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Organising and Managing boundaries: A structurational view of collaboration with Building Information Modelling (BIM)

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Abstract

The construction industry is currently undergoing digital transformation due to emerging technologies. Hence new forms of organisation are needed. Collaborating with Building Information Modelling (BIM) is complex and challenges the management of projects. The ubiquitous digital information sharing among multi-disciplinary actors in BIM-based projects, activates dense inter-organisational processes. This study offers insights into collaboration with BIM, through the theoretical lens of boundaries. By analysing two projects of BIM-based collaboration in the Netherlands, the interplay between structure and agency of collaboration was discussed. The various artefacts of BIM, as boundary objects were interpreted in multiple ways by different communities of practice and this resulted in poor communication and consequently poor collaboration. The findings challenge the prevalent view of BIM as a software artefact and showed that this view only partially supports collaboration. Additionally, a structurational view (enabled by communication, conflict management, negotiation, and teamwork) as opposed to a structural view of collaboration (e.g. BIM as a software) can fully support the implementation of digital innovations. Finally, the paper revealed a 'tactical gap' in the implementation of digital between strategic and operational decision-making needs fine-tuning to ensure better collaboration in projects where digital innovations are adopted. The study concludes with propositions for supporting organisation of teams through integration of activities and the management of BIM-based collaboration in projects beyond merely structural and technological approaches, which dominate the field but from a structurational view instead.

Keywords: Boundary theory; Building Information Modelling (BIM); Collaboration; Digital; Structuration

1. Introduction

Building Information Modelling (BIM) is a subject undergoing intense study in construction Project Management (PM) research. BIM relates to software applications, tools, activities and procedures for generating, managing, and sharing/exchanging digitised information among various multi-disciplinary actors. Due to being a structured way of representing information (Eastman et al., 2008), BIM could be seen also as a digital platform, structure or base for other technologies, such as virtual reality and augmented reality. The use of BIM in construction projects has become increasingly popular, due to project benefits, such as time reduction, coordination improvement, lower costs and fewer returns for information (Azhar, 2011; Bryde et al., 2013). However, the collaboration improvements from BIM are clear for some scholars (Barlish and Sullivan, 2012; Demian and Walters, 2014) and debatable for others (Dainty et al., 2017). In line with this, although technical maturity of BIM is advancing, managerial areas of BIM are still underdeveloped (He et al., 2017). According to

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Liu et al. (2016), the soft aspects of collaboration are challenging effective collaboration with BIM and are as important as the 'hard' factors of BIM. Whereas BIM may improve collaboration among various project actors, there is little research on how different BIM artefacts affect actors' roles and shape their collaboration. Despite BIM being currently a very popular paradigm in construction (Azhar, 2011), in practice firms struggle to collaborate with it in projects (Dossick and Neff, 2010). This paper focuses on this issue. Among the numerous different applications of BIM throughout the construction lifecycle (Hartmann et al., 2008), this study focuses on BIM from design until pre-construction phases, where collaboration is crucial when moving from the front-end of projects to realisation.

Sebastian (2011) provided evidence of changing roles of the clients, architects, and contractors due to BIM, which typically follows contextual and institutional pressures to use BIM in projects (Cao et al., 2017). BIM has penetrated into the work routines of numerous multi-disciplinary actors and challenges how it is used in firms, due to lack of education and training (Bryde et al., 2013). Not only architects and structural engineers but also clients, contractors, and suppliers gradually include BIM in their practices. For example, the work of contractors changes by involving suppliers earlier in the process (Papadonikolaki and Wamelink, 2017) or by creating specialised BIM departments (Ahn et al., 2015). Thus, the firms of various construction stakeholders are transformed according to their understanding of BIM, which tends to be diverse, as consultants and contractors are typically more 'hands-on' with the technology. In BIM-based collaboration, actors adopt or develop BIM responsibilities and roles at both technical and inter-personal levels (Gu and London, 2010). Also, new specialised BIM-related roles emerge. Therefore, not only various BIM artefacts, but also these numerous emerging BIM roles, such as BIM managers and BIM coordinators, might further hinder collaboration, if not adequately managed and coordinated (Akintola et al., 2017). This multiplicity of BIM artefacts and roles aligns with the transition of Project Management (PM) literature that has gradually shifted from tool-oriented approaches towards complex and dynamic set of process- and behaviourally-driven considerations (Söderlund, 2004).

The various national BIM policy agendas instigate and demand a cultural shift towards increased collaboration and consistency of information sharing. This study focused on emerging BIM artefacts and roles through the conceptual lens of boundary objects, which are useful devices for recognising incongruent meaning, conflict but also the potential enablers of effective collaboration (Star and Griesemer, 1989). The paper aims to gain a deeper understanding of BIM-based collaboration through review of theory and analysis of empirical data to address the following research objectives and understand:

- The influence of BIM as a digital technology on the structure and agency of collaboration in project networks,
- The emerging competences and roles that facilitate collaboration in BIM-based projects,
- How BIM and digital technologies can foster integration of activities to support the management of projects.

The paper is structured as follows. First, related past work on boundaries and BIM as a digital technology is presented. Then, the research gap on lack of understanding in how the management and organisation of boundaries affects BIM-based collaboration follows. Next, the research methodology is reported. After analysing the data, findings are discussed alongside literature. The paper concludes with a summary and suggestions for construction practitioners to overcome the gap among actors and leveraging from BIM artefacts as boundary objects to facilitate Project Management in BIM-based collaboration.

2. Theoretical basis and knowledge gap

2.1. Project Management and collaboration

Construction is a project-intensive industry (Morris, 2004). Project-intensive industries rely upon temporary or semi-permanent project teams (Turner, 2006), and thus managing information, communication and knowledge is highly significant. For the Project Management Institute (PMI, 2017), integration management, communications management and stakeholder management are key knowledge areas of the discipline, all of which are related to collaboration of these temporary teams. Projects undertaken by temporary inter-organisational teams may hinder knowledge sharing and good coordination in complex products. Therefore, there is a need to broaden the PM discipline to specifically include both tool-oriented approaches for assisting with the execution of processes as well as aligning process- with behaviourally-driven considerations (Söderlund, 2004). Engwall (2012), (p. 612) concluded that "we need to understand how project management principles and techniques are used in different empirical settings" and simultaneously enrich pluralism in theoretical perspectives of PM. To this end, BIM could be seen as a novel technology-laden process for PM.

Mattessich and Monsey (1992) defined collaboration as a dynamic and mutually beneficial and well-defined relationship entered into by two or more organisations to achieve common goals. However, in reality, not all collaborative relationships are well-defined, well-structured and truly mutual, or indeed working towards the same goals. For Malone and Crowston (1994), (p. 4), collaboration is a simpler term, which essentially describes people "working together on an intellectual endeavour". This goal-oriented definition of collaboration, focuses more on a strategic level, rather than operations, where interactions among team members are governed by dialectic theory. According to the socio-constructive nature of collaborative design proposed by Schön (1984) and Hey et al. (2007), the collaborative design is a collective creative endeavour, where multidisciplinary project actors consciously co-create design solutions. Similarly, Kvan (2000) suggested that collaborative design could be better called 'compromised design' as it is a quite time-consuming task that necessitates relation management among actors.

In PM, effective collaboration among various stakeholders allows temporary-based organisations to utilise multivariate expertise and produce new competences to the teams (Carlile, 2004). Koskela et al. (2018) commented on this temporal phenomenon of construction and called for appropriate ontological training for project participants to be able to break away from the traditional 'substance-based' metaphysics to a 'process-based' metaphysics where clarity and collaboration emerge and is a critical part of a successful implementation of any project. Whereas there is indeed little agreement in defining collaboration (Hardy et al., 2005), (p. 58), effective collaboration could be seen as process that leverages the different expertise among actors to create innovative, synergistic solutions beyond their individual goals (Ibid). In the light of construction digitalisation and BIM, the digital capabilities of teams that affect information flows, also affect collaboration and the degree to which people work synergistically.

