Implementation of Building Information Modeling in Infrastructure Construction

Lessons from Norway and Vietnam

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Summary

Industrialization, innovation, and infrastructure are important drivers in improving employment and income (United Nations, 2015b). To meet the United Nation's Sustainable Development Goals by 2030, developing countries need to invest more in research and innovation that aims to improve their infrastructure (United Nations, 2015a). More basic infrastructure, such as roads, information and communication technology (ICT) systems, and electrical power grids, is essential to improving standards of living and protecting the environment in developing countries (ibid.).

Construction researchers have found that the use of ICT increases construction efficiency. Adwan and Al-Soufi (2016) classified 21 sets of ICT technologies used in construction, including web-based platforms, Building Information Modeling (BIM) based technologies, CAD- and 3D CAD–based technologies, virtual reality, and video conferencing. Among these, BIM is an information system that facilitates digital collaboration in construction. BIM provides an environment for data sharing based on 3D models, and it has been used to increase productivity and quality of building construction. In the context of transportation infrastructure, BIM reduces errors, provides better understandings of projects, and improves project performance (SmartMarket Report, 2017). In my construction industry experience, 3D modeling was applied to infrastructure projects that include roads, bridges, and railways. 3D models of infrastructure, such as that related to railways (stations and line alignments) and bridges, was used to detect design clashes and support communication with stakeholders. More broadly, BIM implementation is rapidly increasing in the context of infrastructure construction (Bradley et al., 2016), and examples include the integration of 3D infrastructure models with other technologies, such as geographic information systems, global positioning systems, laser scanners, and photogrammetry (Bradley et al., 2016; Costin et al., 2018). Researchers have also reported on BIM applications in different phases of the infrastructure life cycles (ibid.). In general, BIM supports infrastructure construction by reducing costs and risks and increasing reliability (Costin et al., 2018). The trend of rising use shows BIM's potential to benefit the infrastructure sector.

Infrastructure is critical if developing countries are to achieve their Sustainable Development Goals, which motivated me to explore BIM implementation in that context. Since developed countries is leading in BIM use, this thesis explores whether they can learn from the experiences of more advanced countries. To identify useful lessons, I conducted a comparative analysis of BIM implementation in a developed and a developing contexts. Moreover, BIM-related innovation communities were studied to understand how BIM practices can be further strengthened in infrastructure projects. This thesis focused on the following research question:

"How can the implementation of Building Information Modelling be improved to support infrastructure projects in a developing context?"

I chose an interpretive case study research design. To obtain an understanding of BIM implementation in different contexts, I conducted a cross-case analysis of it in Norway and Vietnam, with the former exemplifying a developed country and the latter a developing country. Cross-case analysis is a research method that assists scholars in their comparisons of commonalities and differences to produce a synthesized outcome (Khan & VanWynsberghe, 2008). This thesis's contributions are expected to support BIM implementation in developing countries.

In this thesis, I applied two frameworks from the institutional perspective, namely institutional isomorphism (Dimaggio & Powell, 1983) and institutional action (King et al., 1994). These frameworks were chosen because they can support the development of an improved understanding of BIM implementation and BIM innovation. The isomorphism framework consists of coercive, normative, and mimetic pressures (Dimaggio & Powell, 1983) that help explain why construction organizations use BIM. The institutional action framework includes six types of institutional actions, namely knowledge building, knowledge deployment, subsidy, mobilization, standard setting, and innovation directive (King et al., 1994). These institutional actions influence IT innovation and thus help reveal how construction communities develop BIM innovation.

The data were collected from two infrastructure projects and two construction communities. I conducted interviews and collected data from relevant reports, websites, and online discussions. Regarding BIM implementation in infrastructure projects, the InterCity in Norway and the Thu Thiem 2 Bridge in Vietnam provided empirical evidence. Twenty-one project team members described how they implemented BIM in their projects. Regarding BIM innovation in construction communities, I gathered data from buildingSMART Norway and the BIM Vietnam Community. Twenty-one members from each of these organizations described how and why they voluntarily contributed to their community work.

This thesis's findings are presented in five published academic articles. The first paper is a systematic review of BIM's implementation in developing countries which provides an overview of the research topic. The review showed that a large part of the developing world lacks BIM research on infrastructure, facility construction, and professional communities. The second paper describes the case of Vietnam's Thu Thiem 2 Bridge which offers an example of how to overcome the barriers presented by traditional regulations in order to apply BIM. For this project, a Finish consultant collaborated with a local consultant to meet the local requirements of the project cost and paper-based approval. Without the approval of the client and the relevant authorities, the project would not have involved BIM. The third paper is a study on BIM implementation in the Norwegian InterCity Project which reveals how BIM-related experience from other types of projects can be leveraged for railway construction. It was the first time the project members had used BIM in Norwegian railway construction, and they drew on 3D modeling experiences from bridge, road, and building construction to create a new BIM handbook. The fourth paper is an analysis of the buildingSMART Norway (bSN) community which demonstrates how community work can drive BIM innovation. The members of this community participated in and sponsored innovation. In this way, bSN members not only explored new BIM uses but also found practical solutions to their problems. The fifth paper provides a comparison between BIM communities in Norway and Vietnam which reveals how construction communities in different stages of development innovate with BIM. The comparison highlighted key institutional actions for BIM innovation, specifically knowledge building and subsidy. Other institutional actions supported to diffuse the technology further.

This thesis's theoretical contributions extend the understanding of institutional effects on BIM implementation and institutional actions on innovation development in construction communities. The BIM implementation studies reveal (1) how teams mimic experience from other construction projects to apply BIM to railways and bridges for the first time, (2) how top management supports that adoption of new technology in infrastructure construction, and (3) how professional networking activities inspire project members to upgrade their BIM knowledge. The BIM innovation studies describe how construction communities use (1) knowledge building to generate innovative BIM solutions, (2) subsidy action to provide resources for community activities, (3) knowledge deployment and mobilization to diffuse BIM, (4) standard setting to define consensus practices for collaboration, and (5) innovation directive to mandate BIM use at work.

This thesis's practical insights are suggestions for better BIM implementation in developing countries, particularly in their infrastructure projects. Project members can benefit from a better understanding of (1) gaining support for BIM implementation from clients and the relevant authorities, (2) the essential roles of BIM champions, and (3) gaining innovative solutions to implement BIM in construction communities. Further, construction community organizers can find suggestions related to (1) motivating members to participate in community activities and (2) facilitating knowledge sharing to create new BIM solutions. This thesis also offers examples that construction practitioners can review to gain BIM knowledge, BIM tool add-on programming skills, and the solutions professional communities have used to implement the technology.

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List of Abbreviations

AEC	–	Architecture, engineering, and construction
BCF	–	BIM collaboration format
BIM	–	Building Information Modelling
bSN	–	buildingSMART Norway
BVC	–	BIM Vietnam Community
CAD	–	Computer-aided design
CEN	–	European Committee for Standardization
CSR	–	Corporate social responsibility
DQMC	–	Dai Quang Minh Corporation
HCMC	–	Ho Chi Minh City Council
ICE	–	Institute of Construction Economics
ICT	–	Information and communication technology
IFC	–	Industry Foundation Classes
IPD	–	Integrated project delivery
IS	–	Information systems
PMT	–	Parametric modeling technology

1 Introduction

The World Bank (2015b) classified 135 low income countries as developing, and these countries need to invest more in infrastructure to meet their Sustainable Development Goals by 2030 (United Nations, 2015a). Implementing novel information systems (IS) is widely viewed as essential to performance improvement and useful in information integration, thereby helping the construction industry to overcome its fragmentation. New information and communications technology (ICT) systems can provide platforms for collaborative design, collaborative construction project management, and the interorganizational management of construction projects (Xue et al., 2012). An example of a collaborative system in construction is Building Information Modelling (BIM). The use of BIM systems may lead to improved work efficiency in construction (Doumbouya et al., 2016), which is important for an industry in which labor productivity has been stagnating since the 1960s (Goodrum et al., 2009). Some of the benefits attributed to BIM include better visualization of construction designs, better communication among people with different backgrounds, and more flexibility in facilitating changes to construction design (Doumbouya et al., 2016). In particular, opportunities to integrate costs, schedules, building design information, and as-built information (e.g., 4D, 5D, and 6D BIM) are the major advantages of new BIM technology (Smith, 2014a). In this context, BIM has the potential to improve the efficiency of infrastructure, such as bridges, roads, railways, tunnels, ports, and harbors (Cheng et al., 2016). Therefore, developing countries can use it to build necessary infrastructure more efficiently. In this way, developing countries have better chances of achieving their Sustainable Development Goals by 2030.

Although BIM provides various benefits to infrastructure construction (SmartMarket Report, 2017), its use in developing countries seems understudied, which constitutes a research gap worth addressing (Bui et al., 2016).

1.1 Motivations

This thesis is primarily intended to fill the above-mentioned research gap. BIM is expected to improve the performance of the construction industry in both developed and developing countries. Despite a multitude of prospective advantages, BIM implementation seems thus far widespread only in developed countries. In developing countries, academic literature has reported that China, India, and Malaysia are BIM pioneers, while other countries are underrepresented (Bui et al., 2016). Bui et al. (2016) revealed that most of the BIM studies in developing countries have examined technology transfers, importing standards, and collaboration approaches. This finding highlights developed countries as important sources of BIM experience for developing countries. Therefore, this thesis uses cross-case analyses to compare the BIM practices of developed and developing countries. The purpose is to identify useful lessons in the experiences of developed countries. This research not only contributes to the literature but also supports developing countries in their quest to achieve their Sustainable Development Goals by 2030 (United Nations, 2015a).

Another motivation was to improve the way infrastructure projects are delivered in Vietnam, my home country. From my work experience in the Vietnamese infrastructure sector, particularly the Ben Thanh underground central station design package of Metro Line 1 in Ho Chi Minh City, I know that the creation and communication of design information can be challenging. This project was of national importance, and the estimated cost of the central station was approximately USD 350 million. Line 1 was about 20 km long and crossed different urban areas, from downtown to the suburbs. Therefore, a large number of stakeholders with different backgrounds were involved in the design. From the start of the Metro Line 1 project, the submissions and approvals were based on 2D paper drawings. It was not until more than two years into the project that the consultants presented the finalized design based on 3D, which received many objections from other parties. The vice chairman of the city council, who had the final decision on the project, requested that the locations of the ventilation towers be changed. The ensuing discussions indicated that the parties and people participating in the project misunderstood one another; in particular, those without technical backgrounds were critical of the design. If these parties had been involved in the early conceptual design stages, they may have understood the situation better, and the design could have been discussed and changed along the way. However, traditional paper-based design methods limited the opportunity for the inclusion of nontechnical stakeholders and failed to serve as effective means of communication.

1.2 Problem statement

Based on the research gap and the motivations presented above, this thesis is intended to contribute to improving the implementation of BIM, an information system facilitating digital collaboration, by addressing the following research question:

"How can the implementation of BIM be improved to support infrastructure projects in a developing context?"

