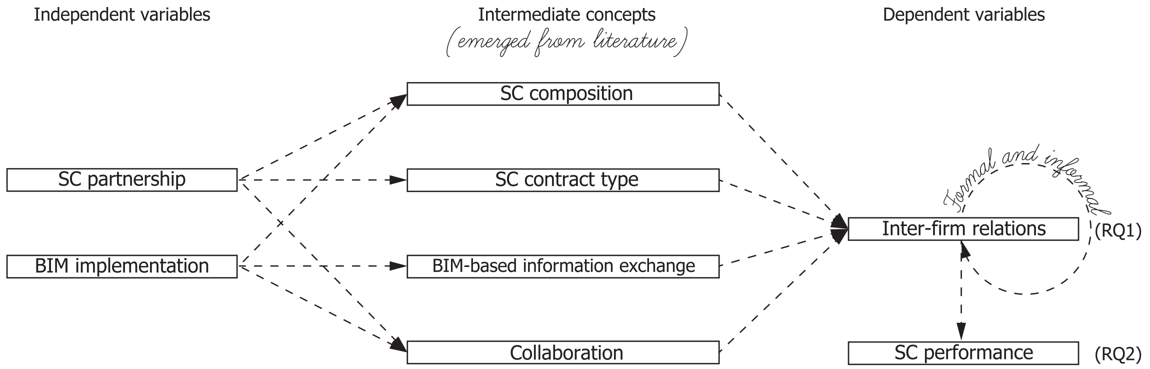

Figure 1. The conceptual model of the study and the relation between the research questions.

Methods

Mixed methods approach

Methodological rationale

Thinking in terms of systems originated from the need for responding to multi-dimensional problems beyond black-box approaches. The focus on operations research emerged during the interwar period. Systems thinking theories emerged soon after World War II and offered a more constructivist approach to the positivism of operations 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*. "Network" is a newer term than "System" and mostly relates to the representation of a set of things (nodes) and a set of relations (links), i.e. a system. Network Science in Social Science began with Granovetter's (1973) studies on ties among social groups. The construction industry has been described as a system or network of firms with an emphasis on their relations (Dubois and Gadde 2000, 2002, Bygballe and Jahre 2009). These networks exist at a project- or market level and are temporary or permanent. The main challenge of such networks is the complexity of numerous involved firms and their inter-relations (Gidado 1996, Winch 1998, 2002). The qualitative approaches to managing complexity in construction networks lack the ability to grasp the multi-faceted relations among firms.

Larsen (2011) recognized that for complexity, both a positivist approach, focusing on systems' structure and an interpretivist approach, focusing on actors, are needed. In SCM research, there has been a need for a more balanced approach between "inductive research methods (typically qualitative) in addition to deductive methods (typically quantitative)" (Golicic *et al*. 2005). After all, SNA, despite being considered a merely quantitative tool, has also been used for interpretative analyses (Loosemore 1998) or analysis of trust (Buskens 2002). In Table 2, SNA was primarily used in project-based studies. As this study focused on inter-organizational construction networks and particularly SC partnerships, it deployed SNA as a methodological tool to represent and understand them.

Mixed methods were applied, to balance deductive with inductive thinking. The mixed methods consisted of case study research, through qualitative data, and SNA and modelling, using quantitative data. The SN and modelling analyses (deductive) were used to describe, explain and compare explicit formal relations to informal inter-organizational structures. These relations stem from the emerging BIM-based collaboration and answer the formal part of RQ1. The empirical explorations of the cases (inductive) were used to describe and interpret the complexities of two BIM-enabled SC partnerships and answer the informal part of the first (RQ1) and second research question (RQ2).

Case study methodology

The overarching research method was case study research. The cases were selected for providing a "real-life context" to the study (Yin 1984). The focus was inter-organizational, i.e. the inter-firm relations. The case study design did not concentrate on "focal" firms of the SC partnership, e.g. contractor, but instead it devoted equivalent time to all partners. The number of interviewees was not proportional to the project scale; there were fewer interviewees in Case A. Despite being a research limitation, the lack of interviewees could also indicate lower SC integration in Case A. Whereas the unit of analysis was the firm – to explore the formal relations via SNA – to ensure a grounded understanding and avoid biases (Eisenhardt and Graebner 2007) employees from various hierarchical levels were interviewed for the informal relations.

Case study selection

Two cases of BIM-enabled SC partnerships in the Netherlands were analysed. The cases were cross-sectional studies of interaction episodes of the two chains, embedded in their time and space context (Gadde and Dubois 2010). The Netherlands was selected as the location for these analyses because of the popularity of BIM and SCM.

First, SCM and SC partnerships in the Dutch construction industry have been popular for replacing the traditional tendering processes (Vrijhoef 2011). The innovation of SCM in procurement processes lies in that simple and short documents are used to prescribe SC partnerships, i.e. framework agreements (Pryke 2002). These SC partnerships were based on pre-existing long-term relations that aim at increasing process and product quality. Second, BIM implementation in the Netherlands has been well advanced (Kassem *et al*. 2015). Thus, the existence of quite advanced levels of both SCM and BIM suggests a relevant locale for these explorations.

The two cases could be considered *polar* cases (Eisenhardt and Graebner 2007), due to their different SC strategies and contract types, as Case A deployed sophisticated SC contracts, whereas Case B used simple dyadic contracts. For both cases, however, the BIM implementation was quite advanced, deploying among others, collaboration over CDE, a requirement of UK BIM Level 2. The intention is to generate insights into a spectrum of BIM-using inter-organizational settings through the analysis of these extreme cases. For Flyvbjerg (2006), extreme cases usually "reveal more information because they activate more actors", rather than simply analysing mechanisms in similarly procured BIM-based projects. The deployed BIM-related and strategic processes of the polar cases could suggest steps for further integrating other BIM-enabled SC partnerships. After all, Bengtsson and Hertting (2014) claimed that findings from case studies could be generalized when "expectations about similar patterns [...] in similar contexts" take place, in this case of similar settings of BIM-enabled SC partnering. And although the cases are polar, they are still executed in a similar context.

Case study A was the construction of a multi-functional building complex, which consisted of three volumes with 255 residential units, offices, un underground parking and commercial spaces, located next to a canal, which induced logistical challenges. The contractor, client, heating and energy firms and the facility manager formed the SC partnership, in the form of a multi-party contract for 20 years, namely UAV-GC (Uniform Administrative Requirements for Integrated Contracts). Aside this contract, there were also bipartite SC contracts among various first- and second-tier actors. BIM was applied from Preliminary Design until Pre-construction, and thus, the span of these phases was the research time frame.

Case study B concerned a housing tower, with 83 housing units over a pre-existing shopping arcade, resulting in high technical complexity. The contractor had SC contracts with the architect, structural engineer, steel subcontractor and suppliers, e.g. windows, cladding and roof. BIM was applied from initiation until construction, and an "as-built" BIM would be delivered. The main difference between the cases was the type of contractual relations. Another difference between the two projects was their scale, given that the case A building was much larger. The diverse nature of polar cases could generate insights for a variety of projects. Table 3 summarizes the most distinctive features of the two analyzed projects.

Table 3. Description of cases A and B.

Aspect	Case A	Case B
Contract	Multi-party UAV-GC contract	Bipartite contractual relations stemming from the contractor
Portfolio	The contractor has a wide project portfolio	The contractor has a dry construction project portfolio
Architect	The architect was external to the partnership	The architect was internal to the partnership
Client	The client was internal to the partnership	The client was external to the partnership
Suppliers	The suppliers were hired at pre-construction	The suppliers were hired after Definitive Design
BIM use	BIM is used from preliminary design until maintenance	BIM is used from initiation until construction phase
Maintenance	UAV-GC contract including 20 years maintenance	No maintenance plans
Project scale	Large multi-functional project	Medium housing project
Energy	Special energy requirements	No special energy requirements
History	The partners have previously collaborated in three projects	The partners have previously collaborated in >10 projects

Empirical explorations

Data collection sources

Following the methodological rationale, explained in the previous subsection, various actors from the two selected cases were interviewed. In both Case A and B, within the engineering firms, three functions were interviewed to grasp the informal relations: project/tender manager, lead engineer and BIM modeller. In smaller firms, these functions were merged. Interviewing various functions within each firm contributed to acquiring additional insights into intra-organizational emerging functions. Table 4 presents these interviewees.

The data collection sources were as follows:

- Case documents (SC contracts and BIM protocols).
- Data from the project's website (CDE) on BIM-based information exchanges.
- Interviews with main project actors (Table 4) about the project and the SC.

Case study protocol

The interviews were semistructured and had consistent preparation and data handling. Before the interviews, all interviewees had the same information about study goals

Table 4. Interviewed firms and employees of Case A and B.

Case A			Case B		
Firm	Role/position	BIM user	Firm	Role/position	BIM user
Facility manager	Project manager		Contractor	Project leader	
Contractor	Site engineer	x		Site engineer	x
	BIM manager	x	Architect	Project architect	x
	Design coordinator	x		BIM modeller	x
Architect	Project architect		Structural engineer	Lead engineer	x
	BIM modeller	x	Mechanical engineer	Tender manager	
Structural engineer	Director			Site engineer	x
	BIM modeller	x		BIM modeller	x
Mechanical engineer	Project leader	x	Subcontractor B1	Project leader	
Supplier (Supp2)	Tender manager		Supplier (Supp3)	Director	
	BIM engineer	x		BIM modeller	x

and key concepts via a template document. Question handouts were administered at the start of the interview. The questions concerned the firms' motivations for engaging in SCM and BIM, the implementation of SCM and BIM during the projects and a reflection about performance. The interviewees were free to choose their preferred language for the interview, and all interviewees chose Dutch. The interviews were recorded to aid the transcription and translation. The firms welcomed the use of their input for research but preferred anonymity. The authors were not affiliated with these firms.