2.2. Collaboration in BIM-using projects

2.2.1. Impact of BIM on projects

BIM entails a promising set of digital technologies that influences the processes of generation, representation and sharing building information among various actors and project stakeholders. The interplay between BIM technology and BIM processes is becoming more dynamic and difficult to separate, as the communication capabilities of BIM technology, shape and are being shaped by appropriate digital processes, being both 'agential' and 'structural' and thus, dualistic as defined by Giddens (1984). This interplay, hence necessitates the consideration of process and technology issues simultaneously. According to Giddens (1984), the knowledgeable agency is more central to the traditional structural view of phenomena (than what was thought at that time) and simultaneously, because of the duality, agency and structure are inseparable. As opposed to functionalistic views of social systems, which view structures – that comprise of rules and resources – as systems, Giddens (1984) described structurational systems comprised of both structure and agents without assigning primacy to either. The essence of structurational theory by Giddens (1984) suggests that agency is 'social structure' and people constituting this structure are actors enacting roles, in other words, agents. BIM technology and processes possibly fit the notion of 'structure', which is practically inseparable from 'agency' and actors, and thus affects collaboration through emerging inter-organisational processes and transformations (Papadonikolaki and Wamelink, 2017). Therefore, any consideration of BIM use, implementation and assessment has to adopt a holistic approach.

BIM offers 'ready-packed' capabilities likely to be adopted in projects, due to their immediately shown benefits (Jacobsson and Linderoth, 2010) with regard to data accuracy and better information management (Eastman et al., 2008). These capabilities explain the dominant software-based view of BIM in scholarship (He et al., 2017). The built-in features of BIM applications have options for visualisations and quantity take-off to facilitate understanding of work and support design coordination, called '*clash sessions'* (Eastman et al., 2008). BIM can facilitate design with fluent visualisations, fast shop drawings and their coding and precise interference detection (Azhar, 2011). Such features greatly affect how consultants, e.g. architects and structural engineers, work. The built-in cost estimating features of BIM tools facilitate the work of quantity surveyors and contractors (Azhar, 2011; Bryde et al., 2013).

This study follows a holistic approach to understand the impact of BIM on collaboration, based on the structurational theory of Giddens (1984). On the one hand, BIM-based collaboration pertains to the previously described structural or *hard*, operational and informational aspects of the technology. On the other hand, BIM-based collaboration implicates the agency through interactions among agents and by mobilising relational aspects such as commitment, trust, that emerge from integrating activities when working with BIM. BIM also induces various *soft* gains related to shared information, such as coordination improvement, fewer returns for information (Azhar, 2011; Bryde et al., 2013), and improves collaboration (Barlish and Sullivan, 2012). Both soft and hard factors are important to a BIM-based collaborative environment (Liu et al., 2016). Framing the project environment and shifting common practices to support collaboration among members in BIM-based collaboration is paramount for both design (Merschbrock, 2012; Grilo et al., 2013) and construction processes through lean principles (Tauriainen et al., 2016). The complex phenomenon of BIM-based collaboration on construction projects relies upon artefacts, process, structure, agents and context (Poirier et al., 2016).

2.2.2. BIM as a set of inter-connected artefacts and agents

The use of compatible Information Systems (IS) has been deemed essential for the information exchange among various actors, from designers to suppliers and could be used to integrate the design and construction phases (Dulaimi et al., 2002). Because of its reliance upon information and its capabilities for information management, BIM is an IS, that allows the involved actors to use their preferred systems, meanwhile exchanging compatible information in Industry Foundation Classes (IFC) format, currently the main open data standard (Berlo et al., 2015). To this end, BIM is considered an inter-connected set of digital artefacts by Papadonikolaki et al. (2016), including:

- Three-dimensional (3D) models produced by digital tools, including BIM,
- Generated 2D documentation,
- Web-based information management platforms, also known as Common Data Environments (CDE),
- Specialised sessions for kick-off and clash detections,
- BIM Execution Plans (BEP) and protocols,
- Decision-making instruments, such as contract addendums.

Therefore, various digital objects are nested and form a digital infrastructure for project delivery (Whyte and Lobo, 2010).

Accordingly, this inter-connected BIM system is not an off-the-shelf solution but requires continuous translation, coordination and governance from various multi-disciplinary actors. BIM affects collaborative processes by transforming the information exchange and inciting denser and highly interdependent interactions among actors (Jaradat et al., 2013). Most importantly, as long as digital technologies and BIM are detached from construction, or indeed coordinated design, and seen as an add-on, BIM adoption will lag and its benefits will not be fully reaped (Plesner and Horst, 2013).

Agents are social actors enacting different roles. The impact of BIM on agency and agents comes from the changing roles that actors are called to address that are pertinent not only to domain-related and technical skills but also concern relational issues and soft collaboration skills (Liu et al., 2016). Dossick and Neff (2010) studying interactions among Mechanical, Electrical, Plumbing (MEP) engineers, found that BIM enhanced transparency by showing the connections, whether interferences or clashes. However, BIM did not foster closer collaboration across individuals and firms. The changing nature of the (shared) deliverables and integration of activities and interdependences across professional roles carries implications for construction actors who might engage in roles beyond the disciplines in which they were originally trained in (Jaradat et al., 2013). Davies et al. (2015) stressed that a “combination of personality, experience, and training or education” is necessary to develop social competences for collaboration, communication, conflict management, negotiation, and teamwork with BIM. An investment in social competences could, thus, support the emerging BIM-related roles. These soft competences could complement the traditional technical skills, including the technical skills that BIM use requires. In the context of this paper, *soft* competences that could accompany BIM collaboration are defined as skills that do not require domain expertise or BIM-related technical knowledge, unlike *hard* skills needed for working with BIM artefacts, such as 3D models, documentation and CDEs. Simultaneously, given that the concept of collaboration and integrated activities in construction is also linked to a contractual view by Hughes et al. (2015), it is crucial to acknowledge the context of collaboration and especially procurement approaches that might influence BIM implementation (Eastman et al., 2008; Holzer, 2015), such as Design-Build or Integrated Project Delivery.

2.3. Boundaries and collaboration

2.3.1. Understanding BIM artefacts through boundary objects

Information, communication, knowledge and collaboration are intangible concepts (Kelle, 2010). For Maaninen-Olsson et al. (2008) knowledge boundaries among diverse disciplines during communication are often more pragmatic and thus complex, than the actors perceive them to be and carry both semantic or syntactic connotations. Therefore, reaching a ‘common understanding’ among actors is crucial for communication. Carlile (2004) distinguished among syntactic, semantic and pragmatic boundaries in communication: syntax to represent knowledge, semantics to assign meaning across boundaries of disciplines despite differences and pragmatic to distinguish between jointly transformed meaning from various actors and individual meaning (perceptions).

Star and Griesemer (1989), (p. 393) introduced the term ‘boundary objects’ and defined it as objects flexible enough to adapt to individual needs of the actors using them, yet specific enough to maintain a common meaning across different actors. They went further to state that boundary objects “…inhabit several intersecting social worlds and satisfy the informational requirements of each of them”. Boundary objects not only comprise tangible artefacts but also intangible concepts. All these suggest the notion of ‘structure’, which remains the “most important and most elusive terms in the vocabulary of current social science” (Sewell Jr, 1992), (p. 1). Accordingly, structure is complex and dynamic as it is continuously informed by social interaction (Sewell Jr, 1992). Boundary objects carry different meanings for different communities of practice, but common structures for recognition across these communities, through translation and interpretation (Star and Griesemer, 1989).

Boundary objects are physical or virtual entities, such as physical documents with diagrams and drawings, or electronic documents, such as e-mail communications and online transactions. Additionally, boundary objects carry explicit or implicit information. For example, explicit information can be directly represented, such as drawings or contracts, or information can be implied, i.e. information embedded in drawings or contracts. Boundary objects, due to their vagueness and their potential to encapsulate various meanings allow co-operation without consensus (Star, 2010). Subsequently, boundary objects may” contain at every stage the traces of multiple viewpoints, translations and incomplete battles” (Star and Griesemer, 1989), (p. 413). During actors' use and interaction with boundary objects teams can co-operate without necessarily having consensus and facilitate collaboration. Alin et al. (2013) had stressed the importance of ‘digital boundary objects’ as facilitators of design negotiations. Indeed, BIM was previously defined as a set of inter-connected artefacts that affect how various actors collaborate in projects that resemble the definition of boundary objects.