To answer the research question, I began by reviewing the BIM implementation statuses of developing countries. The review identified research gaps and provided suggestions for five studies that shaped this thesis's focus, part of which is on the quotidian practices of BIM implementation in construction organizations. The understanding of these practices became the foundation for answering the research question. The theoretical lens I chose to explore BIM implementation is the institutional isomorphism framework (Dimaggio & Powell, 1983). It describes institutional effects on organizations (ibid.). In this thesis, institutional effects are also referred to as "institutional influences".

Additionally, construction communities are driving forces in technological development (Ozorhon, 2012; Sarhan et al., 2018). In my experience, construction communities provide BIM standards, knowledge, and best practices to their members. BIM innovations in communities, such as standards, guidelines, and best practices, are resources for implementation solutions in infrastructure projects. BIM innovation in construction communities can be useful in BIM implementation. Therefore, this thesis also explores how construction communities undertake BIM innovation. The theoretical lenses I used to explore BIM innovation were the institutional action framework (King et al., 1994) and open innovation (Chesbrough & Bogers, 2014).

This thesis responds to the primary research question by breaking it into the three sub-questions below.

SQ1: What is the status of BIM implementation in developing countries?

SQ2: What are institutional influences on BIM implementation in infrastructure projects?

SQ3: How do construction communities innovate with BIM?

I chose Norway and Vietnam as representatives of developed and developing countries, respectively, because they have both been active in BIM adoption. Norway has a successful history of BIM implementation, with government agencies and private companies using it in building and infrastructure projects. Vietnam has been piloting it since 2014 with the purpose of using it nationwide by 2021.

This thesis includes case studies of two infrastructure projects and two BIM communities in Norway and Vietnam; I undertook four cases studies in all. The first focused on the Thu Thiem 2 Bridge pilot project in Vietnam. The second focused on the InterCity Project in Norway. The InterCity BIM team led the project consultants in building Norway's first BIM handbook for railway construction. The third case focused on the buildingSMART Norway (bSN) community, which offers an example of how voluntary work can push BIM innovation. Finally, the Vietnamese counterpart of bSN is the BIM Vietnam Community (BVC), and the fourth case focused on it. Despite having limited experience in BIM use and organization, the BVC succeeded in leveraging knowledge from foreign experts and creating add-ins tailored to their members' demands.

1.3 BIM implementation in Norway and Vietnam

This section briefly introduces my research settings: Norway and Vietnam. The purposes are to provide an overview of BIM practices in these two countries and to outline the reasons I chose them for data collection.

1.3.1. BIM practices in Norway

I chose Norway as an example of a developed country because of its successful history of BIM implementation. Some of Norwegian public agencies have formally requested the use of BIM in their projects. For example, the Department for Public Construction and Property Management (Statsbygg), which develops and manages public facilities, made BIM compulsory and has made various contributions to BIM practice through the BIM Task Group and bSN (Haug & Rødningen, 2016). The latter has established many BIM best practices and prepared guidelines for applying open BIM in the country. Open BIM is a vendor-neutral approach to BIM.

Norway has taken two main approaches to developing BIM technology: conventional and open. In the former, companies use their resources to internally develop BIM applications. In the latter, construction practitioners build a common foundation to exploit this technology. An example of the open approach is openBIM, which includes open standards for data exchange in the built environment (buildingSMART, 2019c).

Further, Norway's public and private sectors have both been actively involved in BIM development. In the public sector, Statsbygg issued the first version of its BIM guidelines in 2008 and has been requesting IFC use since 2010 (Hjelseth, 2017; Smith, 2014b). In 2015, Statens Vegvesen (the Norwegian Public Roads Administration) published a BIM handbook for transportation projects, and the agency recommended that managers of Norwegian road and bridge projects apply the handbook. In the private sector, software vendors, including JotneIT and Vianova, began offering BIM tools as early as the 1990s. In 2016, Norway successfully used BIM to complete Stage 3 of Bergen's light rail system (Sherry, 2018). The same year, the Norwegian National Rail Administration started developing a manual for 3D objects on railways (Trimble Solutions, 2016). Finally, in 2018, Norway started a BIM initiative aiming to blend infrastructure and new construction with surrounding landscapes (Wik et al., 2018).

1.3.2. BIM practices in Vietnam

I chose Vietnam as an example of a developing country because of its government's efforts to adopt BIM. Better understanding of BIM implementation will help

Vietnam use the technology more effectively. In 2014, the Vietnamese building regulations recognized BIM implementation as a construction management task. In December 2016, the government approved a BIM adoption plan that set the goal of completing at least 20 BIM pilot projects between 2018 and 2020. The outcomes of the pilot projects will constitute the foundation of a nationwide BIM implementation that will begin in 2021. Furthermore, the Ministry of Construction issued Circular 06/2016/TT-BXD, which allows for the inclusion of BIM implementation costs in construction budgets (Mui & Giang, 2018; Vietnam BIM Steering Committee, 2017). In 2017, a national BIM steering committee was formed to develop implementation strategies and advocate BIM use. This committee's work includes introducing an online information portal and coordinating and guiding government agencies as BIM is implemented (Vietnam BIM Steering Committee, 2017). In 2018, the Vietnamese government launched its adoption plan by selecting 20 pilot projects to experiment with BIM implementation (Decision 362/QD-BXD). The announcement included the following: residential and office buildings (11), transportation (5), hospitals (3), and a water reservoir (1). The project owners will apply BIM during the design, implementation, handover, and operation phases. The relevant government agencies, especially the BIM steering committee, will support the projects to help them overcome BIM-related challenges in regulations, procedures, training, and procurement.

1.4 Theoretical lenses

In this thesis, I adopted the institutional perspective that considers the influence of institutions' (Mignerat & Rivard, 2009) "values, norms, beliefs, and taken-for-granted assumptions" (Barley & Tolbert, 1997, p. 93) on the behaviours of organizations. The institutional context in this perspective is similar to that of the construction industry, as construction organizations follow various norms and values, such as national standards, codes of ethics, and competitive pressures from other companies. Therefore, an institutional perspective is appropriate when it comes to understanding BIM practices in the construction industry. The key to understanding organizational behavior through the lens of an institutional perspective is institutional theory, which has been applied to analyze IS phenomena (Mignerat & Rivard, 2009; Weerakkody et al., 2009). I applied two frameworks of institutional theory - institutional isomorphism (Dimaggio &

Powell, 1983) and institutional action (King et al., 1994) - to understand BIM implementation and innovation development, respectively. Further, I used the open innovation framework in combination with the institutional action framework to explore innovation.

Open innovation (Chesbrough & Bogers, 2014) is an approach to developing technologies in professional communities, and it reduces the risks and costs of technological development. An organization can perform open innovation by facilitating knowledge flows between it and innovation communities (ibid). In this way, the organization becomes a member of the open innovation community. Fleming and Waguespack (2007) defined an open innovation community as “a group of unpaid volunteers who work informally, attempt to make their innovation processes public and available to any qualified contributor, and seek to distribute their work at no charge” (p.166). In this thesis, I used open innovation as a theoretical lens to explore BIM innovation in construction communities.

1.5 Results

My research resulted in five publications in peer-reviewed journals and conference proceedings. Table 1 lists the publications and which sub-questions were addressed in each paper. The full publications are presented in Appendix C.

No.	Paper	SQ1	SQ2	SQ3
1	A review of Building Information Modelling for construction in developing countries	√		
2	Implementation of building information modelling in Vietnamese infrastructure construction: A case study of institutional influences on a bridge project	√	√	
3	An institutional perspective on BIM implementation – a case study of an Intercity railway project in Norway		√	
4	The role of an innovation community in supporting BIM deployment – the case of buildingSMART Norway			√
5	Understanding open innovation in BIM implementation: A cross-case analysis of construction communities in Norway and Vietnam			√

Table 1. List of publications and their relationships to research questions

This thesis aims to provide the following contributions:

1. a review of the status of BIM implementation in developing countries,
2. an expanded understanding of BIM implementation in infrastructure projects,
3. an expanded understanding of BIM innovation in construction communities, and
4. proposed changes for effective BIM implementation in developing countries.

1.6 Thesis structure

This thesis consists of seven chapters. The first introduces the work. The second reviews BIM implementation research in different contexts, including Norway and Vietnam, and presents the reasons for selecting the cases and research foci. Chapter 3 describes the applied theoretical frameworks, which were derived from institutional theory and open innovation. Chapter 4 presents the research methodology used to answer the research questions. Chapter 5 summarizes the key findings and contributions from the five published articles. Chapter 6 discusses the contributions to research and practice, and Chapter 7 concludes this thesis and discusses limitations and suggestions for further research.

2 Related research

BIM, an ICT construction application, was first proposed by Professor Chuck Eastman in the 1980s. In the 2000s, construction projects began to apply it to design activities. Since then, many scholars have provided definitions and interpretations of BIM, and these contributions can be classified into two main perspectives (Bonanomi, 2016). In the first, BIM is considered as only a 3D model (a Building Information Model) that is "the digital representation of physical and functional characteristics of a facility" (National Institute of Building Sciences, 2015, p. 3); 3D models are mainly used to support design processes. The second perspective views BIM as a process (Building Information Modelling) concerning information management and a digital representation (Bonanomi, 2016; Latiffi et al., 2013). The National Institute of Building Sciences (2015) defined BIM as "a business process for generating and leveraging building data to design, construct and operate the building during its life cycle" (p.3). Moreover, "BIM allows all stakeholders to have access to the same information at the same time through interoperability between technology platforms" (National Institute of Building Sciences, 2015, p. 3). From a managerial perspective, BIM is based on communication and information management procedures facilitated by modelling technologies (Eastman et al., 2011). Simply put, BIM is a business process that manipulates construction information with a digital model. It requires interaction between construction practitioners and information technology. Furthermore, theories used in IS research, such as diffusion of innovation (DOI) and institutional theory, have been useful in examinations of BIM topics because they have shown how BIM is a relevant area of IS research (Merschbrock & Munkvold, 2012).

This chapter provides a brief overview of BIM implementation research before focusing more on the context of developing countries and the infrastructure sector.

2.1 BIM implementation research

Doumbouya et al. (2016) reported that BIM improves work efficiency in construction projects. Work efficiency improvement is important in the construction industry, as labor productivity has developed slowly since the 1960s (Goodrum et al., 2009). The benefits of BIM include improved visualization of construction designs, improved means of communication among people with different backgrounds, and more flexibility in facilitating construction design changes (ibid.). Further, BIM presents an opportunity to integrate building information in different construction phases (Smith, 2014a). By facilitating information management throughout the project life cycle, BIM improves collaboration, communication, quality assurance, and delivery (Georgiadou, 2019).

In the domain of construction informatics research, Merschbrock and Munkvold (2012) found 264 BIM studies across seven different categories: infrastructure, communication and coordination, processing, deployment, impact, needs, and transfers. These articles focused on functional affordance, and the authors argued that researchers should pay more attention to human agency for a better explanation of BIM implementation and use. In other words, a social-technical system approach seems to fit BIM studies. This suggestion aligns with the review of BIM implementation in architecture, engineering, and construction (AEC) organizations (Abbasnejad et al., 2020). AEC companies need strategic initiatives, cultural readiness, knowledge capacity, and collaborative network relationships to implement BIM successfully (ibid.).

Additionally, to use BIM's capabilities, construction companies must implement BIM, which involves different processes, such as producing required project information and developing software. This thesis has adopted a broader definition, viewing BIM implementation as a combination of processes, technologies, and policies that promote interactions among parties (Succar, 2009).