Research assistants transcribed and translated the audio recordings. The transcripts were analysed with qualitative analysis software (atlas.ti) by the first author, using descriptive, *in vivo*, and simultaneous coding (Saldanā 2009) in two coding cycles. Additionally, coword and frequency analyses were deployed to facilitate the summary of data and identify "inductive themes" (Krippendorff 2013). Correspondingly, the narratives were analysed based on the affinity of SCM- and BIM-related concepts per firm. The intention was not only to identify informal relations in the chains but also to explore the varying actors' perceptions on those.

Modelling explorations

Organizational network analysis method

SNA was used as a "natural complement" to the cases (Eisenhardt and Graebner 2007). According to Larsen (2011), SNA belongs to the positivist paradigm, whereas interviewing belongs to the interpretivist paradigm. However, although SNA seems more tangible and quantitative as a research method, the underlying intentions are simultaneously interpretivist, as it is "embedded in a positivist perspective with structuralist leanings" (Larsen 2011). SNA was used to analyse the multi-disciplinary firms (actors) and their relations (links), i.e. the organizational network (ON). SNA was used to model and analyse the inter-organizational networks based on their contracts, drawing upon works on contractual analysis (Pryke 2002, 2005, 2012). Node degree centrality and weighted degree were calculated using Gephi software (Bastian *et al*. 2009). Degree centrality was used for identifying the most contractually active/connected nodes (Freeman 1978) in the networks, and weights were attributed to reflect not only on the number of but also on the strength of contractual relations, particularly concerning key actors in the chains: clients, contractors and architects. SNA analysed the contractual relations (from document analysis) and the BIM-based information exchange (from IFC exchanges over the CDE) for the BIM-enabled SC partnerships. The informal relations of collaboration were analysed quantitatively (in frequency matrices) and qualitatively (within narratives) through the afore-described interviews, as those could not have been captured digitally. According to Miles and Huberman (1994, p. 266), having multiple sources of data and employing various data analysis methods contributes to research triangulation and credibility.

Temporally indexed organizational networks emphasizing on information flow

The information exchanges were measured over the CDE, rather than by using post hoc questionnaires, to minimize retrospective bias (Eisenhardt and Graebner 2007). A complementary to the SNA approach was undertaken to include the non-contractual, but BIM-based interactions. Apart from using case documentation, such as contracts and BIM protocols, the actors' web-based interactions over the PSWS or CDE – as specified in the UK Publicly Available Specifications 1192, to coordinate project information – were analysed. This data source incorporates the timing parameter, which is important for understanding the evolving nature of multi-actor construction networks.

Through the CDE, apart from organizational and process data about the cases, building information was also extracted. The CDE stored the information about responsible actor, date and type of shared building information. The building information was obtained from the uploaded IFC files. The IFC files were subsequently analysed with the NIST IFC File Analyzer (Lipman 2011), which provides

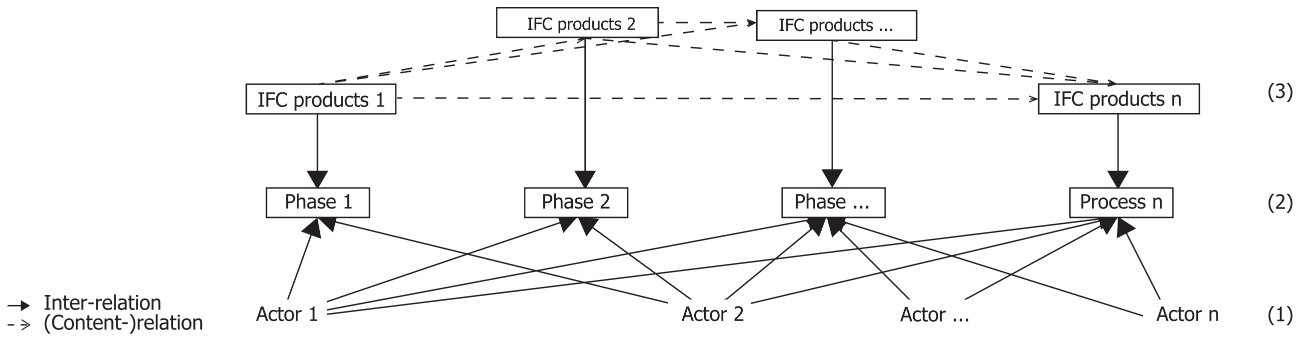

Figure 2. Relations among actors, phases and building information from the CDE.

the types and quantities of the used BIM entities. The data were harvested in spreadsheets and analysed using descriptive statistics in a spreadsheet processing software. The data were collected from definitive design (DD), technical design (TD) and the pre-construction (Pre-C) phases, when engineers' and suppliers' information was merged. The data for the two cases were collected over a period of 11 and 8 months, respectively. The DD, TD and Pre-C phases lasted for the cases 3, 2, 6 and 3, 1.5, 3.5 months, respectively. These phases are equivalent to RIBA Plan of Work (Sinclair 2013) "Developed Design" and up until the end of "Technical Design" phase.

The CDE provided data on the ON, processual-, product-based (IFC) information and was analysed to illustrate the complexities of BIM-enabled SC partnerships. Through this analysis inter-firm relations and BIM-based information exchanges were captured (Figure 1). Figure 2 illustrates how the relations among the (1) actors (ON of the cases), (2) time indexing parameter (from the CDE) and (3) exchanged BIM-based information (analysed IFC files) were defined. As modelling is an abstraction of reality per se, aiming at identifying, rationalizing, and analysing inter-relations among concepts, these afore-mentioned three concepts were combined to guide the analysis of the CDE. Subsequently, an additional goal was to offer new insights into network theory and its applicability to project-based SC partnering research.

Findings

Contractual relations

Four types of contractual relationships were observed in the cases. In increasing order of commitment, these contracts were as follows: (a) normal tendering contract, (b) preferred partners, (c) SC framework agreement and (d) UAV-GC contract. The UAV-GC – used in Case A – is an integrated form of contract, which has a strong project-based focus and could in some projects resonate with prior partnering commitments and further encourage future long-term relations. The UAV-GC is similar but involves more explicit financial agreements than a design, build and maintain contract. UAV-GC contracts are usually created among clients, consultants and contractors to provide re-usable information across projects and inspire long-term goals, e.g. maintenance. The actors of Case A had previous collaborations, but the sophisticated UAV-GC contract was a new formal structure in their SC. The SC framework agreements were short two-party documents that seem simple (Pryke 2002) and focus on their long-term collaboration for a pre-agreed duration, and further either on price or quality aspects or both (Macneil 1977). In Case A, BIM was a contractual requirement from most involved firms. In Case B, the SC agreement also contained a BIM clause for engineers. In both cases, the contractors also held agreements with some engineers, subcontractors or suppliers, who formed a pool of "preferred partners." These preferred partners were firms supposedly already culturally aligned with the contractors. The final selection of preferred partners was made based on the availability of culturally compatible individual employees. Figure 3 illustrates contractual relations (top) and type of exchanged BIM-based information (bottom). The tendering contracts are shown as arrows pointing at the tendered party, and the partnerships are shown as lines weighted according to the longevity of the relationship. Table 5 presents the network analysis of the involved actors based on their degree centrality and weighted degree centrality.

The two cases had different contractual schemes. In Case A, the SC had a strong project-based focus, given that the contractor, the client and two installation firms formed the UAV-GC contract, among four parties (see Figure 3 and Table 5). The architect was traditionally tendered by the contractor. The other actors were either tendered or had long-term contractual agreements with the contractor. In Case B, the partnership was formed only by "dyadic" relations initiated by the contractor. The architect had an exclusive relation with the contractor, which based on Table 5, suggests greater activity and connectivity in the network (Freeman 1978, p. 226). The contractor also had