In the context of PM,Engwall (2012), had previously suggested that Program Evaluation And Review Technique (PERT) could be seen as a boundary object for technical coordination of actions and expectations. Boundary objects have been already associated with innovation (Kimble et al., 2010), Information Systems (Barrett and Oborn, 2010), new technologies (Fox, 2011) and for different functions, such as scheduling (Engwall, 2012; Chang et al., 2013) or training evaluation (Lee-Kelley and Blackman, 2012). Most importantly as boundary objects shape shared understanding (Star, 2010), boundary objects affect communication, information and knowledge exchange and collaboration. Thus, it is important to view BIM artefacts as boundary objects and explore how they contribute to collaboration and support management of projects. This study furthers the study by Whyte and Lobo (2010) on reconceptualising digital infrastructure as boundary objects to unravel implications for management.

2.3.2. Understanding BIM-based collaboration through liminal roles

The relations among different artefacts (and boundary objects) suggest an underlying structure of these artefacts, drawing upon Giddens' (1984) duality of structure and agency, boundary objects (and structures) might well imply the existence of boundary actors (or agents). Identifying joint understanding about objects from users/agents is crucial for the existence of boundary objects (Star, 2010). Levina and Vaast (2005) argued that joint understanding for an object only emerges when agents engage and interact with it and develop a collective identity – that is boundary objects. Such agents that may or may not cross role boundaries are boundary spanners (Levina and Vaast, 2005), boundary brokers (Koskinen, 2008), or mediators (Holzer, 2012) with boundary spanning competences. Naturally, there are some nuances among these terms and thus, for the purpose of this paper, we use the term boundary-spanner throughout, as it has less negative connotations related to lack of trust and higher leadership potential according to Fleming and Waguespack (2007).

Giddens (1984) introduced a significant concept that could provide the distinction in understanding the role of such agents by removing the consideration of agents as existential i.e. rigid, but look at their interactions as practices unfolded across space and time. As such, agents need to be viewed as dynamic rather than static but also maturing both in themselves and within the context of collaboration through emerging processes. It is typical within the context of BIM implementation to observe agents with differing levels of maturity in relation to their understanding of BIM and practice in general, and who 'mature' through the practice of undertaking projects. Projecting this concept forward we can extrapolate that the same agents can be boundary spanners at different times and in different situations/circumstances in a project. As Giddens (1984) stated *"…actors not only monitor continually the flow of their activities and expect others to do the same for their own, but they also monitor aspects, spatial, social and physical, of the contexts in which they move."*

Because of their plasticity, boundary objects may support collaboration but also induce conflict in project teams (Barrett and Oborn, 2010), thus, their study is of dual importance when managing projects. After all, boundary objects could carry a mediating role, which has implications for conflict management in project networks (Iorio and Taylor, 2014). A boundary spanner is an actor with membership and a high level of trust in various communities who can facilitate mediation and collaboration in projects. The role of boundary spanners is that of a "balancing act" (Kimble et al., 2010), as they have authority and enjoy trust from various groups. The boundary spanners translate the meaning of boundary objects and negotiate their meaning across various communities, thus facilitating collaboration among them (Brown and Duguid, 1998). Boundary spanning is essentially competence transfer among disciplines. Typically project managers are 'brokering' across role boundaries and domains, as they are typically 'multi-membership' team members (Koskinen, 2008). However, Levina and Vaast (2005), (p. 354) argued that only agents centrally positioned in relations and possessing "a significant amount of symbolic capital" could function as boundary spanners in practice.

Boundary spanners and boundary objects have been found highly efficient in structuring communication, negotiating and overcoming conflict (Ruuska and Teigland, 2009). Therefore, while viewing BIM as a boundary object that influences collaboration, exploring key actors' involvement and agency is also paramount for understanding the impact of these boundary objects in managing construction projects. Using boundary objects as mental models and as bridges of meaning (Fong et al., 2007), boundary spanners are then needed to work with communities of practice and their 'mental models'. Inter-organisational collaboration may activate role liminality. Liminal roles emerge in knowledge-intensive communities, leverage structural in-betweenness and act as creative agents who "overcome the limitations of conventional hierarchical forms" (Swan et al., 2016), (p. 806), beyond conventional roles' expectations. Turner (1969) described liminal roles as being at the limits of existing structures. In intensive knowledge-sharing environments, such centrally positioned (Levina and Vaast, 2005), (p. 354) liminal roles might include five distinct interpretations of agency, namely: knowledge broker, internal consultant, avant-garde, service provider and orphaned child (Swan et al., 2016). These various interpretations of liminal roles also apply to BIM-based collaborative environments, which are characterised by the existence of BIM consultants, BIM champions (Akintola et al., 2017) and other BIM-related specialists.

2.3.3. Synthesis of theoretical lens and research gap

Levina (2005), (p. 127) showed that focusing on boundary objects alone provides "insufficient insight into whether an object would be effectively used in practice". Therefore, not only the multi-dimensional properties of a boundary object but also its utilisation from various agents make it boundary. This suggests a structurational view of collaboration (Levina, 2005), (p. 128), drawing upon Giddens' (1984) duality of structure and action, according to which an agent 'shapes' the situation and 'is shaped' by the situation. There is additional room to understand collaboration with BIM through boundary objects and boundary spanners, as ultimately, actors are confident that they refer to same objects, but may actually assign varying meanings. Simultaneously, based on the interplay between boundary object and boundary spanner (Fong et al., 2007), understanding the role of key actors in a dialectic BIM-based collaboration is crucial for managing information in projects.

Similar to the syntactic, semantic and pragmatic boundaries of information (Carlile, 2004), agents have also both realist stance and perceived identities. This study aims first at exploring BIM-based collaboration through the lens of boundaries, in boundary objects and liminal roles. Nevertheless, boundaries become important in contingent and difficult to plan situations, where the objects (e.g. BIM) act as anchors for the creation of new meanings, and help to coordinate knowledge across multi-disciplinary agents (Holzer, 2012). Subsequently, drawing upon the empirical data and their confrontation to theory, the study aims at proposing strategies for supporting project management in BIM-based projects enacted by multi-disciplinary networks.

The paper adopts a dialectic view of collaboration, integration, structure, and agency and adds to the literature stream of 'management-as-organising', rather than 'management-as-planning' (Johnston and Brennan, 1996). Drawing upon the theoretical basis and research gap identified above, this study explores the following research questions (RQ):

(1) How do 'boundary objects' influence the structure and agency of collaboration in BIM-based project networks?
(2) How collaboration in BIM-based projects affects the actors' roles in relation to particular competences that facilitate it?
(3) How to support management of projects and integration of activities in BIM-based projects enacted by multi-actor networks?

3. Methodology

3.1. Methodological rationale

3.1.1. Research setting and rationale

This exploratory and interpretivist research intents to understand relevant concepts and identify linkages between theory that might reveal associations in BIM practice (Rooke and Kagioglou, 2007), and ultimately inform researchers and practitioners in managing construction project and collaboration. The research follows a constructivist epistemology, acknowledging that the phenomenon under study, BIM-based collaboration, is constructed in the minds of its immediate participants. The study relied on qualitative data collection and analysis methods.

The study explored BIM-based collaboration in contractually-bound project networks in the Netherlands. This research setting facilitated the observation and exploration of boundary objects and roles in BIM-based work. The Netherlands was an appropriate research setting for cultural reasons, for its ubiquitous consensus-seeking, *'poldermodel'* culture at least at a policy level that fosters close collaboration among social actors (Papadonikolaki, 2016). Winch (2002), (p. 25) describes the Dutch construction industry as a Corporatist type System where the "social partners", – like trade unions – are keen to negotiate instead of seeking confrontation to optimise benefits to the Dutch workforce and the society at large and reduce the costs and risks. To this end, the research setting is an environment that is more likely to be more collaborative and could be better suited to study BIM-based collaboration.