BIM implementation is considered a business process and is generally thought to be complex (Abbasnejad et al., 2020). Successful implementation requires major changes to existing construction business processes including the introduction of technology to several organizations (ibid.). Thus, a range of organizational and technological barriers to BIM implementation have been reported (Eadie et al., 2014; Liu et al., 2015; Siebelink et al., 2020). Frequently experienced implementation barriers range from lack of top management support, lack of competences, low awareness of BIM benefits, low motivation to change, cultural misalignment, costly investments in the creation of new processes, and interoperability issues (ibid.). Furthermore, evaluation criteria are necessary for successful implementation. The studies on evaluation criteria not only provide quantitative metrics but also reveal key drivers of BIM implementation, which include BIM standards, client acceptance, staff training, and financial support for system set up and staff training (Chan et al., 2019; Olawumi & Chan, 2019).

Interestingly, the BIM literature recognizes clients' roles in supporting the adoption of the technology. Useful examples can be found in Sweden and the United Kingdom. Lindblad and Guerrero (2020) expanded the understanding of clients' roles by reporting on how the Swedish Transport Administration (STA) implemented BIM. STA increased BIM use in the Swedish infrastructure sector by deciding to employ it in their projects and two initiatives, namely the BIM and Professional Client initiatives. Following these initiatives, the role of clients was to define BIM requirements, purchase BIM services from suppliers, and govern project development. Dakhil et al. (2019) explored clients' BIM competencies in six cases in the United Kingdom and suggested that clients define desired BIM outcomes for their projects, have proper competencies to secure those outcomes, and lead the implementation process.

The STA's success is particularly impressive when one considers that construction practitioners view various obstacles to using BIM technology in infrastructure projects because the sector is substantially different than the building sector (Cheng et al., 2016). While buildings generally have vertical deployments, infrastructure projects often expand along central lines. This has led construction practitioners to refer to BIM use in infrastructure and building as "horizontal" and "vertical" BIM, respectively (Costin et al., 2018). Nevertheless, BIM applications in infrastructure are increasing (SmartMarket Report, 2017). Costin et al. (2018) found BIM applications in tunnel, bridge, railway, and road projects in Europe and the United States. Additionally, BIM has been used in airports, ports, and harbors (ibid.). It is expected to improve the efficiency of infrastructure management and to enhance value for all stakeholders (ibid.).

Despite BIM's potential to improve the overall performance of the construction industry, its implementation in developing countries has so far been limited (Bui et al., 2016). Hence, the purpose of this thesis is not only to contribute to supporting the use of BIM in infrastructure projects but also to address the lack of BIM implementation research situated in developing countries.

2.2 BIM implementation in developing countries

In developing countries, a variety of existing challenges cause construction delays, poor site conditions, poor working conditions, and accidents (Latiffi et al., 2013). The low efficiency of construction in developing countries implies a promising area for development. Since construction can improve the employment of human and material resources, the industry is considered a driver of growth and the achievement of the United Nations Sustainable Development Goals (Adams, 2004; Anaman & Osei-Amponsah, 2007; Giang & Pheng, 2011). In this context, BIM has the potential to improve the industry's efficiency (Olugboyega & Windapo, 2019).

BIM research covers both technological and managerial topics. Technical topics include data property, standards, and the utilization of BIM technology. Regarding data property, Jiao et al. (2013) reported the use of a cloud application model, namely LubanWay, to address the challenges of data management in construction and facilities management. This cloud computing model was developed for and applied to facilities management in the Shanghai Tower. LubanWay can be used to collect data and to combine engineering and management data, and it has proved particularly effective in cost control (Jiao et al., 2013).

The adoption of BIM standards is another focus in developing countries. Su (2013) found no legal barriers to applying international BIM standards (e.g., AEC/UK or openBIM) in China as long as they are specified as contract addenda to tender documents. Scholars have studied how Industry Foundation Classes (IFC) file exchange formats following the openBIM method can be employed in civil engineering projects in developing countries, which would allow tighter integration across several different engineering systems (Qin et al., 2011) as well as the alignment of different estimation methods (Ma et al., 2011). The findings were promising because they showed that BIM has the potential to significantly reduce workloads and errors in civil engineering projects in developing countries (Ma et al., 2013).

Finally, researchers have explored how BIM can be used. When implemented, BIM has provided design support that has resulted in overall reductions of design time (Shukor et al., 2015; Wang et al., 2014) and clashes (Wang et al., 2014). However, research has also shown that issues of low-quality data and poor collaboration may hinder the effective use of BIM (Chong et al., 2014). Researchers focused on developing countries have examined how terrestrial laser scanning and geographic information systems data can be merged with BIM to create 3D as-built visualizations (Shukor et al., 2015). Other areas include BIM's utility for increasing construction safety (Bansal, 2011), how it drive construction efficiency (Bansal, 2011), and how to overcome hurdles in BIM-based collaboration across companies (Shukor et al., 2015). Sustainable or green construction is another area of BIM research (Rostami et al., 2013). Further, energy saving and carbon reduction as well as energy conservation in the early construction design stages have been studied in developing countries (He et al., 2014).

Researchers have also delved into managerial topics, surveying construction practitioners' perspectives on BIM. In a survey of the Chinese industry, BIM was primarily viewed as useful in promoting contractor competitiveness (Harris et al., 2014). Moreover, even when BIM has been implemented in individual construction companies, its usage has been limited and is still in its infancy, with many barriers yet to be negotiated (Cao et al., 2015). Taking a technical view, practitioners need to improve the compatibility and integration between BIM and current construction software (Cao et al., 2015; Ding et al., 2015). Moreover, BIM use needs to be aligned with daily construction activities (Cao et al., 2015), which has been a challenge, as BIM is fairly complex and difficult to use (Kumar & Mukherjee, 2009). Firms in developing countries view BIM as a risky investment, as its business value remains unclear (Harris et al., 2014). While construction managers appear interested in BIM adoption, they seem unwilling to change the status quo of their firms (Kumar & Mukherjee, 2009), though drivers such as economic benefits, effectiveness, and efficiency could be motivators (Ding et al., 2015). BIM needs support from clients, contractors, and government before managers in developing countries will accept it (Harris et al., 2014; Kumar & Mukherjee, 2009). Moreover, technical training is viewed as important to driving BIM implementation (Ding et al., 2015).

In developing countries, scholars have studied BIM not only from the practitioner perspective but also with a focus on organizational performance. In the latter research stream, the emphasis is on how BIM as an information system influences quotidian operations in the construction industry. Theories frequently applied in IS research, such as institutional theory, the technology acceptance model, and DOI, are used to investigate how BIM can be implemented in practice. A survey of 92 construction projects in China found that coercive or authoritative pressures have significant impacts on the attitudes clients and owners have toward BIM adoption, while architects and contractors are mostly motivated by mimetic pressures and seek to imitate the successful conduct of others (Cao et al., 2014). Furthermore, practitioners' BIM adoption intentions are influenced by their willingness and interest (Xu et al., 2014). Entrepreneurs view integrated project delivery (IPD) based on parametric modelling technology (PMT) as a promising avenue for improving ways of doing business. IPD is considered a good approach to achieving tighter integration in construction projects in developing countries (Nawi et al., 2014), and PMT is viewed as an essential basis for improving the alignment of design technologies (Zeng & Tan, 2007). The use of relational database systems allows graphical and non-graphical data to be managed in one system. Such information infrastructure supports managing, capturing, and representing project data in a dynamic way (Zeng & Tan, 2007). Moreover, BIM systems still allow users to continue generating traditional 2D paper drawings (Zeng & Tan, 2007). However, BIM adoption continues to be low in developing countries (Cao et al., 2015). An attempt to develop a model for evaluating construction ICT applications in general and BIM implementation in particular has been presented in the literature (Enegbuma et al., 2014).

In 2016, researchers began expanding BIM research in developing countries, such as Malaysia, Pakistan, Nigeria, and Vietnam. In Malaysia, the benefits of BIM include reducing cost overruns and improving organizational management (Musa et al., 2019). In Nigeria, (Babatunde et al., 2020) examined BIM adoption drivers among construction practitioners. The 67 collected responses showed that the top six drivers are the desire for innovation, time saving, improved communication, accurate construction sequencing and clash detection, improved design quality, and pressure from clients or the competition (ibid.). In another study, Saka and Chan (2020) identified several barriers to using BIM in Nigerian small and medium-sized enterprises, including resistance to change, lack of government support, lack of demand from clients, lack of awareness, lack of guidelines, high costs of implementation, and mismatches between BIM tool capacity and ongoing tasks.

In Pakistan, researchers have focused on adoption and implementation (Akdag & Maqsood, 2019). The authors found Pakistani construction practitioners have a clear demand for BIM, as it can support management processes, improve communication among stakeholders, and facilitate design alterations (ibid.). However, the use of BIM in medium- and small-scale Pakistani projects seems limited. To gain more benefits from BIM, Pakistani construction organizations need to overcome the setup costs of BIM systems and the lack of trained professionals, lack of BIM education, and lack of market demand (ibid.). Furthermore, construction organizations need supportive initiatives from both the public and private sectors to successfully implement BIM (ibid.).

In Vietnam, the University of Transportation organized the Congrès International de Géotechnique - Ouvrages - Structures (CIGOS 2019) in October 2019. This conference had a track with 10 articles about BIM practice in the country. The topics were education (1), adoption (4), and application (5). The article on education explored the influence of BIM tools on training courses in a vocational school in Ho Chi Minh City (Nguyen & Nguyen, 2020). The authors recommended close cooperation between the industry and training institutes to meet skilled professionals' demands for BIM use in Vietnam (ibid.). The articles on application explored BIM use in steel-plate shear connections (Nguyen & Vu, 2020), the design of hydropower projects (Tran et al., 2020), bridge maintenance (Dang & Shim, 2020a), bridge assessment (Dang & Shim, 2020b), and operation management (Nguyen et al., 2020). The articles about adoption focused on legal issues (Dao & Chen, 2020), cases of implementation (Bui, 2020), perspectives on BIM profession (Le et al., 2020), and nationwide implementation (Matthews & Ta, 2020). The BIM track had four articles on bridges and hydropower projects (Bui, 2020; Dang & Shim, 2020a, 2020b; Tran et al., 2020), demonstrating a growing interest in BIM's use in infrastructure.

2.3 The role of construction communities in BIM innovation

Professional communities that connect parties for the purpose of innovation play an important role in innovation processes (De Silva et al., 2018). To support innovation, these communities perform various activities, such as developing technical standards, promoting best practices, encouraging members to commercialize newly developed technologies, transferring technologies, and diffusing technologies (Carignan et al., 2017; De Silva et al., 2018; Lyytinen & Damsgaard, 2001; Wan et al., 2018; West & Gallagher, 2006). This section highlights major community activities as they relate to BIM diffusion, such as developing standards, supporting education, and building new knowledge.