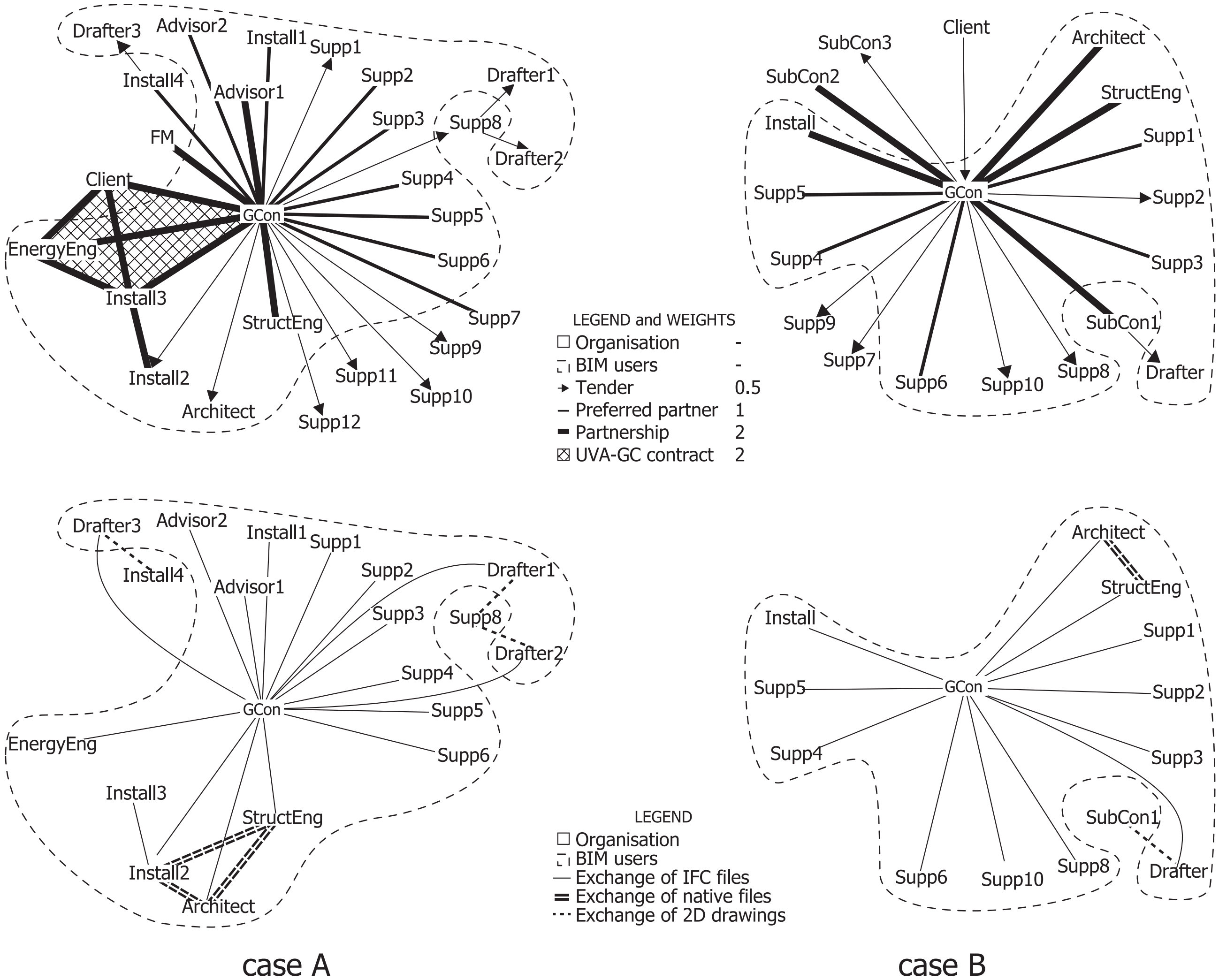

Figure 3. Contractual relations, BIM users (top part) and type of BIM-based information exchange in cases A and B (lower part).

Table 5. Node degree centrality, weighted centrality (see Figure 3) and BIM use per actor.

	Case A				Case B		
Firm	Degree centrality	Weighted degree	BIM user	Firm	Degree centrality	Weighted degree	BIM user
GCon(tractor)	23	31.5	x	GCon	17	20.5	x
install3	4	8	x	SubCon1	2	2.5	
Client	3	6	x	Arch	1	2	x
EnergyEng	3	6	x	StrEng	1	2	x
Supp8	3	1.5		InstEng	1	2	x
Install4	2	2	x	Supp1,3	1	1	x
Install2	2	2.5	x	Supp2	1	0.5	x
Advisor1,2	1	2	x	Client	1	0.5	
StructEng, Install1, Supp2,3,4,5	1	2	x	Drafter	1	0.5	x
Supp1,6	1	1	x	Supp4,5,6,8,10	1	1	x
Supp7	1	1		Supp7,9	1	1	
Supp9,10,11,12	1	0.5		SubCon2	1	2	
Architect, Drafter1,2,3	1	0.5	x	SubCon3	1	0.5	x
FM	1	2					

an exclusive relation with the structural engineer, but this was not reciprocal, i.e. the structural engineer worked also with other contractors. From the centralities of Table 5, the contractor of Case A is more active than the contractor of Case B, due to the quantity (degree centrality) and quality (weighted centrality) of contracts held. Accordingly, the positions of clients and architects in the two cases are completely antithetical: the client is more active in Case

A than Case B, and the architect less active in Case A than Case B (see Table 5).

The curly line in Figure 3 encircles the BIM-using actors to indicate the so-called "BIM-chain" consisted of BIM-using actors who applied it for delivering their services. The agreements upon BIM protocols were reached differently in the cases. The BIM protocol of Case A was created by the contractor, who had an in-house BIM manager, responsible for all BIM-based projects and an additional project-based BIM coordinator. The BIM protocol and the BIM implementation strategy of Case B were codeveloped by the SC partners, who were long-term partners with the contractor. The two BIM protocols had similar document structure and included introduction, project scope, scope of BIM and SCM, phasing and work organization. Although both BIM protocols included the actors' details, the BIM protocol of Case A included detailed responsibilities of the parties pertinent to communication and work division. These differences imply a "top-down" BIM implementation in Case A and a "bottom-up" BIM implementation in Case B. The lower part of Figure 3 shows the type of information exchanges among the BIM-using actors. In Case A, frequent exchanges of native BIM files took place (Figure 3, double lines). In both cases, some firms outsourced BIM to third parties (dashed lines).

Analysis of the BIM-based information exchange

The analysis of the files from the CDE was performed at two levels regarding quantity and content of exchanged information, drawing upon the conceptual model of Figure 2. First, the quantity of the files uploaded on the CDE was analysed as to organization and intensity of information exchanges, as illustrated in Figure 4. The diagrams on the top indicate the number of IFC files uploaded per phase from each actor. The differences of file numbers and versions of the two cases are due to the projects' complexity. The project of Case A was divided into four components (three buildings and one parking garage), which were developed and managed consecutively. In Case B, the project was smaller and the building project information was organized into two components: the housing volume and its connection to pre-existing structures on site. In both cases, the engineers and suppliers created as many different files as the number of different building systems they were designing or producing. The interactions were

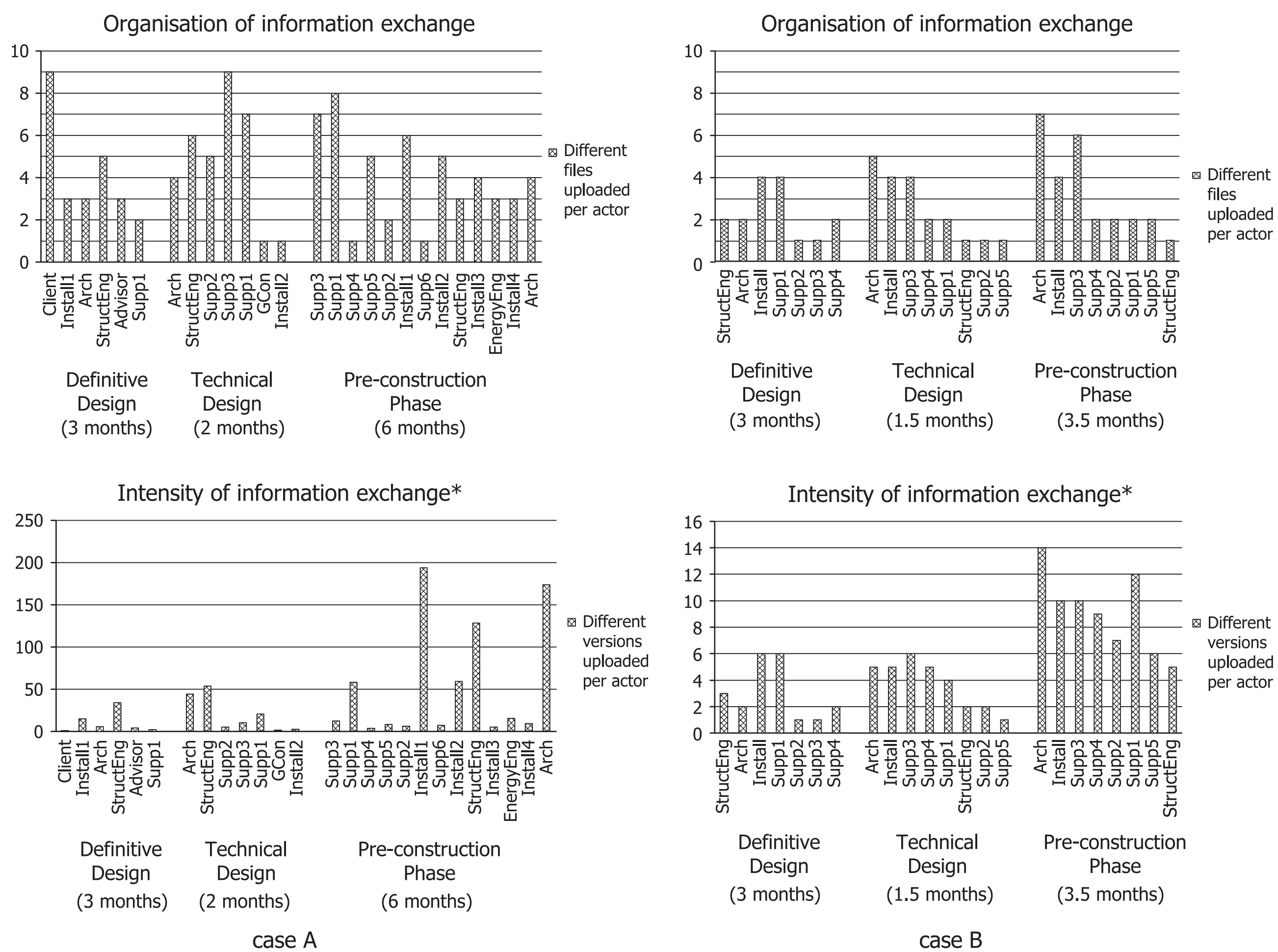

Figure 4. Organization (files per actor) and intensity (versions per actor) of BIM-based information exchanges (IFC) in Cases A and B.
*Note that the axes of the diagrams from Case A and Case B have different scale.