The study concerns two sets of actors organised in two Supply Chain (SC) partnerships respectively. These partnerships not only provided a structured setting for the study but also enabled the data collection process and the unobstructed access to information, given that all project actors saw value in further reflecting on their SC relations. Moreover, this non-antagonistic setting even under economic pressure could potentially deliver lessons for increasing collaboration in BIM-based projects. After all, many government reports and specifications, e.g. the Egan report and the Publicly Available Specifications (PAS) 1192 in the United Kingdom (UK) have been envisaging SC integration, enabled by close collaboration. Such suggestions were well-received in the Dutch context.

The study used case studies (analysed in the next sections) to explore the three research questions. The research design focused on interviewees directly immersed in the phenomenon of BIM-based collaboration to avoid impression management and retrospective sense-making that often arises in interviews among isolated interviewees (Eisenhardt and Graebner, 2007). The two cases were real-world building projects with various directly involved construction practitioners interviewed. The study was interpretative and focused more on information richness, sense, and meaning (Yazan, 2015), than statistical generalisation. Indeed, it focused on theoretical generalisability by limiting confounding variables and only looking at how BIM was used to enable boundary spanning.

3.1.2. Case description

The two cases, Case A and Case B, were selected because they featured similar projects in terms of scale and type. Procurement and contractual relations are important aspects of collaboration in general (Smyth and Pryke, 2008) and closely related to the implementation of BIM. Namely, integrated forms of procurement are considered more fruitful for BIM implementation (Eastman et al., 2008) and this is why both cases were selected for using some degree of integrated procurement. The two projects had long-term but slightly different procurement strategies and contract types: Case A deployed framework agreement contracts, whereas Case B used simple contracts. For both cases, the BIM implementation was quite advanced, deploying among others, collaboration over CDE. The use of two in-depth cases was used to generate insights into a spectrum of observations about boundaries and BIM collaboration.

Case A concerned the construction of a multi-functional building complex, consisted of three volumes with 255 residential units, offices, 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 a partnership, in the form of a multi-party contract, an integrated contract that included sophisticated energy requirements and 20 years maintenance. The contractor was subsidiary of a larger contractor company which took pride and marketed their BIM and sustainability capabilities.

Case B was a housing tower, with 83 housing units over a pre-existing shopping arcade, resulting in high technical complexity. The contractor had a few long-term exclusive relationships with the architect, structural engineer and on-off contracts steel sub-contractor, and suppliers, e.g., windows, cladding, and roof. BIM was applied from Initiation until Construction, and an 'as-built' BIM would be delivered to the client. The main difference between the two cases was the type of contractual relations, that is multi-party contract in Case A and long-term partnerships in Case B. In both cases

BIM was applied at least from Preliminary Design until Pre-construction, and thus the span of these phases, 13 months and 8 months respectively in Case A and B, was the research time frame. This was decided to be consistent with the investigation of BIM-based collaboration from a multi-disciplinary perspective.

3.2. Case study protocol

3.2.1. Data collection and analysis

The cases were studied through primary and secondary data, from preliminary design until preconstruction phase, where collaboration among project teams is intensified, and for identifying the project outcomes after the end of the projects in group interviews, designed for providing rich data and good coverage of the phenomenon (Fontana and Frey, 1994). The primary data was collected through individual interviews with various professionals involved in the projects. To avoid impression management and perceptions of individual subjects, such as managers (Rooke and Kagioglou, 2007), employees from various hierarchical levels were interviewed. The participants were selected on the basis of role in the project and familiarity with the concept of BIM and its implementation in the projects (regardless if they were BIM users or not). A pilot research project investigating another project as case study was used to test and improve the interview protocol and questions.

The interviews were semi-structured to allow for rich insights, lasted about one hour, and had same preparation and data handling. Before the interviews, all interviewees had the same information about the study goals and the interview questions in a one-pager submitted to them by email. Question hand-outs were used in the interview. The interviewees conversed in Dutch and there were at least two native Dutch speakers in the interviewing team to ensure accurate interpretation. With their permission, the interviewees were recorded to aid the transcription and translation into English, by four research assistants, native in Dutch.

The transcripts were analysed with qualitative analysis software (atlas.ti), using both deductive and inductive codes, around collaboration, BIM, competences, roles and activities. Coding was done using the transcripts of the original transcript by part of the author team, which includes a native Dutch speaker and one with a good understanding of Dutch. Synthesis was developed and agreed among all involved authors. The data are presented in the form of quotations in the ensuing section. All quotations included in the paper are translated direct quotations, improved for readability. The interviewees agreed on using their input for research, under anonymity to protect commercial interests. The authors are not affiliated with the firms.

3.2.2. Interview protocol and secondary data

The interviewees were carefully selected based on their direct involvement to the projects, only people who worked on the project were interviewed. They were asked to reflect on their understanding of BIM and their individual roles in the two BIM-based projects. Table 1 contains the interviewees' domain, function and whether they used BIM. The interviewees were first asked to describe their position, the project, the firms' motivation for using BIM, their understanding of BIM and their roles. Apart from reflecting on their roles, the interviewees were encouraged to reflect on the changing roles of their partners in the project. No direct probing techniques were used to receive feedback about all each actor and this was an indication of no significant data. When no information about any actor was received, it was an indication of a not content-based relation between them.

Consistent with a constructivist epistemology, secondary data collected through group sessions, project documentation, such as contracts and BIM models, and press coverage were used to triangulate the information provided by the interviewees and add context and validation to the analyses. The lower part of Table 1 includes the various secondary sources per case. Apart from the interviews during the projects' progression, group review sessions of the cases with sub-sets of the interviewees took place to gain insights into projects' outcomes. These review sessions aimed at grasping the reflections of key case participants about the projects' outcomes. As opposed to the individual interviews, the validation sessions were group sessions (Fontana and Frey, 1994), featuring key project participants, in the form of 'living labs' to confront the

Table 1
Primary and secondary data for the two cases.

Case A			Case B		
Primary data from interviews:					
Firm	Role/position	BIM user	Firm	Role/position	BIM user
Facility Manager	Project Manager		Contractor	Project Leader	
Contractor	Site Engineer	x	Contractor	Site Engineer	x
Contractor	BIM Manager	x	Architect	Project Architect	x
Contractor	Design Coordinator	x	Architect	BIM Modeller	x
Architect	Project Architect		Structural Engineer	Lead Engineer	x
Architect	BIM Modeller	x	Mechanical Engineer	Tender Manager	
Structural Engineer	Director		Mechanical Engineer	Site Engineer	x
Structural Engineer	BIM Modeller	x	Mechanical Engineer	BIM Modeller	x
Mechanical Engineer	Project Leader	x	Sub-contractor B1	Project Leader	
Supplier (Supp2)	Tender Manager		Supplier (Supp3)	Director	
Supplier (Supp2)	BIM Engineer	x	Supplier (Supp3)	BIM Modeller	x

Secondary data from mixed sources:

Case A	Case B
• 'Living lab' session with the contractor's firm	• 'Living lab' session with all partners
• Multi-party contract	• Framework agreement contracts
• BIM execution plan/protocol	• Pull-planning session
• BIM models	• BIM execution plan/protocol
• Clash detection session (MEP)	• BIM models
• Access to CDE	• Clash detection session
• Press coverage	• Access to the project extranet

opinions of the case participants and validate them. Living labs are user-centered sessions focusing on co-creating meaning with the participants, exploring scenarios and evaluating propositions. They presented an opportunity for reflection on their project, similar to a post-completion project review, and particularly regarding BIM-based collaboration and evaluate the preliminary findings of the research. This mixture of methods induced communicative validity by involving the participants to check the accuracy of data and add depth and richness to the data (Sarantakos, 2005), (p. 86). After all, Merriam (1998) acknowledged the need to increase validity in case study methods. The discussions in the validation sessions revolved around whether the projects were delivered on time and budget, about successes and failures in the projects, exploring what-if scenarios and lessons-learned and motivations for change in subsequent projects.