In this thesis, buildingSMART is an example of a professional community engaged in the development of BIM standards. Since its inception in 1995, buildingSMART has focused on solving the interoperability issues that emerge when different BIM tools are used (Autodesk, 2018). buildingSMART consists of an international council and 18 chapters representing countries and regions around the globe. The community has changed its name over the years; prior to 1996, it was called the “Private Alliance,” while from 1996 to 2008, it was known as “the International Alliance for Interoperability,” and since 2008, it has been called “buildingSMART” (buildingSMART, 2019a). According to its charter, buildingSMART is a nonprofit organization focused on openness and neutrality in BIM-based work (buildingSMART, 2019b).

How buildingSMART’s innovation work goes beyond just standardization is signified by its development of the so-called openBIM process. openBIM is a holistic concept aimed at achieving vendor-neutral digital collaboration in construction projects. The openBIM approach encompasses the IFC file exchange format, the International Framework for Dictionaries, the BIM collaboration format (BCF), and the Integrated Delivery Manual ((buildingSMART, 2019b), and the openBIM process was developed in close collaboration with a range of international standardization bodies (ibid.). In recent years, openBIM has become widely adopted in countries such as Norway (Merschbrock & Rolfsen, 2016), the United Kingdom (Shalabi & Turkan, 2017), and the Netherlands (Noardo et al., 2020). In addition, government agencies, such as Statsbygg, have begun mandating the use of openBIM processes in their projects (Merschbrock & Rolfsen, 2016).

Further, construction communities have supported practitioners by sharing their innovation-related knowledge. Knowledge from BIM communities can influence the technology adoption of practitioners (Panuwatwanich & Peansupap, 2013). Knowledge sharing in communities can take the form of active participation in education or reaching out to interested practitioners. Educational institutions, such as vocational colleges and universities, seek to update their curricula through collaboration with BIM communities, and close collaboration between educational institutions and innovation communities helps ensure BIM training programs meet industry needs (Sampaio, 2021). Further, educational institutions are arenas for students to develop BIM innovation (Linderoth et al., 2020).

Moreover, community outreach aids innovation communities in generating new ideas. Examples include the BIM Valladolid Contest (Bellido-Montesinos et al., 2019) and buildingSMART's hackathons (buildingSMART, 2019a) in which tech-savvy university students and industry experts generate new ideas related to BIM technologies. Such activities provide opportunities to explore fresh ideas related to BIM tools, data file exchange formats, and collaboration processes.

The BIM Valladolid contest has been held in Spain since 2014 (Bellido-Montesinos et al., 2019). It is open to multidisciplinary teams from all over the world, although so far, the teams are mostly European (from, for example, Germany, Italy, Spain, and the United Kingdom); however, there has been some participation from Africa and South America (ibid.). Ahead of the contest, participants are invited to prepare proposals describing their solutions, which must fall within the wider area of BIM-based construction projects (ibid.). The BIM Valladolid contest has become an arena in which companies and academia meet to develop new BIM systems and file exchange formats (ibid.).

In a similar vein, bSN has established hackathon events in which students explore innovative ideas with industry practitioners (buildingSMART Norway, 2019a). The 2018 hackathon was focused on finding new solutions for BIM technology in the transportation sector. In 2018, the solutions were to improve the design of the new E39 Highway in Norway. The organizers invited participants to generate concepts related to to digitally producing a representation of the road project. The participants generated a range of novel ideas related to BIM use in transportation.

Conducting these types of BIM contests allows communities to disseminate existing BIM knowledge to industry and generate new ideas.

3 Theoretical perspectives

This chapter introduces the theoretical frameworks I used in my research. Further, the rationale for selecting these theories is also presented. The theoretical lenses are institutional isomorphism (Dimaggio & Powell, 1983), institutional action (King et al., 1994), and open innovation (Chesbrough & Bogers, 2014). While the two institutional frameworks, which I derived from an institutional perspective, focus on organizational changes, open innovation describes how an organization collaborates with communities in innovation processes. The institutional isomorphism framework is the theoretical lens for the BIM implementation studies. Institutional action, referred to as the "Institutional Intervention Model" in this thesis, and the open innovation framework guided the BIM innovation studies.

3.1 Institutional perspective

To understand BIM practices, this thesis uses the institutional perspective suggested in the literature for studying digital innovation and transformation phenomena (Hinings et al., 2018). This institutional perspective assumes that organizational behavior should be understood in an institutional context (ibid.). The institutional context of an organization includes the relationships it has with critical actors, such as suppliers, regulatory agencies, competitors, professional associations, and media (Dimaggio & Powell, 1983; Hinings et al., 2018; Scott, 2014). Organizations follow institutions to achieve legitimacy, including for social acceptance and approvals (Hinings et al., 2018; Ho & Rajabifard, 2016). Definitions of "institution" and "legitimacy" appear below.

"Institutions are comprised of regulative, normative, and cultural-cognitive elements that, together with associated activities and resources, provide stability and meaning to social life" (Scott, 2014, p. 56).

"Legitimacy is a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions" (Scott, 2014, p. 71).

In the IS literature, the institutional perspective is used to examine innovation in organizations. In 2009, Mignerat and Rivard (2009) identified 53 articles published in 20 IS outlets, all of which used the institutional perspective. These articles focused on institutional effects and the institutionalization of innovation (Mignerat & Rivard, 2009). While the institutionalization literature mentions institutions' stages of formation, the term "institutional effect" refers to the external environment's influences on a specific organization (ibid.). In a similar review, Weerakkody et al. (2009) examined 511 articles published between 1978 and 2008 that used the institutional perspective. Among those scholarly works, 28 used institutional effects as central analytical tools. These IS articles were classified into three general themes related to IT: innovation, development and implementation, and adoption and use.

3.2 Institutional isomorphism

Institutional isomorphism is a process that "forces one unit in a population to resemble other units that face the same set of environmental conditions" (Dimaggio & Powell, 1983, p. 149). This process happens in the context of institutional effects that stem from coercive, mimetic, and normative pressures (Dimaggio & Powell, 1983). Coercive pressures arise from "formal and informal pressures exerted on organizations by other organizations upon which they are dependent" (Dimaggio & Powell, 1983, p. 150). Mimetic pressures come from uncertainty and make organizations mimic other organizations that are more legitimate (ibid.). Normative pressures derive from professional organizations through shared norms and expectations of desirable behaviors (ibid.).

Since BIM encompasses implementing ICT in construction projects, it can be viewed as a digital transformation process (Aibinu & Papadonikolaki, 2020; Ernstsen et al., 2020; Koscheyev et al., 2019). The isomorphism framework can be applied to explaining the mechanisms behind digital transformation and technology adoption (Hinings et al., 2018). These mechanisms consist of copying other organizations (mimetic pressures), following rules (coercive pressures), and applying professional standards (normative pressures; ibid.). Further, the institutional isomorphism framework has been applied in the context of construction innovation research. Chan (2018) reviewed how institutional pressures have made practitioners change their working habits to use digital tools in construction practices.

Similarly, Kale and Arditi (2010) noted that the Turkish practitioners in their study applied CAD technology and ISO 9000 because they were afraid their rivals would gain a competitive advantage with the same tools. In another study, Dulaimi et al. (2003) found that Singaporean construction companies innovate because they tend to mimic others in their supply chain. Since BIM is an innovation in construction, researchers have focused on institutional pressures when examining BIM implementation. In China, Cao et al. (2014) found that coercive and mimetic pressures strongly influence BIM adoption. While coercive pressures come from government agencies, owners, and clients, mimetic pressures often stem from other project participants. In another study, Bosch-Sijtsema et al. (2017) found that normative pressures are necessary for BIM adoption.

Besides, innovations can happen under pressures for both change and stasis. Institutional stasis has been a focus of institutionalists as a means of understanding change (Bakir & Jarvis, 2018). The main reason for stasis derive from groups that are benefiting from existing institutions (Acemoglu et al., 2020). These groups maintain the stasis is by combinations of norms, rules, authority structures, power relationships, and traditions (Acemoglu et al., 2020; Bakir & Jarvis, 2018). To support innovation development, understanding why organizations reject to change is useful.

The scholarly works described above document the explanatory power of institutional isomorphism. Based on this explanation capacity and the use of institutional isomorphism in construction innovation research, I chose it as a theoretical framework for understanding cases of BIM implementation.

However, despite its capacity for explaining organizational change, the isomorphism framework does not address institutional complexities, different organizational responses to the same institutional pressures, and a lack of focus on the individual level (Currie, 2009; Hinings et al., 2018).

3.3 The Institutional Intervention Model

King et al. (1994) underscored that innovation is a process of turning an invention into a usable form when said invention is a new idea or new product. Innovation may also take the form of a product developed from an invention. To explore how an organization intervenes in ICT innovation, the authors proposed categorizing organizational activities into six institutional actions (Table 2), which are referred to as the "Institutional Intervention Model" in this thesis.

Forms of action	Institutional action
Knowledge building	Creating the knowledge bases necessary for innovative activity. Typically, conducting and funding basic research belong in this category. Governments may also mobilize large corporations or their agencies to research particular topics of national importance.
Knowledge deployment	Facilitating the dissemination of new knowledge, such as connecting individuals and organizations with knowledge of innovation, creating repositories of technical facts, and providing training.
Subsidy	Using organizational resources to reduce unavoidable costs and risks for innovators. It includes funding for prototypes, the internal production of goods and services resulting from an innovation, the products that complement an innovation, and the reduction of barriers to innovation.
Mobilization	Encouraging external individuals and other organizations to hold the same opinion on innovation. The main instrument for mobilization is promotion and awareness campaigns.
Standard setting	Establishing socially constructed agreements among organizations interested in using an innovation. The implementation of standards is generally voluntary, but it can be mandatory if enforced by law.
Innovation directive	Entails a command to produce, use, or facilitate innovations. Directives appear in requests for a particular technology, investment in research and development, and requirements to use particular products.

Table 2. Six forms of institutional action adapted from King et al. (1994)

A community can be a voluntary group of individuals and/or firms (West & Lakhani, 2008). Communities play important roles in developing technical standards, organizing interactions among members, and encouraging members to create start-ups to commercialize newly developed technologies (West & Gallagher, 2006). Through interactions, members can share their knowledge, develop collective solutions, and and jointly create new products and services. Joint production is an important indication of a successful community (ibid.).

The Institutional Intervention Model has been used to examine ICT innovation diffusion, particularly the role of innovation intermediaries in the process (Lyytinen & Damsgaard, 2001; Scupola, 2006; Somasundaram & Damsgaard, 2005). For example, Lyytinen and Damsgaard (2001) studied the role of industry associations, a group of innovation intermediaries, in promoting electronic data interchange (EDI) in the grocery sector. The authors found that grocery associations in Hong Kong, Finland, and Denmark have successfully connected partners in the sector to increase the uptake of EDI. The effective actions are knowledge building, knowledge deployment, mobilization, and standard setting (ibid.). Construction communities that connect partners in the innovation process are their industry's innovation intermediaries. Since the Institutional Intervention Model can provide a framework for understanding how communities influence innovation, I chose it to explore how construction communities develop BIM innovation.