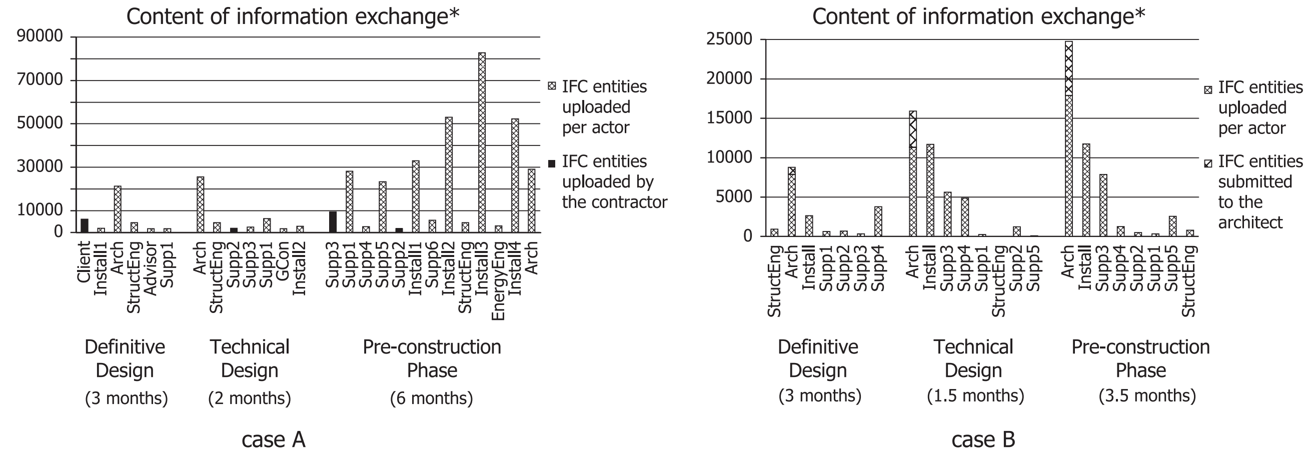

Figure 5. Analysis of the content of information from each actor per phase.
*Note that the axes of the diagrams from Case A and Case B have different scale.

more intense (frequent) in Case A. This difference could be explained not only from the project's organization but also from the special energy demands (solar and geothermal) that required multiple reviews among the involved actors (see Table 3). Moreover, Case A had four different installation firms (energy, sanitary, electrical and mechanical engineers); while Case B had no special energy demands and only one integrated firm provided all installation services: mechanical, electrical and plumbing (MEP).

Second, another level of analysis of the IFC files from the CDE concerned the content of the exchanged information. The number of the IFC entities per discipline indicates the division of work among the actors. Figure 5 illustrates the analysis of the content of information exchange. In Case A, the federated model consisted of 13 segregate models from various actors, while in Case B from eight. In Case, A, an additional combination of proprietary files was made with information from the engineers. This analysis revealed two different types of information exchange among the SC actors. In Case A, the contractor uploaded information on behalf of suppliers. In Case B, the architect was keen to integrate information from some suppliers directly to their architectural model, bypassing the file uploading process on the CDE.

Informal aspects of BIM-enabled SC partnerships

The reflections from the cases were analysed as to informal aspects of communication among project partners and particular in connection with BIM implementation. In Case A, the communication took place through the exact channels described in their contracts. The architect, the mechanical and the structural engineer always communicated via the contractor, with whom they had contracts or made sure to carbon copy them. However, the supplier, who had a "chain contract" (SC framework agreement) with the contractor, sought direct channels to communicate with other suppliers or engineers: "and we must call other suppliers to solve problems with other suppliers. We should not expect to have all the communication pass through the contractor" (Supplier-Tender Manager-A). Surprisingly, this communication ran solely either among the engineers or suppliers, respectively. The engineers (architect, structural and mechanical) had no relations with the suppliers. The supplier, structural and mechanical engineers often discussed the partnership as an approach to manage the financial uncertainties and build trust. However, the contractor admitted that "at this project the supply chain cooperation has not happened well because it has been approached from the money perspective" (Contractor-Design coordinator-A). The architect held a depreciated role in the project because they were hired to develop an existing concept design of a previous architectural firm. The architect agreed that they did not have explicit agreements on the design and the materials with the contractor. The contractor should "actually have agreed on the details in the earlier stages with the architect" (Supplier-BIM Engineer-A). Regarding the performance of the SC, the discussions were at a strategic level: "there is a lot expected of us that normally cannot be expected to be performed; it is a quite one-sided story on behalf of the contractor to us but also towards the other parties" (Mechanical-Tender Manager-A). In the contractor's firm, they reflected and admitted that "eventually to go well the collaboration process was more important than just money" (Contractor-Design coordinator-A).

In Case A, BIM was adopted to potentially facilitate the building maintenance, as prescribed in the UAV-GC contract. Concerning BIM implementation, the contractor admitted that although a BIM protocol was defined early in the process, the respective details, such as the levels of detail (LoD), standards used for details of information exchange were "not unanimously agreed among the parties" (Contractor-Design coordinator-A). However, the role of the BIM coordinator (firm level) and BIM manager (project level) was well-defined. The contractor firm's BIM knowledge "has gone up considerably, and they [the BIM coordinators] may also spend time on our subcontractors to solve export problems physically, or they come here" (Contractor-Design coordinator-A) for problem-solving beyond project's scope. Therefore, the BIM challenges stemmed mostly from inter-organizational and contractual relations, rather than technical BIM issues. The suppliers were not considered strategic by the contractor and involved late in the project. Thus, given that different clash sessions were hosted per building unit and among disciplines, not all parties were familiar with each other. "We need to have permanent contact persons in the companies; this is where the SCM and BIM should have been intertwined" (Supplier-BIM Engineer-A). Whereas some suppliers had advised the contractor earlier during the tendering stage, they were informed to start working on the project at a short notice "and the information was not far yet" because meanwhile they had not been briefed accordingly (Supplier-BIM Engineer-A). Finally, the project was behind schedule due to changes from a Design-Build to a UAV-GC project, by tendering the new architect and imposing various special energy requirements. Some colocations took place only after the start of construction to solve problems on site.

In Case B, the communication took place through channels beyond the formal contractual agreements. The SC partnership was formed having the main contractor as a node connecting the various engineers and suppliers (Figure 3). However, the communication usually bypassed the contractor and was directed from various partners towards the architect, via informal channels, e.g. email or telephone: "So it is not only in meetings, questions are also asked in e-mails. Or by phone; I now need something, then you call each other. We are also very used to come together to sit down and discuss things with each other. In many ways, the information goes back and forth" (Project Architect-B). The partnering relation between contractor and architect made the latter more approachable to other partners: "So our real role [towards the partnership] is only good collaboration and making clear agreements about that. I know that sounds crazy to be our only role" (Project Architect-B). There was a recurring pattern of statements about the higher value of quality and trust over price, among the architect, structural engineer and steel subcontractor. The legal and financial commitments were not jeopardized. Among reported challenges, was the "old-fashioned" client: "If I look back at other SC partnerships, the client also has to participate in it. We miss that in this project" (Mechanical-Site Engineer-B). Regarding the performance of the SC, they reported that several informal aspects could be improved, such as even earlier discussions, and more frequent co-locations: "All parties need to work regularly together, and everyone gives their input" (Mechanical-Tender Manager-B).

In Case B, BIM was adopted because, given the project complexity, the partners "did not dare to do the project in a traditional way" (Project Architect-B). Concerning BIM implementation, most partners claimed that clearer scope about BIM was necessary, such as LoDs and the BIM coordinator's role, which was changed during the project from the architect's firm to an in training BIM-coordinator from the contractor's firm. Although "*this project, which was for the contractor one of the first times they used BIM, it was a little ad hoc*" (Structural Lead Engineer-B), it was more advanced than previous projects where they "did not so do a super BIM model and had to improve a lot at the end, in this project it is better and (…) a lot of things have already been solved" (Subcontractor-Project Manager-B). The partners acknowledged their equal share to design input and codeveloped knowledge, not only of the studied project but also from carrying experiences about "BIM implementation from other contractors via the external BIM knowledge" that their SC partners carried (Contractor-Project Manager-B). The suppliers were involved early in the project: "We modelled the building permit application together with the sub-contractor and only after that the other suppliers modelled" (Architect Modeller-B). Thus, the suppliers developed higher responsibility for their deliverables, since these controls were BIM-based and semiautomated, rather than contractor-lead manual checks. Some pressure in scheduling and ambiguity among the project phases were reported as well.

The narratives confirmed (triangulated) and gave qualitative insights into some of the formal aspects mentioned in the previous sub-section, and in particular regarding the activity and connectivity of key actors in the chains (contractors, clients and architects) and specified an additional set of informal aspects that contributed to the performance of Cases A and B. Table 6 presents recurring concepts across the narratives from observations, analyses and reflections the interviewees made about the projects. The concepts are further classified as to BIM- or SCM-related, respectively, according to whether the concepts co-occurred with them. This numerical data aims at guiding the discussion of the actors' narratives in a structured manner, around emerging "inductive themes" (Krippendorff 2013), rather than pre-defined or top-down selected themes. The concepts with a different frequency between the two cases were further considered insightful for the chains' and projects' performance. Moreover, Table 6 reveals differences in perceptions of these concepts among the different disciplines involved in the two cases.