4. Data presentation and findings

4.1. Boundaries

4.1.1. Duality of BIM concept and artefacts

BIM was perceived in different ways in the two cases. In both cases BIM was used for various artefacts, however, the data revealed were contrasting between the two cases. In Case A, the Architect/BIM modeller mainly considered BIM as a software tool rather than as an information model:

> *"We did not make a conscious choice that we would work with BIM; at the first kick-off meeting it appeared we all had to work with Revit. Each consultant in the consortium must work in Revit. But as an office we were used to work in ArchiCAD. So that was a problem for us, or say a big challenge. We then decided to buy Revit. I did a short course for Revit. So since almost two years, we now work in BIM with Revit and with all other parties in the project. Thus, the challenge was with the software"* (Quotation-1-A).

In Case B, the project leader of the structural engineering firm stated that:

> *"…modelling between 3D and BIM is quite a big difference. Many companies indicate that they work in BIM but mean 3D modelling. Here we should definitely make a distinction"* (Quotation-2-B).

Similarly, other participants from Case B, stated that they were using BIM as an information model, not as software. The project leader went on and explained that BIM entailed a working experience together:

> *"In 2007 we started with 3D drawing and this offered opportunities for collaboration. This requires of course multiple parties to input their information into the model. We now have many years of experience working in 3D, because we recognized the advantages to our subject area. […] So, you can collaborate in designing the building and then use a BIM model as to assemble it together. Also, one can search for clashes and solve these together"* (Quotation-3-B).

Accordingly, their perception of BIM coincided with a different information management process in the two cases. In Case A, the design and pre-construction processes were not aligned with BIM and this caused additional rework according to the design coordinator of the contractor:

> *"Therefore, for us we must learn to use the software. And still, one develops a 3D model and then for construction one still needs the 2D plans. So, in fact, there is double workload. That is, I feel, the most serious issue. And then, when something needs to be changed, or adapted – what frequently happened – one needs to adjust the 3D model, which is very time consuming indeed"* (Quotation-4-A).

In Case A there was sequential knowledge sharing, unlike Case B were the development of the BIM model was more a collaborative process and way of working according to the project lead of the structural engineering firm:

> *"We are now mainly engaged in collaborative 3D modelling and the contact is intensifying. This is because subcontracting parties are increasingly involved in BIM. [Together with the contractor] we aim for integration with all other involved parties and to benefit from each other's contributions as to realize the best possible construction process"* (Quotation-5-B).

Therefore, in Case B, the process of developing a BIM model was structured and BIM was used to articulate collaboration and to optimise the design and building process. Case B had a more well-defined and integrated process, unlike Case A.

4.1.2. Roles and necessary skills for BIM-based collaboration

Working with BIM requires clearly different skills than the traditional way of working. Because the process of working with BIM was different, as shown in the quotes in the section above, BIM affected agents in various ways. In Case A, using BIM revealed problems and conflicts specifically with regards to technical BIM skills, as outlined by the design coordinator of the contractor about the architects:

> *"[The design was provided by the client, so] the architect had to work within an existing model. And they still have difficulties in properly working with BIM; performing clash controls. Also, he worked very messy, e.g. the heat insulation was drawn to cut right across the concrete. […] He didn't have experience with Revit, only with another programme. […]. And it is a very small office that has simply insufficiently knowledge and capacity"* (Quotation-6-A).

Whereas also the structural engineers in Case A were not very experienced, they picked up knowledge of BIM faster than the architects. According to the design coordinator of the contractor:

"The constructor had also an existing BIM model [same as the architect] and in fact what he did was OK. […] He had much more knowledge of Revit. He only dealt with the construction and of course the architectural design is more than that. [But] he also knew about metadata" (Quotation-7-A).

This reveals another potential issue with Case A, beyond BIM skills. The architects admitted that in this project they held different roles than what they had been used to and this created a difference in authority. The architect expressed difficulties in that they cannot discuss ideas with the client, as they are subcontractors to the contractor, whereas they were used to

"have the freedom to work for clients or developers to really design a building where one as an architect is allowed to contribute to the design according to one's own envisioning" (Quotation-8-A).

This can be interpreted as that he felt not valued for his expertise, and this may have affected the collaboration with the PM of the contractor. Another collaborative problem emerged with another partner, the installator, as phrased by the contractor. The installator was unwilling to contribute to the BIM model as long as all other parties were not finished, to avoid rework and coordination. From the perspective of the Case A contractor, there was primarily lack of BIM skills and to a lesser extent lack of collaborative work, but their contribution to collaboration was not mentioned or commented upon:

"With the installators it was different. Some parties are more skilful [in BIM] than others. Installator A was rather poor; e.g. the sockets were designed but not any cables. Although this met the standards, sometimes one did not know where these were located. The mechanical engineers developed everything themselves but were always too late. Once they delivered the final design of the installation, this caused clashes that others then had to solve, and causing delays. So, with him there was no collaborative working" (Quotation-9-A).

However, according to the other interviewees there was a consistent report that the contractor was over-demanding, due to late demands of the client, energy specifications, fixed prices which made the contractor already starting the construction phase while the design phase was not yet finalised. The mechanical engineer stated:

*"We should have asked whether they only need installation drawings or if they expected us to act as consultants? It is important that such is discussed. […] The same is true for the prefab supplier. We really stated during the tendering phase that the design was a mess and we need you to turn it into a good one" (*Quotation-10-A).

In a similar spirit, the installator stated:

"So, it is just a very complicated project where both the contractor and client demand a lot. In this case, the client is a pretty tough one. He really requires a lot from both the contractor and the subcontractors. So, it takes much effort and time to meet his requests. […] Yes, there are many technical challenges, but planning and available time for construction are also challenging. And because it took long before the final design was finalised, the design phase lasted too long. […] And consequently, this put stress on the involved parties. As long as the design is not yet finished, actually one should not really start with construction works, but we had to start construction, because we were under time pressure to meet the planned schedule. So, it has been a struggle to be able to build anyway" (Quotation-11-A).

The expectations of roles were smoother in Case B, as were BIM skills, but here the contractor had actually introduced a person as a mediator, in the capacity of a project-based BIM coordinator. In Case B the boundary spanner was someone who had extensive experience with different actors throughout the design and construction phase. This individual describes his role indeed as boundary spanner regarding communication, but not at the front-end of projects, linking parties:

"Basically, I am the linking pin in the communication among the parties, signalling errors and ensuring that errors are assigned to the right person for further processing. It also includes obtaining clearance from the supervising engineer. So, I deal with the collaboration among the various disciplines. My job starts after the kick-off and signing the formal contracts, and I thus have a coordinating role. I am not involved in the contracting phase. That is decided on by the Board of Directors. I should be present at the time the first model is developed, but I am not. [...] This is a new position, so I get involved during implementation and preparation not concurrent with the commercial guys. At our firm, BIM is still in its infancy" (Quotation-12-B).

4.1.3. Collaboration

Aspects of collaboration emerged when presenting the data on the roles emerging in BIM-based work. Accordingly, the contradicting quotations among the Case A contractor, mechanical engineer and installator, reveal that the collaboration was problematic, governed by the over-demanding attitude of the contractor and was abundant with conflicts (see quotations in the previous sub-section). The situation was problematic, because various partners in Case A complained about each other's performance, which is an indication of poor collaboration (see Quotations 9–11-A). However, the perception of the contractor is that BIM skills were failing, or that others were not meeting expectations or did not collaborate.

On the contrary, in Case B, the BIM coordinator of the contractor discussed how they also organised the information process and structured BIM-based communication and collaboration of other partners. As the BIM coordinator of the contractor noted:

"To us, the model of the architect sets the form and space that defines the borders within which we must operate. Increasingly, we will wipe out the model of the architect as

we add the new models of subcontractors. So basically, we replace the model of the architect with information from subcontractors. So, the architect models the areas e.g. spaces, rooms and facades, which are then filled in with data provided by the other involved parties. We act according to this principle. We set the limits to operate and, in this way, we develop the model" (Quotation-13-B).

Contrastingly, in Case B it was mentioned that because of BIM, the relations among actors change. For Case B architect, part of the problem was that the client should have been included in the process, not simply using 2D and making changes in paper:

*"And the traditional client still thinks that 3D comes down to a 2D plan. However, we no longer work in this way. And you need to guide your client in that journey. We have, of course, a very beautiful model. We can show all images he wants, he can 'walk' through the model. […] More and more, this will be our future. Even municipalities use BIM models or will start to use these models in their controlling procedures. But we are not yet there. We still need to take some more, important steps" (*Quotation-14-B).