However, the model has limitations when it comes to identifying motivations for innovation (King et al., 1994). Therefore, King et al. (1994) also proposed the concepts of supply-push and demand-pull forces, which are combinations of institutional actions. Supply-push forces support the process of creating new applications for inventions, thus generating innovations (ibid.). For example, buildingSMART International develops applications for openBIM concepts, and these efforts result in BIM standards for collaboration via the open approach. Demand-pull forces come from the demands of potential users (ibid.). For example, Statens Vegvesen mandates BIM use in its infrastructure projects. This request creates demand for BIM applications in Norwegian infrastructure construction. Nevertheless, these concepts are unclear when it comes to explaining why innovation happens in specific ways. For example, Cobuilder and Catenda, two Norwegian software vendors, developed two different BIM innovations. While Cobuilder contributed to the product data template, Catenda supported the buildingSMART data dictionary. The two vendors had previous experience in a similar national context. To explore motivations and how innovations happen, I adopted the open innovation perspective. The theoretical guide for the innovation studies was therefore the combination of the Institutional Intervention Model and open innovation.

3.4 Open innovation

In 2003, open innovation emerged from an idea to open companies' innovation processes to external individuals and organizations. Open innovation has promoted technological development in various industries, including the chemical, mobile phone, movie, and automotive sectors (Chesbrough, 2007). Open innovation is "a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model" (Chesbrough & Bogers, 2014, p. 17). Indeed, the open approach helps technological development processes overcome barriers in the more conventional methods of innovation.

At the same time, companies recognize the rising costs of technological development and the shortening life cycles of new products. This makes them reluctant to invest in innovation. However, companies still restrict access to their technologies through intellectual patents and ownership. It is common to find a company that uses only 5%–25% of its patented technologies (Chesbrough, 2007). This fact limits innovation by restricting external ideas about available technologies. Open innovation facilitates knowledge's flow in and out of organizational boundaries, and companies use inside-out flows to earn profits by providing their technologies to the market via licensing or spin-offs. Anyone with innovative ideas can pay a fee to use patented technologies. In the opposite direction, outside-in flows harness inventions from external sources through various means, such as the buying of licenses. The external sources include customers, competing companies, academia, and companies in other industries. Companies can also perform a so-called coupled process, which allows knowledge to flow in both directions (Chesbrough, 2003; West & Gallagher, 2006). By facilitating knowledge flows, the open approach stimulates innovation and provides new development paths for underused ideas. This approach encourages companies to apply external ideas if they are considered better than internal ones (Winkel et al., 2008).

To benefit from BIM, construction companies have invested in BIM innovation through various channels, including open innovation. An example of the open approach to BIM innovation is openBIM, “a universal approach to the collaborative design, realization, and operation of buildings based on open standards and workflows” (buildingSMART, 2019c). openBIM is simply a digital language for the open and free exchange of information on the built environment. With openBIM, construction partners can work together regardless of the software they use through a vendor–neutral data exchange format. In the opposite way of working, referred to as “closed BIM,” the software tools come from just one vendor (Borrmann et al., 2018). Since construction involves different disciplines and tasks, it is difficult for a single software vendor to provide tools that match all the demands of the industry. Complicating things is the fact that construction companies use different software systems. These systems should support interoperability for effective collaboration. If construction data cannot be exchanged from one software system to another, practitioners have to process the data every time they receive them. Gallaher et al. (2004) reported that the cost of correcting software interoperability in the United States reached $15.8 billion in 2002. Construction owners and operators covered about two-thirds of this cost, while the outstanding amount was the province of contractors, suppliers, architects, and engineers (ibid.).

I chose open innovation to explore BIM innovation in construction communities because this theoretical framework explains why organizations take part in collective innovation. The main motivation for the open approach to innovation is gaining the business benefits that come from saving development costs and reducing risks. Further, this framework explain why innovations happen in different ways. In the open innovation approach, innovations emerge through combining innovative ideas and available technologies. Regarding BIM innovation, construction communities have applied the open approach to push the technology further. Thus, an analysis using the open innovation lens is necessary to broaden the understanding of how construction communities support BIM innovation.

4 Research approach

This chapter presents the research design for this study, including research assumptions, data collection processes, and analytical methods. I chose this research design because it was best suited to answer the primary research question in a coherent and logical way. Additionally, quality criteria are here identified as measures to improve this thesis's trustworthiness.

4.1 Research perspective

The research perspective accounts for any of the researcher's ontological and epistemological assumptions. While ontology refers to assumptions about social reality, epistemology makes assumptions about the nature of knowledge (Delanty & Strydom, 2003). These assumptions relate to each other and shape the research philosophy (ibid.). Explicating one's research philosophy supports researchers in their efforts to gain valid knowledge of the studied phenomena.

Orlikowski and Baroudi (1991) summarized three research philosophies that have been applied in the study of IS phenomena. The philosophies are positivist, interpretive, and critical research. Each philosophy contains assumptions about ontology and epistemology (ibid.). Positivist studies assume that phenomena are objective and include a priori fixed relationships. By using structured instrumentation, positivist researchers focus on testing theories to increase predictive understandings of phenomena (ibid.). Interpretive studies assume that people create their own understandings of phenomena through interaction. Interpretivists aim to understand the deeper structure of a phenomenon in its context (ibid.). Critical studies assume that social realities are created by humans and are continuously developed through competing ideas. Critical researchers critique the status quo of phenomena to transform restrictive conditions (ibid.). I chose the interpretive research philosophy to respond to the research question because the ontological and epistemological stances of this approach are in line with my perspective. In my perspective, I believe that reality is constructed based on my experience. Further, I understand social phenomena through others' thoughts on them.

Interpretivists adopt social constructionism ontology, which posits that the nature of social reality is subjective (Lee, 2004; Orlikowski & Baroudi, 1991). On the one hand, social reality, which includes organizations, groups, and social systems, is constructed by individuals. On the other, it shapes individuals' experience and knowledge. The interpretive epistemological stand assumes that researchers interpret and explain social processes (Orlikowski & Baroudi, 1991). The interpretation is subjective and sustained in a particular setting (ibid.). In this way, researchers' backgrounds and the contexts of research phenomena can influence the research findings (ibid.).

4.1.1 Role of the researcher

Walsham (1995) suggested that a researcher should choose the role of an outside observer or an involved observer to obtain interpretations of the research phenomenon. Each role has its own strengths and weaknesses. An outside observer is at a distance from the studied organization and therefore has no direct personal interest in the interpretations and outcomes. Because of this, study participants can be relatively frank when expressing their views. Involved observers, meanwhile, insert themselves in the participant group for a period of time and therefore have better access to data but might be biased in their interpretations (ibid.).

I conducted the case studies as an outside observer for two reasons. First, maintaining distance from the studied organizations helps limit bias in the research. Second, the data came from different construction organizations in two countries. Joining one of the organizations was not an option within the time frame of this study.

4.1.2 Role of theory

This thesis adopted the institutional isomorphism framework, the Institutional Intervention Model, and the open innovation approach to guide the data collection. These theories were also the foundations of coding categories in the data analysis process.

Regarding the selection of theories, Walsham (2006) offered three suggestions. First, theories can be chosen in different phases of a thesis. Second, researchers can use them in a light or tight way. Third, theory selection is based on the researcher's experiences, background, and interests. I adopted these suggestions in this thesis. Initially, the theoretical lenses were institutional isomorphism and the Institutional Intervention Model. During data analysis, I found that the chosen theoretical lenses did not sufficiently explain a part of the data from the BIM community cases. Therefore, I added open innovation to the theoretical foundation to improve my interpretation of the innovation phenomenon. Second, I used the theories in a light way, focusing on their practical implications. The theories were the initial guides for establishing my research design, data collection and analysis processes. Third, I selected the theories because I found their explanation capacities fit the construction industry and community.

4.1.3 Research strategy

Consistent with the interpretive philosophy, this thesis adopted a qualitative approach to studying BIM implementation. A qualitative approach is responsive to the research context and aims to develop a thick description for exploring and understanding research phenomena in an inductive style (Creswell, 2014; Fitzgerald & Howcroft, 1998).

Among the different qualitative methods, the interpretive case study method offered several advantages to this thesis. First, it has helped IS researchers develop thick descriptions of organizational inquiries (Walsham, 1995). Second, interpretive researchers acknowledge it as a suitable means of answering "why" and "how" research questions (ibid.). Third, IS researchers have used it to explore a broad range of topics (ibid.).

I chose a multiple case study research design (Yin, 2017) because it supports the exploration of research phenomena across different situations, allowing for an understanding of the influences from similarities and differences between the cases studied (Baxter & Jack, 2008). This capacity enables researchers to draw useful lessons for BIM implementation in different contexts.

4.2 Case selection

The cases were selected based on the criteria below.

i. Participated in construction industry.
ii. Had experience implementing BIM.
iii. Was willing to provide information for the research.

The selected countries were Norway and Vietnam, representing a developed and a developing contexts, respectively. I chose Norway as an example of a developed country because of its successful history of BIM implementation. Some public agencies have formally requested that BIM be used in their projects. For example, Statsbygg made BIM compulsory in their projects and has made various contributions to BIM practice through the BIM Task Group and bSN (Haug & Rødningen, 2016). The latter has introduced many BIM best practices and prepared guidelines for applying open BIM in the country (ibid.). The selected cases in Norway were the InterCity Project and the bSN.

I chose Vietnam as an example of a developing country because of the high growth rates of its economy and construction industry. The Vietnamese average growth rate from 2000 to 2015 was 6.47% (General Statistics Office of Vietnam, 2016). In comparison, the average growth rate of developing countries from 2000 to 2015 was 4.28% (United Nations Conference on Trade and development, 2019). Since growth is partially enabled by high investment in infrastructure (The United Nations Economic Commission for Europe, 2016), the high growth rate indicates that Vietnam was investing in infrastructure. Insights into BIM implementation will support Vietnam in building infrastructure more effectively.

4.2.1 The InterCity Project

The InterCity Project entails 270 km of railway and 25 new stations connecting Oslo, Lillehammer, Halden, Porsgrunn, and Hønefoss in Eastern Norway. The new line will increase train traveling speeds to 250 km/h, and the travel times between cities will be reduced by 35%–42% of today’s travel times (Bane NOR, 2017). The project consists of four lines: Dovrebanen, Vestfoldbanen, Østfoldbanen, and Ringeriksbanen. I collected data during the design stages of the Dovrebanen line, a 75-km double track from Sørli to Lillehammer. Bane NOR, the Norwegian railroad administration, plans to complete this part of the project by 2034. The new line will reduce the travel time from Oslo to Lillehammer by 50 minutes, or 38%. The project plans must pass two approvals at the municipal level before they are started. This case study was conducted in the second quarter of 2017, when the design was ready for the second municipal approval. A screenshot of the Dovrebanen BIM model can be found in Figure 1.

Figure 1. Screenshot from the Dovrebanen BIM Model
(© 2017 Helga Nes, RIFs årsmøte, BaneNOR)

I chose to focus on this part of the project for several reasons. The first criterion was that the project participants resembled a typical constellation of actors involved in the design of railway projects, which was necessary to ensure that my research captured how institutional pressures influence BIM-based work. The second criterion was a project in which digital modeling technology was used in the design stage. The third was that I needed a railroad project in which BIM had been implemented with some success. The Dovrebanen project fulfilled this criterion, as the project team won the Autodesk 2016 AEC Excellence Award, which recognized their successful BIM application.