Table 6. Occurrences of recurring concepts across the narratives of the cases' interviewees.

		Case A					Case B					
Topic	Concepts	Architect	Structural	Mechanical	Contractor	Supplier	Architect	Structural	Mechanical	Contractor	Supplier	Subcontractor
SCM	Legal commitments	13	7	9	16	7	10	12	7	12	4	13
	Equal partners-SCM	5	2	8	6	4	1	5	5	0	1	6
	Price-orientation	13	6	18	25	6	7	3	4	12	1	12
	Quality requirements	5	1	4	2	1	1	4	3	6	2	6
	Previous experiences	2	3	9	15	10	4	10	4	8	1	13
	Safe atmosphere	2	3	13	2	14	2	1	5	4	0	13
SCM and BIM	Early discussions	2	5	10	5	15	13	6	14	18	2	5
	Shared learning	3	8	10	35	13	9	11	7	18	3	16
	Informal communication	5	10	9	12	19	3	9	8	3	5	5
	Joint responsibility	10	3	6	11	11	12	5	4	6	0	9
	Partner selection/investment	6	5	5	15	8	4	2	2	10	5	5
	Collaboration (together)	8	8	3	6	10	4	18	6	19	8	17
	Clear scope	13	5	6	17	2	9	10	3	14	2	3
	Consensus	6	2	0	1	7	11	2	7	1	1	6
BIM	BIM clash controls	5	6	1	5	5	1	5	4	6	3	2
	BIM coordinator	5	3	0	3	3	1	3	1	4	3	1
	BIM protocol	4	1	0	12	1	1	1	0	0	0	0
	BIM agreements	21	13	1	19	1	2	6	2	10	2	1
	Common Data Environment	2	0	4	1	4	0	1	0	5	2	0
	Colocation	2	0	0	1	1	3	3	6	5	1	3
	Continuous phasing	5	1	6	7	4	3	0	2	4	1	2

Table 7. Summary of formal and informal relations of case A and B.

Dimension	Case A	Case B
Formal	The overall project planning was decided from the top management of the UAV-GC contract	The construction plan was decided in pull-planning sessions among the suppliers
	BIM competency was a factor of tender award	Cultural alignment was a SC selection criterion
	The BIM clash sessions were held per building unit and discipline; many federated models	The BIM clash-sessions were held at a contingency level; only one federated model
Informal	The actors focused more on the project	The actors focused more on the SC partnership
	The BIM collaboration process was pre-defined	The BIM collaboration process was flexible
	The engineers never conferred with the suppliers	The communication extended across multiple tiers
	The BIM protocol was detailed but not followed	The BIM protocol included basic agreements
	Colocations took place only to troubleshoot problems that emerged on site	Regular colocations of the team was encouraged
	The use of informal communication channels was minimal and always through the contractor	The use of informal communication channels was highly encouraged across multiple tiers

Two types of BIM-enabled SC partnerships

The two cases were selected not only based on their affinity to SCM and BIM but also as polar cases with distinct features. Their comparison could generate insights into configurations for BIM-based projects and SC partnerships. Table 6 summarizes recurring concepts from the case participants' reflections, and Table 7 contains the most divergent observations from the cases. Among the formal aspects that influenced the cases' performance, was the relation/position of certain key actors within the SC. The "old-fashioned" client added to the unclear scope and changes in Case B, whereas the internal SC position of the architect contributed to the integration of the engineers and suppliers and encouraged informal communication. However, in Case A, the architect did not play a central role in the collaboration. In both cases, the actors felt pressure to meet the deadlines. The time pressure in Case A was caused by the late involvement of the suppliers, whereas in Case B, they were involved early. Concerning informal inter-firm relations, Case B was engaged in colocations and informal communications that bypassed the contractual relations. Finally, there had been no clear vision for a future collaboration with the partnership of Case A, while the SC of Case B had been already planning their next project. Overall, it could be assumed that Case A was more formal, e.g. transactional, contractual, price-driven, whereas Case B was more informal, relational and collaboration-driven.

Discussion

Asymmetrical relations in BIM-enabled SC partnerships

Both cases displayed asymmetries between formal and informal aspects of BIM-enabled SC partnerships (RQ1): the formal contractual agreements did not correspond to the informal flows of communication and collaboration. On the one hand, Case A had a sophisticated UAV-GC contract, which could instigate further SC integration, and various formal relations among preferred partners (Figure 3); however, the communication was not extended across multiple tiers (Table 7). On the other hand, Case B entailed a few bipartite SC contracts and preferred partnerships stemming from the contractor (Figure 3), but surprisingly, the emphasis was placed on collaboration and on informal communication channels that bypassed the contractor (see quotations of Project Architect-B) and were based on permanent contact persons across firms (Table 7). The latter conforms with Bresnen and Marshall (2000, p. 235) who questioned whether partnering can be actively "engineered" by simply applying contractual techniques and claimed that exploring the partnering inter-relations requires the analysis of both formal and informal aspects. The narratives of Case B implied a safe atmosphere (Table 6) and subsequently a shift towards "high-involvement" relations in construction (Gadde and Dubois 2010) (see mid-part of Table 6). The only indication of low integration in Case B was that increased client's involvement was additionally desired (see quotations of Mechanical-Site Engineer-B). Although both cases had long-term contracts, Case A was primarily based on formal relations, i.e. it was "transactional", whereas Case B relied on equal partners' input to achieve consensus, instigate higher project quality (Table 6) and reach SC integration, i.e. it was "relational" (Leuschner *et al*. 2013). Resulting from the above, some propositions or strategies (S) for initiation of BIM-enabled SC partnerships are as follows:

- (S1) Defining the partnering scope, i.e. "transactional" versus "relational", facilitates joint understanding and application of BIM-enabled SC partnering;
- (S2) Education about BIM and SCM visions of clients supports their participation in BIM-enabled SC partnering.

This "transactional" or "relational" character outlined the chains' BIM implementation. Case A, which had more long-term contractual relations than Case B (Figure 3 and Table 5), focused mainly on selecting SC partners based on BIM competency (Tables 6 and 7). However, in Case B not all strategic partners were BIM users and BIM adoption was considered a gradual shift in their practices, which was managed by frequent co-locations, denser collaboration and consensus-seeking decision-making (Tables 6 and 7). Therefore, whereas BIM becomes a prerequisite for suppliers' selection (Mahamadu *et al*. 2014), the composition and function of the BIM-chain depends on the either transactional, or relational nature of the SC partnership (see Table 7).

An unexpected finding was that in Case A, an asymmetry was also observed between engineers' and suppliers' formal and informal relations, who were not strategic SC partners (Figure 3). The suppliers focused more on informal SCM concepts, e.g. past experience, joint responsibility and need for collaborative work (Table 6), than the engineers, who reflected more on informal aspects of BIM implementation, e.g. BIM-related LOD agreements, and BIM's impact on project phasing. Whereas the sample is small, different perceptions of BIM-enabled SC partnering manifested between engineers and suppliers that probably originate from the longer history of SCM in suppliers' culture (Fernie and Tennant 2013, Gosling *et al*. 2015), rather than the engineers'. The engineers were primarily attracted to the concept of BIM and the suppliers to SC partnering. Drawing upon the previous two paragraphs, the following strategies are suggested for fostering BIM-enabled SC partnerships:

- (S3) BIM-competence partner selection criteria support the corporate compatibility of BIM-enabled SC partnerships;
- (S4) The diffusion of SCM philosophy among first-tier actors, e.g. engineers, develops the inter-firm informal relations in BIM-enabled SC partnerships.

Based on the previous, there are two complementary sets of strategies for BIM-enabled SC partnerships for minimizing the asymmetries at the strategic decision-making level of the chains. First, regarding the initiation of the partnership, emphasizing on the chain's scope and, if necessary, educate on the common scope across all actors is necessary for engaging them. Second, concerning the implementation of SC partnering, selection and continuous re-evaluation and diffusion of the partnerships' shared scope is necessary for actively ensuring symmetric relations.

The impact of BIM-enabled SC partnering on the chain's performance

Formal aspects of BIM-enabled SC partnerships, e.g. contracts and CDE use, proved to be crucial but not sufficient to manage project complexity and improve SC performance (RQ2). However, informal aspects of the BIM-enabled SC partnerships, such as early discussions, communication across multiple tiers and colocation provided complementary structures to support the partnership's and project's performance. Whereas both cases had long-term contractual agreements, these formal aspects could not predicate SC performance. In Case A, the contract type was sophisticated and involved numerous actors; however, this was not sufficient to engage the whole partnership (Table 3). This could be potentially due to the weak role of the architect, who was external (tendered) to the partnership. Thus, the partnership of Case A remained largely transactional and did not further integrate.