They had tried to include the client in the collaboration, but this client was considered a traditional partner who likes to changes things later on, and this requires re-modelling in BIM, whereas BIM could allow for early involvement of the client. According to the Case B architect:

"The client is, I believe, the only one who was not participating in this process, so the client has quite a strange position. Normally, we want the client to be involved and make decisions. Because they did not participate, this actually disturbed the whole process. That is because they are a traditional client. They only asked for drawings to make their changes to. They made changes, they did even so during the construction when it was not really feasible to do. It is always possible to make changes, but it costs a lot of money and it is no longer efficient" (Quotation-15-B).

*"Yes, as a metaphor, you may think we are on the direct high-speed intercity service, while the client is still on the regional commuting train. He thinks he can change things at any time, because it had always been that way. And it is really hard for them to board our high-speed train. This is perhaps the most beautiful metaphor. Clients find it difficult to trust in you, as they are suspicious about the building industry at large "(*Quotation-16-B).

4.2. Project outcomes

Case A was completed on time with no delays observed. However, not all initial project aspirations were fulfilled, probably because there were incongruent BIM motivations (external or internal) within the project network. For example, they did not manage to optimise and control the logistics in site using BIM-based methods, as they were hoping at the beginning. Regarding their aspiration to deliver 'as-built' BIM models to the facility management organisation, this took place as planned, but they still face challenges into streamlining this information for facility maintenance. Regarding their BIM-based collaboration, the contractor firm admitted that

"the communication was not very good" (Quotation-17-A).

Overall, their varying firm sizes and BIM capabilities were a limitation in executing this project, e.g. the architect's firm was understaffed to manage the complexity of such a prestigious and unique project. This is in accordance with the dissatisfaction in Case A from at least three participants. However, for the contractor the project was seen as a success, at the expense of the others. The contractor's Design coordinator recognised that the greatest limitation of the project was the fact that

"*with this project, we had a design from another architect at the beginning (…) If it was his own design, he would have been more responsible*" (Quotation-18-A).

The BIM manager of the contractor stated:

"*we think it is important to select partners that recognise the value of BIM themselves*" (Quotation-19-A)

and the design coordinator added that:

"*we know that BIM is the future and that all the partners have to adapt*" (Quotation-20-A).

Case B project was also completed on time. As the project was part of a larger investment, the project network was awarded continuation in the next phase. The project team perceived this as a recognition of their successful BIM-based collaboration. Given that the client hired the same supply chain was seen as an indication that the project was successful. Regarding, their BIM-based collaboration, the project actors admitted that they improved their BIM capabilities immensely through these repetitive projects. However, they stressed that although the design was similar, the design preparation was the opposite of 'copy-paste', as with the advent of digital technologies, they were continuously amending their BIM implementation and collaboration processes. The project leader of the sub-contractor stated:

"*it is better to have the client as part of the team because it is better to have the tensions with them at the beginning of the project, rather than at the end. […] This will force them to be more responsible in what they want. They cannot change it later on if they are committed earlier on*" (Quotation-21-B).

According to the project leader of the architectural firm, the philosophy of Case B on BIM-based collaboration was that:

"*BIM gives better projects, because then you know each other and what to ask from your partners to think different and it helps to build trust in the long run*" (Quotation-22-B).

5. Discussion

After presenting the empirical data, the first part of this section discusses them by revisiting the key literature that has shaped relevant arguments and present the answers to the research questions. The second part of the discussion then focusses on a reflection of the contribution to theory and knowledge in the field of project management, present the implications for practice and state the research limitations of the study.

5.1. Organising and managing boundaries in BIM-based collaboration

5.1.1. Boundary objects and collaboration in BIM-based projects (RQ1)

This work contributed to knowledge around collaboration and its role in digital technologies and BIM by moving this debate from the causality of BIM and collaboration (Dainty et al., 2017) to adopting a structurational view of it. Essentially, BIM and digital technologies do require more collaboration to be effective but also generate closer co-working patterns among teams. The study revealed that BIM artefacts were used as boundary objects in the manner Star and Griesemer (1989) described in the collaboration of BIM-using teams in cases (see Quotations 9-A,13-B). The data re-stated the potential for BIM artefacts to be used as boundary objects. This is in accordance with previous studies on how BIM and digital artefacts facilitate work among multi-disciplinary teams (Whyte and Lobo, 2010; Iorio and Taylor, 2014). However, the empirical data shed additional light on the properties that constitute BIM artefacts boundary objects and how these are used in practice through the cases. Namely, Case A did not utilise the full potential of BIM artefacts as boundary objects for work coordination, as it was considered only a piece of software (see Quotation-1-A). This software-based view of BIM was put forward as problematic for project coordination by He et al. (2017). Contrariwise, in Case B, the actors perceived BIM as a framework of working together and co-creating buildings (see Quotation-3-B). The approach of Case B resonates with Carlile (2004) defining boundary objects as jointly transforming meaning among actors.

BIM artefacts were boundary objects with limited functionalities in Case A, as there was a sequential knowledge sharing process with a lot of rework (Quotation-4-A), similar to linear and over-the-wall models of collaboration (Papadonikolaki et al., 2016). Whereas BIM artefacts were used as boundary objects for communication consistent with Carlile (2004), it hardly improved conflict management. According to the data, the BIM process followed was contra-productive, as they duplicated work (Quotation-4), thus effective BIM use depends on how BIM process was managed. Instead, in Case B, BIM artefacts were used as boundary objects for organic project development, problem solving and proactive conflict resolution, i.e. 'bottlenecks' identification (Quotation-5-B). Therefore, although BIM artefacts were seen as boundary objects for collaboration in both cases, the perception of what constitutes BIM as well as individual's definitions of collaboration were key aspects of working with BIM. After all, boundary objects carry different meanings for different communities of practice (Star and Griesemer, 1989). BIM artefacts as boundary objects influenced collaboration and integration of activities in project teams but mainly supported the structure of collaboration and not the agency (answer to RQ1), as in Case A (structural collaboration) the interplay between structure and agency was less balanced than in Case B (structurational collaboration). Namely, in Case A the duality of structure and agency underperformed and more emphasis was given in the structure (rules, resources) than the agency due to conflicts among the team members (Quotations 9–11-A), whereas in Case B the duality and balance between structure and agency was better evidenced in the data (Quotations 13–14-B).

5.1.2. Actors' competences and roles in BIM-based collaboration (RQ2)

According to Levina and Vaast (2005), joint understanding around boundary objects emerges after agents engage and interact with it and assign to it a collectively-created meaning. To this end, agents cross boundaries and develop liminal roles, the same way that boundary objects enable collaboration. These boundary spanners that allow for fluid identities (Levina and Vaast, 2005; Koskinen, 2008; Holzer, 2012). In BIM-related literature, such agents are usually referred to as BIM champions (Akintola et al., 2017) or firm-based BIM managers and project-based BIM coordinators. Case A had both one BIM manager and one BIM coordinator (see Table 1) from the contractor's firm, whereas Case B had only the role of project-based BIM coordinator. Surprisingly, this role was alternated between the architect and the contractor, which shows that potentially both professionals might carry the necessary competences to engage in roles beyond the disciplines originally trained (Jaradat et al., 2013). The data showed that such liminal roles acted beyond conventional roles' expectations resonating with Swan et al. (2016) as in the intensive collaborative BIM process, authority can be usually challenged in teams (Quotation-7-A). Nevertheless, technical and discipline-related skills are not alone enough to support BIM-based collaboration; soft competences need to complement those.