4.2.2 The Thu Thiem 2 Bridge project

The subject of this case study was a large infrastructure construction project in Vietnam. The 1,473-meter-long bridge is one of five connections crossing the Saigon River in the center of Ho Chi Minh City. The cable-stayed construction is set to become a landmark in the region thanks to its pylon's height of 111 meters above water level. The bridge, which links the Thu Thiem district to the old city center, features six traffic lanes and two pedestrian walkways on either side of the deck. In 2008, Ho Chi Minh City Council (HCMC) allocated €80 million to fund the project. Once enough land was acquired to begin construction in February 2015, a private corporation, Dai Quang Minh (DQMC), was appointed to oversee the bridge design and construction activities and has been in the client role since the agreement was signed. The agreement included deploying BIM technology throughout the design and execution phases (Tuoi Tre Newspaper, 2015). The city's intention was to embrace the use of BIM following a wider national strategy seeking to increase digitalization in the Vietnamese construction industry (an example of the BIM models used in the project is depicted in Figure 1). In addition to requests from the city, DQMC must also comply with national construction regulations monitored by relevant authorities, such as the Department of Transportation, the Ministry of Construction, the Ministry of Transportation, and the Institute of Construction Economics (ICE).

A Finnish consultancy (WSP Finland Øy) was appointed to work alongside the local consultant (TEDI South) to deliver the bridge's engineering design. The BIM vendors supplying the software and ICT support were from Finland and were called Viasys VDC and Tekla. All the project partners had to follow Vietnamese regulations.

I selected the Thu Thiem 2 Bridge project for several reasons. First, it constitutes Vietnam's first implementation of BIM technology in an infrastructure project, and the institutional context of BIM software implementation in Vietnam is poorly understood. Second, this project is viewed as an international leader; this was signified by the team's winning of the international Tekla Finland and Baltics BIM Awards for the bridge design in 2017, which indicates that studying this advanced practice may yield important insights for companies elsewhere. Moreover, international collaborators on this project seemed to have worked well together, with the Finish consultants named creative company of the year by the Embassy of Finland in Hanoi for their contribution to Finnish-Vietnamese relations. Finally, the knowledge and experience gained by local engineers are likely to shape the development of Vietnam's national BIM standards for infrastructure.

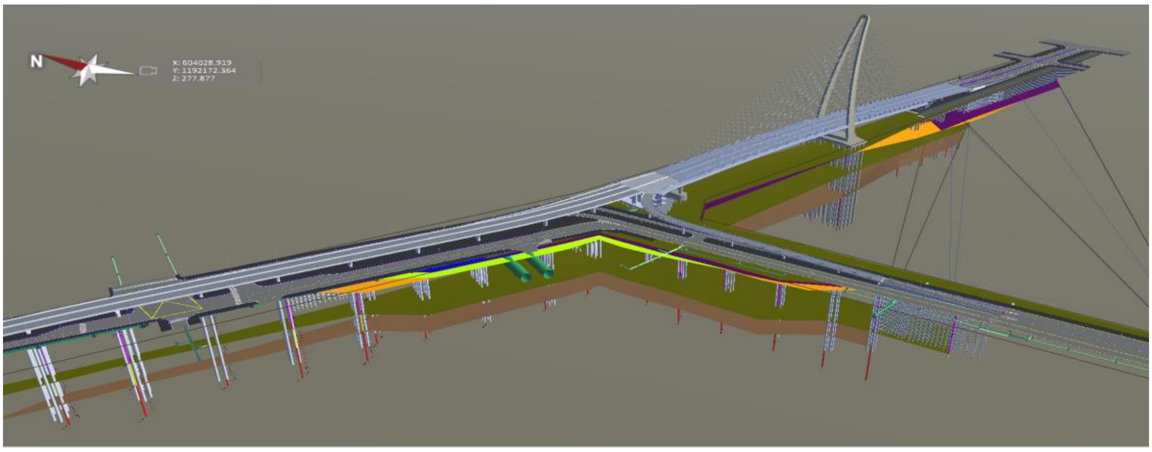

Figure 2. Thu Thiem 2 Bridge in Ho Chi Minh City, Vietnam
[Courtesy TEDI South]

4.2.3 The bSN community

bSN is a member of buildingSMART International. The establishment of bSN began with a Norwegian construction delegation's visit to the Singapore Building and Construction Authority in 2003. During that visit, the Singaporean agency showcased the use of BIM and IFC for developing and sharing electronic plans. Impressed, the Norwegian delegation decided to establish an organization to promote openBIM in Norway. Since the establishment, bSN has initiated various BIM-related activities and exerted positive influence on the dissemination of openBIM. These activities include participating in standardization, organizing hackathons, preparing BIM tool training, organizing annual conferences and meetings, arranging different discussion groups, and providing BIM-related information (buildingSMART Norway, 2019b). In 2010, Statsbygg began requesting the use of openBIM in their projects (Merschbrock & Rolfsen, 2016), making Norway the first country to do so. Statsbygg was also an active member in the establishment of bSN. Besides Statsbygg, other Norwegian organizations have also adopted the open approach to BIM, such as the Norwegian National Rail Administration (Bane NOR) and various software vendors and consultants. At the time this study's data collection, bSN had 131 organizational members, including government agencies, software vendors, contractors, consultants, universities, and standardization organizations. bSN's organization fits well into the scope of the open innovation community, and the group is an example of successful openBIM promotion. With positive influence, diversified activities, and different types of members, bSN is a suitable case for exploring how an innovation community advances BIM technology in construction.

4.2.4 The BVC community

The BVC was established in 2015 so Vietnamese construction practitioners could share experiences implementing BIM, and its members are people working in the Vietnamese construction industry. Similar to bSN, the BVC has no restrictions related to joining their activities. Both bSN and the BVC are nonprofit organizations.

At the end of 2018, the BVC had nearly 3,200 registered members, all of whom were individuals. The community's Facebook group has been the main communication channel since its establishment. BVC members come from different types of construction organizations, such as government agencies, state and private companies, associations, and universities. Its main activities are seminars and BIM tool training workshops. At the time of data collection, the BVC seemed more active than other Vietnamese BIM communities, with various online and offline events.

4.2.5 Connecting the cases

As mentioned in the research strategy section, a multiple case study design allows for the comparison of the differences and commonalities of BIM practices in various contexts. To ensure the research leads to useful findings, comparisons should be performed in a meaningful way. Figure 3 presents how the four studied cases were connected.

Case 1 and Case 2 provided data on BIM implementation in a developed and a developing country. In these infrastructure projects, BIM was either piloted or applied for the first time. These two cases revealed institutional influences on infrastructure projects (SQ2). Further, the cross-case analysis of the two infrastructure cases revealed useful suggestions for BIM implementation in a developing context. These suggestions are this thesis's primary contributions. Case

3 (bSN) and Case 4 (BVC) were selected to explore BIM innovation in construction communities. These communities are not only in different contexts but also at different phases of development. The insights from these innovation cases described how construction communities innovate with BIM (SQ3). Similar to the BIM implementation study, the cross-case analysis of the two construction communities provided insights not only into innovation but also how to use community resources for BIM implementation in infrastructure projects. The insights from the cross-case analysis of BIM communities are supplemental to the primary contributions mentioned above.

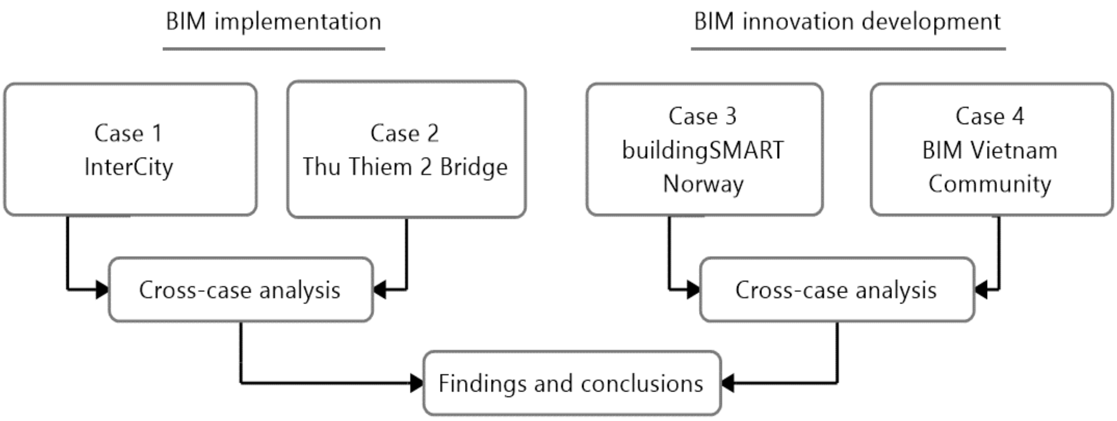

Figure 3. Research design

4.3 Data collection

Data are essential to responding to research questions, and flawed data provide unreliable answers regardless of how good the analyses are (Politano et al., 2017). This section presents how the applied data collection techniques, including interviews and document analyses, gathered the information required for my interpretive inquiry.

4.3.1 Interviews

Interviews are a primary method in qualitative research because they can collect thick descriptions of a given research topic (Oltmann, 2016). Therefore, this thesis adopted them as its main data collection technique. I developed Interview guides based on the institutional isomorphism framework and Institutional Intervention Model I used in the BIM implementation and BIM community cases, respectively.

The interviews were semi-structured because that format helps researchers collect individual thoughts through open-ended questions (Adams, 2015). Because of this approach, the data consisted of different views and provided an understanding of the research topic. Table 3 below describes the data collection methods used in the cases.

Role	InterCity Project	Thu Thiem 2 Bridge Project
Project managers	Planner (responsible for route planning) Project leads (managed overall performance)	Project leads (managed overall performance)
Technical experts	Railway engineers Geologist	Geologists Bridge engineers
BIM managers and coordinators	Digital transformation expert (implemented BIM, prepared BIM handbook) Project coordinators (connected relevant disciplines)	Digital transformation experts (implemented BIM, adapted to local regulations) Project coordinators (connected relevant disciplines)
Interviews	10	11
Data collection	May 2017–June 2017	June 2017–July 2017

Table 3. Roles and functions of interviewees in BIM implementation studies

For the BIM implementation studies, the interview guide was comprised of 17 open-ended questions, allowing interviewees to share their experiences with BIM-based work (see Appendix A). The opening questions were aimed at learning about their professional backgrounds and roles in the project. The next three thematic areas were designed to capture the regulative, normative, and cognitive elements (Dimaggio & Powell, 1983) the interviewees experienced in their BIM work. The questions captured how institutional pressures manifested in quotidian project activities (e.g., experience sharing and training), work materials (e.g., certificates, standards, models, and procedural guidance), and in the actors' documentation related to BIM. The interviews concluded by asking interviewees to identify the principal elements that inspired them to adopt BIM technology. Table 3 gives an overview of the roles and activities of the interviewees in the two BIM implementation studies.

For the BIM innovation studies, the interview guide included two sections (see Appendix B). The first focused on the working experiences and backgrounds of the interviewees. The second consisted of nine open questions related to community activity and the interviewees' participation. Developed using the Institutional Intervention Model, these nine open questions identified different forms of community action. I also asked follow-up questions to get as much detail as possible. Table 4 describes the roles and activities of the interviewees from the Norwegian and Vietnamese BIM communities.