In Case B, earlier discussions took place (Table 6), and the suppliers were involved after the definitive design phase (Figures 4 and 5). The early discussions across first-tier (engineers) and second-tier (suppliers) actors increased the interactions among the project team and incited informal aspects of partnering. The early involvement could be evidence of a shift where the suppliers would assume a more dominant, rather than reactive role in design (van Nederveen *et al*. 2010). However, as the client rarely participated in early discussions of Case B, the adversarial culture could not be avoided (El-Sheikh and Pryke 2010). Whereas early actors' involvement has been deemed possible for BIM implementation (Eadie *et al*. 2013), an additional long-term SC partnership relation, and particularly *relational*- rather than *transactional*-oriented, could support BIM and encourage further SC integration. Drawing upon the cross-case comparison, the next "strategic" courses of action are proposed:

- (S5) Unanimous decisions about BIM scope, protocol, standards and CDE complement the formal contractual relations in BIM-enabled SC partnerships;
- (S6) Participation of architects in the BIM-enabled SC partnership is crucial, as their input in BIM work is irreplaceable;
- (S7) Early involvement and discussions with project suppliers increases project and SC performance as they become codesigners and cocreators.Whereas BIM competency was a partner selection criterion for Case A, it was apparently not sufficient for successful BIM implementation (Figure 3, Table 6 and 7). In Case A, the acquired BIM knowledge was well circulated within the contractor's firm (see quotations of contractor-design coordinator-A) but did not advance BIM knowledge across the other firms. This could be yet another indication that BIM implementation requires support from informal relations, beyond contracts, such as early discussions, frequent and strategically placed co-locations (Dossick and Neff 2010) and an inclination for shared (knowledge) learning across the chain (Whyte and Lobo 2010). The frequent colocations facilitated the integration of BIM-enabled SC partnering. This practice took place

in Case A after the start of the construction, where the partners were gathered once a week on-site for problem-solving. In Case B, the frequent use of colocations supported the partners' informal communications and BIM-based collaboration (Table 6 and 7). Desiring even more frequent colocations (see quotations of Mechanical-Tender Manager-B) indicates the need for consciously aligning these colocation practices with BIM implementation. Gosling *et al*. (2015) have shown how strategic partnerships involve their partners directly through activities such as training programmes, shared technology and colocations, all of which present an opportunity to increase performance in BIM-based projects. Finally, the following "operational" strategies are suggested:

- (S8) Frequent and wisely strategical colocations among multiple tiers support the development and cultivation of informal inter-firm relations;
- (S9) Deploying BIM-learning sessions for project-based and partners' development purposes enable continuous attainment BIM-related objectives.

Apart from the strategic-level decision-making, which could be supported by the strategies proposed at the end of the previous subsection, complementary courses of action (strategies) could minimize the asymmetries at the operational level of the partnerships. First, a balanced approach in the composition of actors and communication structures is necessary for engaging all project participants. Second, an emphasis on joint processes for work (colocations) and learning could ensure the actors' continuous engagement.

Emerging functions and structures in BIM-enabled SC partnerships

The studied BIM-enabled SC partnerships identified emerging functions and structures. The BIM managers and BIM coordinators (functions) were responsible for defining BIM protocols and execution plans (structures) collectively with the other disciplines and federate the segregate IFC models. These emerging functions can be categorized as more informal than formal. Whereas they used documents to define their agreements, their functions pertained more to informal partnering relations such as communication, previous common experience or shared learning (Table 6). The BIM coordinator and BIM manager roles were functions vaguely defined across the cases. In Case A, there were both a firm-based BIM manager and a project-based BIM coordinator in the contractor's firm, whereas, in Case B, these roles were performed by a BIM coordinator in the architect's firm and an in-training BIM-coordinator in the contractor's firm. Undoubtedly, the architect's model was the basis for the work of the other partners (Figure 4). However, the architect's firms had varying roles and responsibilities in Cases A and B, depending on their contractual obligations and their actual input. This difference could later suggest a reconfigured SC partnership with more strategic actors in the "BIM-chain", such as the architect, who could additionally facilitate the informal communication beyond their contractual obligations (see quotations of Project Architect-B). In Case B, the architect was more proactive, held informal communication with partners from many tiers and was also responsible for integrating information from non-BIM using actors (Figure 4 and Table 7). These narratives also concur with the findings of Gu and London (2010) that design disciplines were more keen to engage in a collaborative culture than other disciplines. The architects' contribution to the BIM process extended beyond their technical tasks, included more informal tasks, which is in direct contrast to the traditional perception of their role (Higgin and Jessop 1965).

The BIM protocols were emerging flexible structures that pertained to operational and tactical decisions, and although elaborate, did not include aspects such as standards, codes, phasing, and responsibilities across the project lifecycle. Rezgui *et al*. (2013) stated that the BIM actions from various disciplines at different lifecycle stages are crucial for governing the BIM process. In Case A, the phasing was obscure because the actual timelines did not attend the prescriptions set on the BIM protocol (Figure 4). This mismatch could be explained because the contractor alone prepared the BIM protocol and it was not unanimously accepted/codeveloped by all partners (see quotations of contractor-design coordinator-A). To this end, the flexible and high-level BIM protocol of Case B provided resilience to their BIM chain. The BIM process was supported by extra informal communication means, such as emails, and phone calls. This confirmed the findings of Demian and Walters (2014) that informal communication through email is irreplaceable (see quotations of Project Architect-B). Thus, balanced formal and informal structures are required to govern BIM-based collaboration.

Another unexpected finding of the study was around the CDE use that confirms the findings of Thorpe and Mead (2001) as to being a means to circumvent the traditional – or contractually defined – communication channels and to support storage and organization the multi-disciplinary information required for BIM-based projects. The analysis of the CDE illustrated how the initial architectural model in Case A, was gradually reduced in size across the various design-related phases, by being gradually replaced by models prepared by other disciplines (Figure 5). In Case B, the architect was incorporating information from non BIM-using partners, and their model grew in number of entities (Figure 5). Again, this is in direct contrast to the traditional perception of various actors' contribution (Higgin and Jessop 1965), as currently in the BIM era, their contributions change constantly throughout the "model development" phases. Using BIM protocols and CDE would require additional informal aspects pertinent to partnering to be effective, such as seeking consensus, accepting joint responsibility and having long-term objectives for shared learning (Table 6).

Research implications

Theoretical contribution

Both tangible and intangible constructs from various data sources (contracts, CDE, interviews) were analysed to answer the research questions about what formal and informal relations of firms can be distinguished in BIM-enabled SC partnerships (RQ1) and how choices about formal and informal relations of BIM-enabled SC partnering affect the performance of the SC partnership (RQ2). Indeed, exploring partnerships' inter-relations, requires the analysis of both formal and informal aspects (Bresnen and Marshall 2000, p. 235), which necessitates a combination of data sources. This combination aligns with debates about balancing inductive with deductive thinking in SC research (Golicic *et al*. 2005), and particularly by examining both qualitative and quantitative data. Furthermore, as BIM implementation has a socio-technical nature, a mixed method was pursued. The formal relations (contractual relations, online exchange of BIM-based information over the CDE) were deduced from SNA, modelling, and quantitative data and the informal relations (such as collaboration, consensus, shared learning, safe atmosphere and joint responsibility) were induced from the narratives of cases' participants (answer to RQ1). Overall, the qualitative data enriched the quantitative data and analyses and vice versa. First, insights into the involvement, division of work and processes of various actors could not have been obtained by interviews consistently. Second, the emergence of recurring constructs, such as *consensus* and *safe atmosphere* (Table 6), could not have been identified via analytical approaches and quantitative data. From the cross-case analysis and drawing upon the qualitative data, the "transactional" (Case A) and "relational" (Case B) approach that these formal and informal relations affected the performance of the SC partnerships was identified (answer to RQ2). This is corroborating evidence on the additional relational integration that the traditional operational perspective on SC integration needs. (Leuschner *et al*. 2013). The contribution of this approach would be new insights into SCM concepts, SC integration, SNA methods and exploring BIM implementation as an emergent phenomenon.

The study extends extant understanding of BIM and SCM as although BIM has been considered an enabler for SC integration (Cic 2011), its deployment has to be complemented with various formal and informal functions and structures. To analyse BIM-based information exchanges, the CDE analysis was selected as a tangible means to complement contractual analyses via SNA, as BIM implementation is a dynamic process and cannot be fully captured by post hoc data collection, which has so far been the norm in construction SNA. Potentially, analysing the CDEs, which have now been largely mandated in UK BIM Level 2, might be a promising way forward for applying SNA in construction, as it facilitates the understanding of BIM-based collaboration (Charalambous *et al*. 2013). Contractual and BIM-based information analyses could provide a comprehensive image of BIM-enabled partnering. After all, it is previously suggested that digital – in this case BIM based – relations require additional contractual arrangements (Whyte and Lobo 2010). However, due to the nature of BIM domain, digital and contractual relations are neither identical, nor linearly dependent, as BIM functionalities impact the actors in varying ways, beyond any contractual or quasi-contractual prescriptions. Further research could include also data collection and ON analysis from additional communication channels, e.g. ethnographic observations from emails and phone calls.

Research limitations

Focusing on BIM-enabled SC partnerships only in the Netherlands does not allow for statistical generalization, but it offers rich contextual information. The Dutch construction market was a relevant locale to test newly introduced innovations, such as BIM and extensive partnering. Whereas the market is small, it has a high rate of BIM adoption and possibilities for second hand, or "external" BIM knowledge (see quotations of Contractor-Project Manager-B). The overall instilled consensus-seeking culture of Dutch construction firms (Dorée 2004), could be considered apart from a research limitation, a promising way forward for informing BIM policy-makers about the potential enrichment of BIM with SCM philosophy. Accordingly, in the future, cross-cultural case selection would shed more light on the complex socio-technical phenomenon of BIM-enabled partnering, which is increasingly becoming global.