Similar to different perceptions of BIM and collaboration in the cases, there were different perceptions and expectations of BIM-related competences and roles. In Case A, they approached BIM more as a digital technology and tangible (Quotation-6-A), but in Case B, they were using it more from a relational approach (Quotation-12-B). This supports findings by Bosch-Sijtsema et al. (2019) where actors perceived their new BIM-related/digital roles as more relational then technical that required more soft than hard skills. In Case A, the lack of brokerage or spanning capacity on behalf of the agents resulted in less coordinated BIM work (see Quotations-9-11-A). The liminal roles in Case B were developed around competences such as those described by

Davies et al. (2015): a *"combination of personality, experience, and training or education"*. After all, investing in social competences is likely to support new BIM-related roles (Liu et al., 2016), and in turn facilitate collaboration, communication, conflict management, negotiation, and teamwork with BIM. The engagement of roles in BIM-based collaboration of Case A, was more transactional and technical, whereas in Case B more communicative. The roles in Case B were liminal roles, as they were unconventional, non-hierarchical and transitional. The liminality in Case B was supportive of the structurational view of collaboration. To this end, the extent to which BIM-based collaboration supported the duality of structure and agency, depended upon the actors' roles and competences developed: social or technical and whether role liminality was activated. (answer to RQ2). The merely structural collaboration with BIM in Case A was associated with more transactional actors' roles emphasising on technical skills. On the contrary, in Case B, the actors' roles were more interactive and displayed a mix of hard skills and soft competences.

5.1.3. Managing projects through integrated activities with BIM (RQ3)

Managing projects and especially in construction, which abound with project-based firms, boundary objects can be used for technical coordination of actions and managing expectations (Engwall, 2012). Because BIM is a relatively new concept, its boundary condition is closely linked to and can support innovation (Kimble et al., 2010; Fox, 2011). Indeed, the rich empirical basis of this study supported that BIM as a boundary object affects and is affected by all key activities that involve shared understanding (Star, 2010), such as communication (Quotation-6-A), information exchange (Quotation-13-B), knowledge exchange (Quotation-22-B) and collaboration (Quotation-5-B). To this end, in the context of BIM, collaboration is what emerges from the former concepts and thus at different maturity levels, revealing a dualistic nature, depending on the activities supported. Both cases displayed room for improvement regarding the integration of BIM-based work into project management activities. Most notably, both cases showed how multi-variate institutional pressures affected the motivations of project teams to collaborate with BIM and reconcile their differences in a dynamic environment (Cao et al., 2017).

The empirical basis revealed that although BIM had the potential to support project management activities around information and knowledge exchange and collaboration, these were manifested differently between the two cases. In Case A, BIM was considered more of an 'add-on' of their existing business-as-usual activities (Plesner and Horst, 2013) (Quotation-1-A). Whereas they recognised the value to select BIM-savvy business partners (Quotation-19-A), they were not actively involved in their development and inter-firm knowledge-sharing among their partners (Papadonikolaki and Wamelink, 2017). This improvised approach towards BIM deployment in Case A is further evidenced through the difference in BIM expertise among the project network, across the whole chain from consultants to contractors (Quotations-6-7-A). Contrariwise, the scope of BIM use was strategic in Case B (Quotations-3,22-B), where its adoption and implementation came from the perspective of developing and been developed 'together'. The only source of discord in the strategic vision of BIM in Case B was regarding the roles and (lack of) engagement of the client (Quotation-21-B). Thus, the alignment of BIM-based work and its associated collaborative processes with project management at a strategic level by holding a structurational view of collaboration and encouraging the development of liminal roles in fast-pacing changing settings is crucial for leveraging the acclaimed collaborative benefits and improvements from BIM and digital technologies (answer to RQ3).

5.2. Reflection

5.2.1. Contribution to the advancement of theory

According to the 'management as organisation' approach, information systems could support communication and collaboration within and among groups (Johnston and Brennan, 1996). However, the study revealed that collaboration is partially supported by BIM artefacts. The study also highlighted a transition in digital areas from a tool-oriented approach towards behaviourally-driven considerations, similar to the transition of PM literature (Söderlund, 2004). Therefore, digital affects PM field not also regarding the introduction of new tools but also by introducing new forms of collaborative working (Theoretical contribution A-high-level). This research contributed to existing literature and knowledge base about digital innovation and introduction of new tools and processed, by exploring how BIM-based collaboration unfolds through the lens of boundaries. The intent was to investigate whether theory can be developed from this study and to this end, by transferring findings that include thick descriptions of the phenomenon under investigation (Geertz, 1994). This study responds to the call from Engwall (2012) that to understand the influence of techniques – in this case of BIM – on PM in different empirical settings as well as to enrich theoretical pluralism in PM. The contribution to PM field is on highlighting the importance of digital technologies, such as BIM, for construction projects as they shift project, inter-organisational, intra-organisational and professional boundaries (Theoretical contribution A-field-level). To this end, digital and BIM is an emerging field of research that carries implications for collaboration, integration, communication and stakeholder management, key knowledge areas of PM (PMI, 2017).

We addressed this through rich empirical cases studies of BIM-based project networks analysed through the lens of boundaries, which is closely related to PM discipline (Engwall, 2012) and theoretically contributed to the conceptualisation of a dialectic view of collaboration and in particular holding a structurational view drawing upon (Levina, 2005). By acknowledging the duality of structure and agency (Giddens, 1984), the study advanced the theory of collaborating with BIM by Liu et al. (2016) and Oraee et al. (2017), by highlighting the differences between a structural view of collaboration in BIM-based project networks, where BIM was conceptualised as mere structure (see quotations on Case A), and a structurational view of BIM-based collaboration, where agents' proactive behaviour enhanced the structure and vice versa (see quotations on Case B) (Theoretical contribution B-field-level). This contribution can be extrapolated beyond construction projects, as digital technologies and innovations related to digital necessitate new forms of working together and collaborating in projects, by recognising individual agency of equal importance to structural transformations (Theoretical contribution B-high-level).

From a broader perspective, these two case studies captured episodes in the high-velocity environment of digital transformation in construction, where dynamic capabilities are becoming hard to sustain (Eisenhardt and Martin, 2000). In the context of the increasing institutionalisation of digital technologies such as BIM (Morgan, 2019), markets are changing, business models are fluid and new players enter the market, which suggest a high-velocity market. Eisenhardt and Martin (2000) reframed the concept of dynamic capabilities from an organisational perspective (Kay, 2018) to depart from their association with linear, unconscious, rigid and mindless routines defined by economics scholars (Kay, 2018) and discussed their adaptive, fragile and semi-structured nature in high-velocity markets instead. To this end, it could be argued that in the boundary conditions of digital transformation in construction firms encounter unstable, experimental, iterative and simple interactions among agents (Eisenhardt and Martin, 2000). From a practical PM perspective, this work underlined an important capability for PMs to develop: inspiring their teams to work across boundaries (Theoretical contribution C-high-level) After all, effective collaboration induces competence development in teams (Carlile, 2004).

5.2.2. Contribution to knowledge from empirical evidence

The study made a knowledge contribution to the theory of collaboration in projects and especially when using innovative information technologies. First, it was identified that a structural-based view of collaboration using BIM artefacts cannot support the implementation of digital innovation (see answer to RQ1). This offered a qualified response to the debate about the collaboration improvements offered by BIM. A plethora of studies supports the collaboration benefits of BIM (Barlish and Sullivan, 2012; Demian and Walters, 2014) that are debatable for others (Dainty et al., 2017). This study departs from this dichotomy and claims that BIM artefacts supported more the structure than the agency of BIM collaboration (Knowledge contribution A).

Second, the duality of structure and agency, revealed that new roles and competences are needed beyond the traditional boundaries, such as collaboration, communication, conflict management, negotiation, and teamwork (see answer to RQ2). After all, effective collaboration allows temporary-based organisations to utilise multivariate expertise and develop new competences in teams (Carlile, 2004). Although, scholars identified the need for communication, conflict management, negotiation and teamwork skills in BIM work (Davies et al., 2015; Liu et al., 2016), the study further revealed that these behaviours enable a structurational (Case B) rather than a structural (Case A) view of collaboration in BIM-based project networks. Therefore, apart from a competence-based view of roles, role liminality was enabler of collaborative work with digital (Knowledge contribution B). In Case B, liminality supported the structurational view of collaboration.