Role	bSN	The BVC
Community lead	Chairman of construction association (led the roadmap for BIM in Norway) Manager (organized bSN activities)	
BIM tool developers	Directors (led BIM tool developments) Managers (led BIM implementation)	
BIM managers and consultants	Consultants (led and implemented BIM strategies)	Consultants (led and implemented BIM strategies) Managers (led BIM implementation at construction sites and design departments) Bridge experts (implemented BIM in bridge projects)
University	Lecturers (performed BIM research and education)	Lecturer (performed BIM research and education)
Standardization	Managers (coordinated BIM standardization at the local and international levels)	
Interviews	11	10
Data collection	Nov 2018–Jan 2019	Sep 2018–Jan 2019

Table 4. Roles and functions of interviewees in BIM innovation studies

4.3.2 Document analyses

Document analyses can provide data for qualitative research without the intervention of investigators (Bowen, 2009). This thesis used this method to obtain additional information from the studied cases. The collection process included finding, selecting, and analyzing the relevant documents from the studied cases. The purpose of this process was to provide initial understandings of the infrastructure projects and community activities before the interviews. For example, information on the Thu Thiem 2 Bridge was collected in advance to grasp the project's organizational structure, parties involved, expectations, and obstacles. The data sources were online articles, the investor's websites, and the consultants' websites.

4.4 Data analysis

Analyses help researchers interpret meaning in the data they collect (Kawulich, 2004) and develop insights into the cases they study. The data in this thesis were mainly gathered from interview recordings and field notes. I used NVivo to facilitate the analyses. The procedure I used is described below.

- I gathered relevant documents, recordings, and field notes.
- I transcribed interview recordings.
- I imported the texts into Nvivo.
- I created categories based on the theoretical frameworks.
- I developed categories to capture ideas fell outside the theoretical frameworks based on my analysis of the transcripts.
- I coded the texts to assign quotes to relevant categories.
- I prepared my initial findings and sent them to interviewees and colleagues for feedback.

I transcribed and coded the recordings from the BIM implementation studies by importing documents into NVivo. I placed interviewees' statements into Nvivo nodes that identified interviewee backgrounds and the coercive, mimetic, and normative features of the isomorphism framework (Dimaggio & Powell, 1983). I listed any statements that did not fit into these categories as "Other Opinions". Appendix A has more details about the coding categories, including examples. The statements in each category revealed the meaning of the institutional effects on BIM implementation in the InterCity and Thu Thiem 2 Bridge projects.

I also transcribed and coded the interview data from the BIM innovation studies in NVivo. I used the Institutional Intervention Model (King et al., 1994) as an analytical framework, and the six institutional actions described in Section 3.3 formed the nodes. Additionally, the background of the interviewees and other opinions about BIM comprised two more nodes in the analysis. The “Other Opinion” category covered any statements that fell outside the framework and revealed member’s motivations for participating in the community work. Appendix B has more details about the coding categories, including examples. The coded statements described how and why bSN and the BVC contributed to BIM innovation.

After the analyses, I sent the initial findings to interviewees for feedback. They had one month to respond. Come the deadline, only Paper 4 received feedback from two interviewees; it did not require modification.

4.5 Quality criteria

Assessment criteria were necessary to ensure the quality of this research. To assess the quality of interpretive studies, researchers apply evaluation frameworks. Some examples include trustworthiness criteria (Guba & Lincoln, 2001), the seven principles (Myers & Klein, 2011), and the big tent criteria (Tracy & Hinrichs, 2017). I chose the big tent model because it is considered the most comprehensive and is comprised of the following eight criteria: (1) worthy topic, (2) rich rigor, (3) sincerity, (4) credibility, (5) resonance, (6) significant contribution, (7) ethics, and (8) meaningful coherence. Below, I describe how I addressed these criteria. Since ethical issues are critical to the case study method, the criteria are mentioned in the next section.

The research topic is worthy because it is relevant to the IS discipline and researchers who examine the use of BIM in construction. This thesis describes the interactions between construction practitioners and BIM, an information system facilitating digital collaboration. The research results contribute to the discourse on BIM implementation in developing countries. Another audience of this thesis is practitioners who are implementing BIM in infrastructure construction. The insights from this thesis support more effective implementations of BIM. Furthermore, the topic is timely in that the research can support developing countries as they improve their infrastructure so that they can achieve their Sustainable Development Goals by 2030.

To achieve rich rigor, this thesis uses an interpretive case study method to examine its topic. I gathered much of the data from interviews with construction practitioners. I also drew on other data sources, such as documents, online articles, and newsfeeds, to validate the interviewee’s statements. The chapters on my theoretical frameworks and methodology provide more detail on how I collected and analyzed data. This thesis resulted in suggestions for effective BIM implementation in infrastructure projects and BIM innovation in construction communities. The detailed transparency of how data were collected and analyzed are reflective of this thesis’s rigor. Further, I sent final drafts of the case studies to interviewees for feedback, which also increased the overall rigor.

The sincerity criterion relates to the transparency of the biases inherent in a researcher’s background and present in the research (Tracy & Hinrichs, 2017). In this thesis, my motivation and background were presented in the introduction. Further, my experience in the Vietnamese infrastructure sector influenced my interpretation of the interviewees’ views on applying new technology to bridge projects. My experience also led me to focus on management- and regulation-related issues, thus creating a possible bias in my interpretations of BIM implementation. My interpretations of the InterCity Project also included a similar bias. My background has no specific influence on my interpretation of the construction community studies.

To achieve credibility, this thesis includes thick descriptions of BIM implementation and innovation in two contexts. I not only discussed the findings with my supervisors and co-authors but also with the interviewees. The interviewees received completed manuscripts for feedback before submission. My colleagues at Oslo Metropolitan University were also invited to provide feedback on the manuscripts. Furthermore, I discussed the research findings in conferences, such as Creative Construction 2016, PACIS 2018, ISD 2018, and BIM 2019. In this way, the manuscripts were reviewed both by researchers and construction practitioners to ensure the credibility of the research.

Resonance is about the impact of research on readers via manuscript aesthetics, relatable generalizations, and transferable findings (Tracy & Hinrichs, 2017). By describing the studied phenomena in detail, researchers help their readers connect the findings to their own experience (ibid.). In this thesis, I have informed the reader of contextual influences by providing descriptions of BIM practices in Norway and Vietnam. These two countries represent developed and developing contexts, respectively. The findings are transferable to similar contexts, such as other developing countries or other types of infrastructure projects.

I also aim to provide significant contributions to the IS discipline and IT research on construction. Regarding the former, this thesis broadens the understanding of institutional pressures on BIM implementation and the understanding of institutional actions' influence on BIM innovation in construction communities. These contributions extend the discourse on the use of IS in construction. My findings describe issues with implementing an ICT system in various construction contexts. Further, I present findings on how construction communities in different phases of development pursue innovation. Regarding IT research in construction, my findings offer direction on how to improve BIM implementation in infrastructure projects. Prerequisites and suggestions for successful BIM adoption are outlined in the Contributions Chapter. Further, the BIM innovation studies offer insights into how knowledge can be better acquired by professional communities.

The meaningful coherence criterion was secured by the alignment of the research question and methodology. I began the research with a systematic review of BIM implementation in developing countries. The review identified research gaps in infrastructure, facility construction, professional community activities, and the lack of BIM studies in a large part of the developing world. The review results directed the research focus. To arrive at solutions for improving BIM use in infrastructure construction in developing countries, I applied an interpretive case study method, which generated thick descriptions of the BIM implementation and innovation cases. Furthermore, my findings are discussed in comparison to related BIM studies to highlight my contributions to the literature. The case study findings are useful not only to infrastructure projects in Vietnam but also in other developing countries with similar contexts.

4.6 Ethical considerations

The case study method raises ethical considerations such as freedom of participation, the influence of research on the on-going work, and confidentiality (Queirós et al., 2017; Widdowson, 2011). The first consideration shapes the approach to the interviewees. After sending the research participation invitations to potential interviewees, I only contacted recipients who agreed to conduct interviews. Before the interviews, the interviewees received letters of consent informing about the confidentiality, and how the provided data would be used. The interviewees were free to withdraw from the research at any time if they felt inconvenient. By providing the description of how the data was collected and analyzed, I ensured the freedom of participation for the interviewees.

Furthermore, I applied the anonymous principle to limit the research influence on the interviewees' work and secure confidentiality. In this research, the collected data includes the interviewees' experiences with clients, relevant authorities, colleagues, managers, and companies regarding BIM implementation. The fear of negative consequences from the recorded statements might hinder interviewees to provide relevant information. Therefore, the anonymous principle was applied during the research by assigning codes to the interviewees instead of using their names and excluding any statements which could expose their identities. The interviewer informed the interviewees about the anonymous principle before the interviews started. Furthermore, the interviewees received the completed manuscripts and had one month to check for any issues related to anonymity and any possible influence on their on-going work. After the deadline for feedback, the interviewees did not return any such concerns.

5 Results

This chapter presents the five publications that addressed the sub-questions stated in Chapter 1. These articles were published in peer-reviewed journals and conference proceedings, as listed in Table 5. Reflecting the interdisciplinary focus of this study, the selected outlets were both from IS and construction management. The full versions of the articles are included in Appendix C.

1. Bui, N., Merschbrock, C. & Munkvold, B. E. (2016). A review of Building Information Modelling for construction in developing countries. *Procedia Engineering*, Vol. 164**,** 487-494.
2. Bui, N. (2019). Implementation of Building Information modeling in Vietnamese infrastructure construction: A case study of institutional influences on a bridge project. *The Electronic Journal of Information Systems in Developing Countries*, Vol. 86, Issue 4.
3. Bui, N., Merschbrock, C., Munkvold, B. E. & Lassen, A. K. (2018). An institutional perspective on BIM implementation – a case study of an intercity railway project in Norway. *27th International Conference on Information Systems Development (ISD2018).* Lund, Sweden.
4. Bui, N., Merschbrock, C., Munkvold, B. E. & Hjelseth, E. (2019). Role of an innovation community in supporting BIM deployment: the case of buildingSMART Norway. *WIT Transactions on The Built Environment*, Vol. 192**,** 329-342.
5. Bui, N., Merschbrock, C., Munkvold, B. E. & Hjelseth, E. Understanding open innovation in BIM implementation: A cross-case analysis of construction communities in Norway and Vietnam. Under review for *Construction Management and Economics*.

Table 5. List of publications

Paper 1: A Review of Building Information Modelling for construction in developing countries

Focus: Most developing countries face large knowledge gaps and can be characterized by limited and occasional technological innovation (World Bank, 2015a). Wells (2001) reported that the output per construction practitioner in developing countries is approximately one-ninth of that of workers in high-income economies. Since construction is a driver of the economy (Adams, 2004; Anaman

& Osei-Amponsah, 2007; Giang & Pheng, 2011), leveraging technology to improve its efficiency is a promising area for development. It has been suggested that construction projects will be more effective and productive with ICT applications (Latiffi et al., 2013). BIM can offer many benefits to construction. By presenting the status of BIM implementation in developing countries, Paper 1 identified areas for improving construction efficiency for developing economies.