Conclusions

Apart from individually adding to the knowledge base of SCM and BIM domains, the study provided evidence on BIM implementation from SC partnerships and proposed strategies (S1-S9) for BIM-enabled SC partnering. It analysed formal and informal relations of two different

BIM-enabled SC partnerships and how they affected the performance of the chain. The construction networks were found to be asymmetrical as to the formal and informal relations among the SC actors. Sophisticated contracts and selection of BIM-competent partners were not sufficient to instigate and cultivate informal relations among the SC partnerships. The integration depended on whether the partnership was *transactional* (Case A) or *relational* (Case B). Overall, the innovative and sophisticated BIM-based processes from Case A required additional informal aspects, such as interest towards seeking consensus, collocating, accepting joint responsibility and an inclination for shared learning (Table 6). Following the relational orientation of Case B (see S1), the SC partnerships could further support BIM implementation, by emphasizing more on informal structures and early discussions and communication across multiple tiers (S3-S4). The integration also depended on the composition of the strategic or internal partnership and particularly on the participation or not of clients and architects (see S2 and S6). The architect was a vital link of the BIM chain for BIM implementation in the SC partnership, given that they were responsible for creating the initial architectural BIM model that was further distributed to other actors. Accordingly, achieving integration includes strategies (S8-S9) for collaborative structures regarding colocations and early actors' involvement. Among unexpected research findings were emerging BIM-related functions in the firms of architects and contractors, for the deployment of innovative and integrative technologies, e.g. online collaboration via CDE (Figure 5).

The paper offered a fresh constructivist and inter-organizational perspective on the old concept of SCM, which was previously approached from a focal-firm mindset. Additionally, it offered new insights into the deployment of SNA for BIM-related research. Drawing upon previous SNA studies in construction (Table 2), the quantitative analysis of the CDE was chosen as a complementary data source for capturing the BIM-based information exchanges of the ON across time. Comparing digital BIM-based information exchanges over the CDE with actors' contractual centralities provided a pragmatic image of the partnership, as BIM-based and contractual relations were not identical, nor necessarily linearly dependent (Figure 3). Whereas contractually the contractors were the most active and connected actors, in the "BIM era" the architects are stepping up to play a dynamic role in BIM-based collaboration and informal communication. Accordingly, a combination of BIM-savviness and keenness to diffuse BIM knowledge across the chain would be a promising way forward for further integrating design and construction and diffusing both BIM practices and SCM philosophy (see S1-S4). Subsequently, two complementary sets of strategic (S5-S7) and operational (S8-S9) courses of action are proposed for symmetric BIM-enabled SC partnerships. Analysing inter-organizational complexities of BIM-enabled SC partnering could contribute to further developing SCM philosophy and ameliorating the utilization of BIM, given that not only inter-organizational BIM-related studies are sparse, but also BIM implementation essentially unfolds in complex inter-organizational settings.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Eleni Papadonikolaki http://orcid.org/0000-0003-1952-1570

References

Ahn, Y.H., Kwak, Y.H. and Suk, S.J., 2015. Contractors' transformation Strategies for adopting Building Information Modeling. *Journal of management in engineering*, 32 (05015005), 1–13.

Alsamadani, R., Hallowell, M. and Javernick-Will, A.N., 2013. Measuring and modelling safety communication in small work crews in the US using social network analysis. *Construction management and economics*, 31, 568–579.

Amor, R., 2015. Analysis of the evolving IFC schema. *In*: J. Beetz, L. Van Berlo, T. Hartmann, and R. Amor, eds. *32nd CIB W78 information technology for construction conference (CIB W78 2015)*, Eindhoven: CIB, 39–48.

Baiden, B.K., Price, A.D.F. and Dainty, A.R.J., 2006. The extent of team integration within construction projects. *International journal of project management*, 24, 13–23.

Bastian, M., Heymann, S., and Jacomy, M., 2009. Gephi: An open source software for exploring and manipulating networks. *International association for the advancement of artificial intelligence (AAAI) conference on weblogs and social media (ICWSM 8)*, San Jose, CA: ICWSM, 361–362.

Bavelas, A., 1950. Communication patterns in task-oriented groups. *The journal of the acoustical society of America*, 22, 725–730.

Bengtsson, B. and Hertting, N., 2014. Generalization by mechanism: thin rationality and ideal-type analysis in case study research. *Philosophy of the social sciences*, 44, 707–732.

Bresnen, M. and Marshall, N., 2000. Partnering in construction: a critical review of issues, problems and dilemmas. *Construction management and economics*, 18, 229–237.

Bryde, D., Broquetas, M. and Volm, J.M., 2013. The project benefits of building information modelling (BIM). *International journal of project management*, 31, 971–980.

Buskens, V., 2002. *Social networks and trust*. Thesis. Amsterdam: Interuniversity Center for Social Science Theory and Methodology-Thela.

Bygballe, L.E. and Jahre, M., 2009. Balancing value creating logics in construction. *Construction management and economics*, 27, 695–704.

Charalambous, G., *et al.*, 2013. Collaborative BIM in the cloud and the communication tools to support ited. *Proceedings of the 30th CIB W78 international conference on applications of IT in the AEC industry (CIB W78 2013)*, Beijing: CIB, 58–67.

Chinowsky, P., Diekmann, J., and Galotti, V., 2008. Social network model of construction. *Journal of construction engineering and management*, 134, 804–812.

Chinowsky, P.S., Diekmann, J. and O'Brien, J., 2010. Project organizations as social networks. *Journal of construction engineering and management*, 136, 452–458.

Chowdhury, A.N., Chen, P.H., and Tiong, R.L., 2011. Analysing the structure of public–private partnership projects using network theory. *Construction management and economics*, 29, 247–260.

Cic, 2011. *A report for the government construction client group building information modelling (BIM) working party strategy paper* [online]. Available from: http://www.bimtaskgroup.org/wp-content/uploads/2012/03/BIS-BIM-strategy-Report.pdf [Accessed Access Date].

De Bruijn, J. and Ten Heuvelhof, E., 2008. *Management in networks: on multi-actor decision making*. Abingdon: Routledge.

Demian, P. and Walters, D., 2014. The advantages of information management through building information modelling. *Construction management and economics*, 32, 1153–1165.

Dike, I.U. and Kapogiannis, G., 2014. A conceptual model for improving construction supply chain performanceed. *Proceedings of the 30th annual association of researchers in construction management conference (ARCOM 2014)*, Portsmouth: ARCOM, 1029–1038.

Ding, Z., Zuo, J., Wu, J., and Wang, J.Y., 2015. Key factors for the BIM adoption by architects: a China study. *Engineering construction and architectural management*, 22, 732–748.

Dorée, A.G., 2004. Collusion in the Dutch construction industry: an industrial organization perspective. *Building research and information*, 32, 146–156.

Dossick, C.S. and Neff, G., 2010. Organizational divisions in BIM-enabled commercial construction. *Journal of construction engineering and management*, 136, 459–467.

Dubois, A. and Gadde, L.-E., 2000. Supply strategy and network effects – purchasing behaviour in the construction industry. *European journal of purchasing & supply management*, 6, 207–215.

Dubois, A. and Gadde, L.-E., 2002. The construction industry as a loosely coupled system: implications for productivity and innovation. *Construction management and economics*, 20, 621–631.

Dulaimi, M.F., Ling, F.Y.Y., Ofori, G., and Silva, N., 2002. Enhancing integration and innovation in construction. *Building research and information*, 30, 237–247.

Eadie, R., *et al.*, 2013. BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in construction*, 36, 145–151.

Eastman, C., *et al.*, 2008. *BIM handbook*. 2nd ed. Hoboken, NJ: John Wiley & Sons.

Egan, J., 1998. *Rethinking construction: report of the construction task force* [online]. Available from constructingexcellence.org.uk/wp-content/uploads/2014/10/rethinking_construction_report.pdf [Accessed Access Date].

Eisenhardt, K.M. and Graebner, M.E., 2007. Theory building from cases: opportunities and challenges. *Academy of management journal*, 50, 25–32.

Elmualim, A. and Gilder, J., 2014. BIM: innovation in design management, influence and challenges of implementation. *Architectural engineering and design management*, 10, 183–199.

El-Sheikh, A. and Pryke, S.D., 2010. Network gaps and project success. *Construction management and economics*, 28, 1205–1217.

Fernie, S. and Tennant, S., 2013. The non-adoption of supply chain management. *Construction management and economics*, 31, 1038–1058.

Flyvbjerg, B., 2006. Five misunderstandings about case-study research. *Qualitative inquiry*, 12, 219–245.

Freeman, L.C., 1978. Centrality in social networks conceptual clarification. *Social networks*, 1, 215–239.

Gadde, L.-E. and Dubois, A., 2010. Partnering in the construction industry – Problems and opportunities. *Journal of purchasing and supply management*, 16, 254–263.

Gidado, K.I., 1996. Project complexity: the focal point of construction production planning. *Construction management and economics*, 14, 213–225.

Giel, B. and Issa, R.R.A., 2016. Framework for evaluating the BIM competencies of facility owners. *Journal of management in engineering*, 32 (04015024), 1–15.

Golicic, S.L., Davis, D.F., and McCarthy, T.M., 2005. A balanced approach to research in supply chain management. *In*: H. Kotzab, S. Seuring, M. Müller and G. Reiner, eds. *Research methodologies in supply chain management*. Heidelberg: Physica-Verlag, 15–29.