Third, collaborative work is not only governed by day-to-day issues but also by strategic visions and engagements of the project networks (see answer to RQ3). Previous work on managing digital technologies, such as BIM, during project delivery, has focused only at an operational level, neglecting the necessary interplay among the three types of decision-making processes inside a firm: (a) operational, (b) administrative (or tactical), and (c) strategic Ansoff (1965), (p. 8). This study highlighted the need to cover the 'tactical gap' around digital technologies and BIM between strategic (primarily concerned with competitive advantage, growth, finances, and purchasing) and operational decision-making (primarily about efficiency and effectiveness) to ensure the right conditions to deploy strategies and support the operational decision-making. In the rapidly changing environment of digitalisation in construction, firms struggle to sustain dynamic capabilities (Eisenhardt and Martin, 2000), such as allocating resources, product development and alliance formation. The empirical data contributed to our understanding of why and how strategic decision-making on digital technologies', such as BIM, adoption influences how collaborative work emerges (Knowledge contribution C).

The study also revisited the concept of boundaries from an organisational and managerial perspective and offered new data to this stream of literature. At a middle-range theory level, the study added to the knowledge base of BIM-based collaboration research by offering new empirical data on BIM collaboration from a project network perspective, providing a real-world view of the PM benefits of BIM (Bryde et al., 2013). To this end, the study offers an empirical basis around project team motivations for BIM use and complementing the work on intra-organisational motivations by Cao et al. (2017). The empirical sample and the differences between the two cases also confirmed the prevalent view of BIM as a software at the expense of its managerial implications (He et al., 2017). The study complemented past work done by to Liu et al. (2016) and Oraee et al. (2017), also touching upon the concept of roles and competences needed to facilitate collaboration (Jaradat et al., 2013; Davies et al., 2015). This argument expands of the dualistic nature of the BIM-based collaboration by drawing parallels to the dualistic nature of the PM discipline, which although has its roots in planning techniques that focus on the structure of projects, also emphasises on learning, participation, action and behaviour from temporary firms' literature (Söderlund, 2004), which are agential concepts per se.

5.2.3. Implications for practice and policy

This study carries implications for project managers in construction and practitioners dealing with managing innovation and digital technologies. The association between structural collaboration and transactional roles (see answer to RQ1) call for further alignment with social capital (see answer to RQ2) and strategy (see answer to RQ3). At a project and inter-organisational level, some propositions for BIM-using teams that would engage in BIM implementation could be as to:

- Conceptualising and supporting collaboration with innovative digital technologies by emphasising on both agency and structure, beyond structural improvements from tools (see Quotations-3,12-B),
- Encouraging the development of soft competences beyond traditional boundaries, such as communication, conflict management, negotiation, and teamwork (see Quotations-3,5-B);
- Integrating the use of innovative digital technologies into project strategy (see Quotations-10-A,14-15-B,18-A).

At an industry level, there exist reports of low digitisation in construction sector regarding labour in Europe (MGI, 2016). Therefore, it is important to reflect on how digital technologies and particularly BIM can contribute to improving and re-inventing the nature of work. In Europe, to control various nuances and instrumentalities of BIM, and prescribe BIM implementation to reap its acclaimed benefits, various national initiatives from the government and professional industry associations suggest quasi-contractual means of digital collaboration among actors. These propositions presented above have different applicability depending on the context e.g. in the UK the pre-contract BIM Execution Plan' (CPIc, 2013) under the efforts of the UK BIM Level 2 mandate prescribes collaboration in BIM-based projects but its Dutch equivalent, 'BIM Protocol' Norm is issued but not mandated by the Dutch Government Building Agency (GBA) (Rijksgebouwendienst, 2012). Both mandates are inspired by the – only recently in 2016 mandated – Norwegian 'BIM Manual' which was created by Statsbygg (2011). Also, in the UK, various Publicly Available Specifications (PAS) have been issued to prescribe BIM implementation in project delivery, namely the family of PAS 1192. However, these efforts to increase collaboration, can only structurally affect it and do not take into account the agential component of BIM collaboration.

The low digitisation in construction implies an overarching skills shortage, especially in Europe. These pertinent challenges are now more relevant than ever, as the future digital agenda, envisioned throughout the UK Industrial Strategy will be even more technologically-intensive, abound with structural views of project delivery. The European Union has been following the steps of the UK and plans to align policies about BIM mandate at a European level, although UK scholars argue that the mandates intensify the digital divide (Dainty et al., 2017). To this end, policy-makers should recognise that the skills shortage also relates to soft competences and an agential view of projects, beyond any technical skills that focus only on the structure of projects. Competences such as communication, conflict management, negotiation, and teamwork should be part of any attempt to increase and strengthen the digital skills in construction.

5.2.4. Research limitations and further research

The analysis of the two cases thus showed both differences and similarities, but conceptualises collaboration through the lens of boundaries by placing an emphasis on the latter. It is difficult to draw generalisation by just two cases and further studies of similar and different work practices are needed, however the study attempted to generalise towards theory. There are many different work settings and the ways they are organised differ, which in turn could imply that their organisation of activities also differs. For example, project literature often emphasises uniqueness as an important qualifier of projects, but projects re not entirely unique. Similarly, BIM-using actors sustain the "reproduction of structures" and also facilitate their transformation through transposing schemas and remobilising resources to create new structures (Sewell Jr, 1992), (p. 27). To this end, although the cases studied and their projects are per se unique, they are embedded into their history and context (Engwall, 2003). After all, due to the long duration of the multi-party contract in Case A and the long-term partnerships in Case B, the projects were not purely temporal, but carried elements of constancy (Brookes et al., 2017). Future research will extrapolate more the relation between the type of the procurement and the level of BIM collaboration. Additionally, as the study was conducted in the Netherlands, future avenues of research will include replication and extension of the study to other cultural settings.

An important limitation of this paper was the decision to study two cases in depth, rather than a larger number, which made it difficult to draw strong generalisable conclusions. Nevertheless, case study methodology typically focuses on richness of data rather than full generalisation (Merriam, 1998). This study certainly enhanced the understanding of BIM-based collaboration in different projects, but future empirical work might include more cases and preferably in different research settings. Another particularity of the study is the focus on projects only in the Netherlands. However, after rich contextualisation of the research setting, the study gave a realistic representation of the phenomenon under investigation. The two cases act as a purposeful homogeneous sample.

6. Conclusions

The intense digitalisation that the construction industry goes through calls for re-examining and re-conceptualising collaboration among project teams. Currently, BIM as a digital technology is found at the forefront of digital transformation in construction, yet it is wrongly thought as merely a software. The comparative case of two BIM-using project in the Netherlands, revealed new insights into what makes collaboration in BIM-using networks, though the lens of boundaries. Although BIM is typically seen as an 'add-on' technology, it affects not only the structure of collaboration, but also its agency. Essentially, BIM artefacts act as boundary objects and influence BIM-based collaboration from a structurational perspective, including both a structural-based view of collaboration and agential aspects of knowledge sharing and innovation (answer to RQ1).

To this end, actors are called to step in and actualise roles beyond their domain expertise and the technical or hard skills needed to use the technology. Due to the influence of duality of structure and agency on BIM-based collaboration, the actors' roles and competences develop beyond hard skills (structural BIM-based collaboration in Case A), towards including soft competences (structurational BIM-based collaboration in Case B) (answer to RQ2). Namely, communication, conflict management, negotiation, and teamwork are also needed to complement the digital skills that the construction industry is currently in short supply of. Additionally, BIM artefacts as boundary objects generate different functions and roles depending on the management aspect in which it is used. This aligns with the dualistic nature of project management, constituting thus BIM as a concept intertwined with PM practice.

Whereas BIM objects support the need for greater communication among actors, due to the variety of digital artefacts and digital roles, effective collaboration might become complicated and hindered if not aligned with project strategy. To align BIM-based work and BIM artefacts with the associated collaborative processes in PM, it is essential to mobilise integrative initiatives at a strategic level (answer to RQ3) to bridge the 'tactical gap'. Drawing upon the empirical data, the study summarised the necessary integrative activities for BIM-based collaboration as follows. Thinking beyond tools for operationalising collaboration through innovative digital technologies, encouraging and developing boundary spanning capabilities and integrating innovative digital technologies into project strategy are key for leveraging from digital innovation in construction and re-inventing collaborative work.

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