Gosling, J., *et al.*, 2015. Supplier development initiatives and their impact on the consistency of project performance. *Construction management and economics*, 33 (5–6), 1–14.

Granovetter, M.S., 1973. The strength of weak ties. *American journal of sociology*, 78, 1360–1380.

Gray, C., 1996. *Value for money: helping the UK afford the buildings it likes*. Reading: Reading Construction Forum.

Gu, N. and London, K., 2010. Understanding and facilitating BIM adoption in the AEC industry. *Automation in construction*, 19, 988–999.

Guo, G., Larsen, G.D., and Whyte, J., 2013. Digital interaction patterns on construction projects: a study of dynamic approval processesed. *Proceedings of the 30th CIB W78 international conference on applications of IT in the AEC industry (CIB W78 2013)*, Beijing: CIB, 109–118.

Higgin, G. and Jessop, N., 1965. *Communications in the building industry: the report of a pilot study* London: Routledge.

Hossain, L., 2009. Communications and coordination in construction projects. *Construction management and economics*, 27, 25–39.

Hossain, L. and Wu, A., 2009. Communications network centrality correlates to organisational coordination. *International journal of project management*, 27, 795–811.

Howard, H., *et al.*, 1989. Computer integration: reducing fragmentation in AEC industry. *Journal of computing in civil engineering*, 3, 18–32.

Kassem, M., Succar, B., and Dawood, N., 2015. Building information modeling: analyzing noteworthy publications of eight countries using a knowledge content taxonomy. *In*: R. Issa and S. Olbina, eds. *Building information modeling: applications and practices in the AEC industry*. Reston, VA: ASCE Press, 329–371.

Klijn, E.H., 2008. Policy and implementation networks: managing complex interactions. *In*: S. Cooper, M. Ebers, C. Huxham, and P. Smith Ring (eds.) *The oxford handbook of inter-organizational relations*. Oxford: Oxford University Press, 118–146.

Klir, G., 2001. *Facets of systems science*. 2nd ed. New York: Kluwer.

Korpela, J., *et al.*, 2015. The challenges and potentials of utilizing building information modelling in facility management: the case of the center for properties and facilities of the university of Helsinki. *Construction management and economics*, 33, 3–17.

Krippendorff, K., 2013. *Content analysis: an introduction to its methodology*. 3rd ed. Thousand Oaks, CA: Sage.

Larsen, G.D., 2011. Understanding the early stages of the innovation diffusion process: awareness, influence and communication networks. *Construction management and economics*, 29, 987–1002.

Leuschner, R., Rogers, D.S. and Charvet, F.F., 2013. A meta-analysis of supply chain integration and firm performance. *Journal of supply chain management*, 49, 34–57.

Lipman, R., 2011. *IFC file analyzer* [online]. National Institute of Standards and Technology (NIST). Available from: http://www.nist.gov/el/msid/infotest/ifc-file-analyzer.cfm [Accessed Access Date].

Liu, L., Han, C., and Xu, W., 2015. Evolutionary analysis of the collaboration networks within national quality award projects of China. *International journal of project management*, 33, 599–609.

London, K. and Kenley, R., 2001. An industrial organization economic supply chain approach for the construction industry: a review. *Construction management and economics*, 19, 777–788.

Loosemore, M., 1998. Social network analysis: using a quantitative tool within an interpretative context to explore the management of construction crises. *Engineering, construction and architectural management*, 5, 315–326.

Love, P.E., *et al.*, 2014. A benefits realization management building information modeling framework for asset owners. *Automation in construction*, 37, 1–10.

Macneil, I.R., 1977. Contracts: adjustment of long-term economic relations under classical, neoclassical, and relational contract law. *Northwestern university law review*, 72 (6), 854–905.

Mahamadu, A.-M., Mahdjoubi, L., and Booth, C.A., 2014. Determinants of building information modelling (BIM) acceptance for supplier integration: a conceptual model. *In*: A. Raiden and E. Aboagye-Nimo, eds. *Proceedings 30th annual ARCOM conference*, Portsmouth: Association of Researchers in Construction Management, 723–732.

Miles, M.B. and Huberman, A.M., 1994. *Qualitative data analysis: an expanded sourcebook*. Thousant Oaks, CA: Sage.

Moreno, J.L., 1960. *The sociometry reader*. Glencoe, IL: The Free Press.

Morton, S.C., *et al.*, 2006. Managing relationships to improve performance: a case study in the global aerospace industry. *International journal of production research*, 44, 3227–3241.

Navendren, D., *et al.*, 2014. Challenges to building information modelling implementation in UK: Designers' perspectives. *In*: A. Raiden and E. Aboagye-Nimo, eds. *Proceedings of the 30th annual association of researchers in construction management conference (ARCOM 2014)*, Portsmouth: Association of Researchers in Construction Management, 733–742.

van Nederveen, S., Beheshti, R., and de Ridder, H., 2010. Supplier-driven integrated design. *Architectural engineering and design management*, 6, 241–253.

Nummelin, J., *et al.*, 2011. Managing Building Information and client requirements in construction supply chain - Contractor's viewed. *Proceedings of the CIB W078-W102 joint conference: computer, knowledge, building*, Sophia Antipolis: CIB.

Park, H., *et al.*, 2011. Social network analysis of collaborative ventures for overseas construction projects. *Journal of construction engineering and management*, 137, 344–355.

Pryke, S., 2002. Construction coalitions and the evolving supply chain management paradox: progress through fragmentationed. *Proceedings of the RICS foundation construction and building research conference*, Nottingham: Nottingham Trend University.

Pryke, S., 2004. Analysing construction project coalitions: exploring the application of social network analysis. *Construction management and economics*, 22, 787–797.

Pryke, S., 2005. Towards a social network theory of project governance. *Construction management and economics*, 23, 927–939.

Pryke, S., 2012. *Social network analysis in construction*. West Sussex: John Wiley & Sons.

Pryke, S. and Pearson, S., 2006. Project governance: case studies on financial incentives. *Building research and information*, 34, 534–545.

Pryke, S., Zagkli, G., and Kougia, I., 2011. Resource provision ego-networks in small Greek construction firms. *Building research and information*, 39, 616–636.

Rezgui, Y., Beach, T., and Rana, O., 2013. A governance approach for bim management across lifecycle and supply chains using mixed-modes of information delivery. *Journal of civil engineering and management*, 19, 239–258.

Ruan, X., *et al.*, 2012. Knowledge integration process in construction projects: a social network analysis approach to compare competitive and collaborative working. *Construction management and economics*, 30, 5–19.

Saldanã, J., 2009. *The coding manual for qualitative researchers*. London: Sage.

Scott, J., 2012. *Social network analysis*. 3rd ed. London: Sage.

Sedita, S.R. and Apa, R., 2015. The impact of inter-organizational relationships on contractors' success in winning public procurement projects: The case of the construction industry in the Veneto region. *International journal of project management*, 33, 1548–1562.

Sinclair, D., 2013. *RIBA plan of work 2013 overview* [online]. Royal institute of british architects. Available from: https://www.ribaplanofwork.com/Download.aspx [Accessed Access Date].

Solis, F., Sinfield, J.V., and Abraham, D.M., 2012. Hybrid approach to the study of inter-organization high performance teams. *Journal of construction engineering and management*, 139, 379–392.

Son, H., Lee, S., and Kim, C., 2015. What drives the adoption of building information modeling in design organizations? an empirical investigation of the antecedents affecting architects' behavioral intentions. *Automation in construction*, 49 (Part A), 92–99.

Taylor, J.E. and Levitt, R., 2007. Innovation alignment and project network dynamics: An integrative model for change. *Project management journal*, 38, 22–35.

Thorpe, T. and Mead, S., 2001. Project-specific web sites: friend or foe? *Journal of construction engineering and management*, 127, 406–413.

Vrijhoef, R., 2011. *Supply chain integration in the building industry: The emergence of integrated and repetitive strategies in a fragmented and project-driven industry*. Amsterdam: IOS Press.

Vrijhoef, R. and Koskela, L., 2000. The four roles of supply chain management in construction. *European journal of purchasing and supply management*, 6, 169–178.

Wambeke, B.W., Liu, M., and Hsiang, S.M., 2011. Using Pajek and centrality analysis to identify a social network of construction trades. *Journal of construction engineering and management*, 138, 1192–1201.

Wamelink, J. and Heintz, J., 2015. Innovating for integration: clients as drivers of industry improvement. *In*: F. Orstavik, A. Dainty, and C. Abbott, eds. *Construction innovation*. 1st ed. West Sussex: John Wiley & Sons, 149–161.

Wasserman, S. and Faust, K., 1994. *Social network analysis: methods and applications*. Cambridge: Cambridge University Press.

Whyte, J. and Lobo, S., 2010. Coordination and control in project-based work: digital objects and infrastructures for delivery. *Construction management and economics*, 28, 557–567.

Winch, G., 1998. Zephyrs of creative destruction: understanding the management of innovation in construction. *Building research and information*, 26, 268–279.

Winch, G.M., 2002. *Managing construction projects*. 1st ed. Oxford: Blackwell Science.

Winch, G.M., 2005. Rethinking project management: project organizations as information processing systems. *In*: D.P. Slevin, D.J. Cleland, and J.K. Pinto, eds. *Innovations: Project Management Research 2004*. Newton Square, PA: Project Management Institute, 41–55.

Yin, R.K., 1984. *Case study research: design and methods*. 1st ed. Beverly Hills, CA: Sage.