Findings: Paper 1 isolated BIM-related articles with a focus on developing countries and work that was published before 2016, and it classified them under a BIM implementation framework (Jung & Joo, 2011). This framework included three dimensions technical consideration, perspective-based considerations, and construction-based considerations. In total, 25 articles were identified. The scope of the research was limited to topics related to technology transfers, importing technology, standards, and approaches to collaboration in developed countries to the context of developing countries. Limited attention was given to BIM implementation in infrastructure and facilities projects in developing countries. The collected scholarly works noted that China (13), Malaysia (9), and India (3) were pioneers in BIM studies before 2016. The technical aspects of BIM were the main focus, consisting of 12 (48%) articles. In this category, researchers focused their inquiries mainly on implementations of commercially available BIM software packages made by software vendors located elsewhere. Researchers also debated how this could be accomplished by focusing on open file exchange formats, such as IFC, in software development. Judging from the articles reviewed, there appeared to be a need for researching and creating local BIM software adaptations customized to various developing countries. This constituted an important area for further research. The perspective and construction business function categories received less attention. However, the articles belonging to these categories revealed the important role of government in removing major barriers to BIM implementation as well as the need to receive technology transfers from more developed contexts.

Contributions: Based on a systematic review of the literature, Paper 1 presented an overview of BIM research in developing countries and identified gaps in BIM research in that context. To address these gaps, future researchers may focus on (1) how professional communities and industry clusters promoting BIM can be cultivated in developing countries, (2) approaches or requirements for BIM collaboration, and (3) the development of an effective strategy for BIM implementation. In-depth comparisons between developed and developing contexts might be another interesting area to explore.

Paper 2: Implementation of building information modelling in Vietnamese infrastructure construction: A case study of institutional influences on a bridge project

Focus: Following the suggestions from Paper 1, Paper 2 provided an understanding of BIM implementation in a developing context. It contributed to the field by exploring institutional effects (Scott, 2014) on organizational behavior in the context of BIM implementation. This contribution was the result of a case study on the Thu Thiem 2 Bridge. IS development literature was expanded by Paper 2's examination of how BIM can be institutionalized and thereby increase construction firms' efficiency in a development context.

Findings: Using the institutional isomorphism framework, Paper 2 described how the effects of institutional pressures led to successful BIM implementation in the Thu Thiem 2 Bridge project. The successful factors were support from authorities and guidance from a BIM champion. A BIM champion is a person with the technical skills and motivation to lead an organization's BIM implementation (Messner & Anumba, 2013). Additionally, the project team had to overcome three barriers that hindered innovation. These barriers originated from mandatory construction regulations, such as paper-based submissions, cost estimate regulations, and the technological capacity of Vietnamese companies. Mimetic pressure became coercive, and the BIM champion conducted various seminars and workshops to provide BIM knowledge to the client and authorities. After the authorities acknowledged BIM's benefits, they recommended that project owner formally request BIM. This was the reason the local consultant applied BIM. The consultant had a strong motivation to seek related knowledge and collected it not only from other project members but also outside sources, including short courses, workshops, seminars, conferences, and online channels. In this way, the local project team exposed itself to mimetic and normative pressures. The support of the authorities and the acquisition of knowledge made BIM implementation successful in the Thu Thiem 2 Bridge project.

Contributions: Paper 2 described how the project team overcame traditional barriers to implement BIM. Using the institutional isomorphism framework, Paper 2 revealed important factors in successful BIM adoption. The description of institutional effects contributed to understandings of BIM implementation in the IS discipline. The project team's experience might be transferable to other projects in similar contexts. Further, this paper suggested some suitable topics for future studies, such as the gap between local requirements and software capacity, the influence of authorities, the role of BIM champions in consultant teams, and the role of the construction community in adopting new technologies in a local context.

Paper 3: An institutional perspective on BIM implementation – a case study of an intercity railway project in Norway

Focus: Paper 3 presented BIM implementation in the Intercity Project in Norway. Since InterCity was the first Norwegian railway project to use BIM, this case study served as a BIM pilot project in the context of a developed country. Paper 3 applied the institutional isomorphism framework (Dimaggio & Powell, 1983) to describe the implementation process. Understanding institutional effects on this BIM-based work might be a good starting point for other construction project teams seeking to implement the technology in their projects because they can draw on the insights that motivated the InterCity Project team.

Findings: Paper 3 described how institutional pressures influenced BIM implementation in the InterCity Project. The contracts with the consultant implied coercive pressures by requesting 3D model delivery. The contract terms provided a solid reason to apply 3D modeling, but the level of detail required for the model was insufficient. The client could influence BIM practices in projects depending on a combination of top management support, contracts and rules, and the degree of BIM expertise present in their organization. Coercive pressures exerted by the municipalities also influenced the digital modeling.

Normative pressures influenced the project team members who participated in professional and social networks. There was considerable peer pressure in Norwegian professional communities to use digital modeling. While the project team's reasons and motivations for BIM implementation resulted from coercive and normative pressures, the process of BIM implementation followed best practices from other projects, thus revealing the influence of mimetic pressure.

Contributions: Paper 3 identified how institutional pressures affected the project team's BIM implementation in the InterCity Project. Further promoting successful BIM diffusion in railroad projects would require all three institutional pressures to take effect. Paper 3 also provided insights into technology implementation that could be transferable to other projects and countries. From a theoretical perspective, the InterCity case indicated a hierarchy of institutional pressures, which might be an interesting topic for future studies.

Paper 4: Role of an innovation community in supporting BIM deployment: the case of buildingSMART Norway

Focus: Paper 4 explored the role of construction communities in supporting BIM implementation. The data were collected from bSN. To make sense of them, I adopted the Institutional Intervention Model (King et al., 1994), which describes different institutional actions that drive innovation.

Findings: Paper 4 identified the important role of community leaders, who should have strong technical competences and be able to unite their communities. In addition to strong leadership, bSN members derived both commercial and social benefits from participating in their community. The commercial benefits included support for a prototype and the acquisition of knowledge. Members presented examples of business services they developed based on community input, such as using IFC to visualize BIM models via an online portal. The social benefits were the business relationships that came from making contributions to the community and included member's motivations to participate in it.

All six forms of institutional action specified in the Institutional Intervention Model were found in the bSN case. However, knowledge building and subsidy were the key actions. These actions appeared in many activities, including hackathons, student awards, and the employment of four full-time staff. Furthermore, the community activities included inside-out and outside-in knowledge flows, which were indicative of an open innovation approach (Chesbrough & Bogers, 2014) in bSN.

Contributions: Paper 4 expanded the understanding of BIM innovation in construction communities. The bSN case highlighted the importance of leadership and members' motivations to contribute their resources to the joint development of BIM. To innovate, construction communities should focus on knowledge building and subsidy. Additionally, Paper 4 showed how a construction company turned community contributions into business values.

Paper 5: Understanding open innovation in BIM implementation: A cross-case analysis of construction communities in Norway and Vietnam

Focus: Paper 5 explored how institutional actions influence construction communities as they innovate with BIM. Its purpose was to broaden knowledge of how construction communities support innovation and how their members benefit from community work. To fulfil the research purpose, Paper 5 presented a cross-case analysis of the bSN and the BVC communities through the lens of the Institutional Intervention Model (King et al., 1994). Paper 4 also described how bSN supports BIM implementation in a local market.

Findings: The findings revealed similarities and differences in the communities' influence of industrial practices. Members of both bSN and the BVC were willing to contribute to their communities on voluntary bases. Sponsoring events and working hours were prominent types of contribution. Further, bSN members paid a membership fee, which is the main resource for the community's operational budget. The membership fee constituted a large part of the bSN budgets, which allowed for the employment of four full-time management staff. These staff members played an active role organizing activities, particularly connecting members, and finding sponsors for events. Members' main motivations were relationship building and corporate social responsibility, the principles of which require companies to consider the ethical and economic aspects of business activities (Bevan & Yung, 2015). In this light, ethical considerations motivate construction companies to contribute to community work. While bSN followed the management of buildingSMART International, the BVC organized activities using only ideas from the steering board. The guidance from buildingSMART International also directed bSN's innovation efforts toward open standards. In contrast, members paid no fee to join the BVC's activities, which relied on a voluntary steering board. The BVC's innovation directions stemmed from members' initiatives and had a strong focus on adapting new BIM tools to the local context. Despite these differences, both bSN and the BVC acquired new knowledge, facilitated the sharing of experiences, and supported members in adopting BIM.

Contributions: Paper 5 described the influence of institutional actions on construction communities innovating with BIM. The insights from the cross-case analysis provided examples for other construction communities seeking to innovate. The paper found that the key to innovation is knowledge building, which generated innovative ideas related to the use of BIM. The resources for knowledge-building activities stem from members and include working hours, membership fees, and the sponsoring of research projects. Further, community management boards should disseminate knowledge to members through different communication channels to ensure BIM innovation. This paper also presented the Institutional Intervention Model's capacity to explore the innovation activities of professional communities. The findings revealed that all institutional actions were used, and knowledge building, knowledge deployment, subsidy, and mobilization are particularly important.

6 Contributions

This chapter presents practical and theoretical contributions, which constitute the central value of this thesis. Construction practitioners can benefit from the practical contributions, including the understanding of BIM implementation in infrastructure construction and BIM innovation in communities. By applying institutional theory to explore BIM implementation challenges in the construction industry, this thesis provides theoretical contributions to the IS discipline.

6.1 Contributions to practice

The cases I studied not only addressed research gaps but also provided implications for construction practitioners seeking to implement BIM in infrastructure construction and innovate with BIM in their communities. Here, these practical implications are presented in two subsections. The first describes how project teams use the experience of members and construction communities to overcome barriers to BIM implementation. The second explores how construction communities encourage practitioners to generate BIM innovations. BIM innovations, in return, support the implementation process and increase the uptake of the technology.

6.1.1 BIM implementation in infrastructure construction

This subsection presents three key findings that project teams can use to implement BIM when prior experience is limited. This thesis's findings reveal that project members can gather suggestions for implementation from construction communities, that they can learn from similar projects, and that they can leverage project members' experience. First, project teams can learn how clients support the implementation process. Second, they can learn how BIM champions lead project teams in overcoming obstacles. Third, they can learn how BIM implementation benefits construction communities. By participating in construction communities, project members can discuss problems that they are dealing with and be exposed to the innovative solutions of other members. Innovative solutions are supportive of the BIM implementation process.

(1) Clients are crucial: With client support, the InterCity and Thu Thiem 2 Bridge project teams overcame barriers in their traditional processes and developed the technical capacity to apply BIM to infrastructure construction for the first time. This finding aligns with the survey studies conducted in China and Hong Kong (Cao et al., 2014; Chan, 2014; Dakhil et al., 2019; Lindblad & Guerrero, 2020) in which researchers identified clients and government authorities as the main drivers of BIM. In this thesis, the findings illustrate how clients support BIM implementation in a developing context.

Project guidelines are useful to the development of national BIM guidelines. BIM guidelines focus on describing BIM requirements and deliverables (AbuEbeid & Nielsen, 2018). Another focus of BIM guidelines is identifying the roles of different project stakeholders (ibid.). Without guidelines, stakeholders need to negotiate these details before every project implementation. By using national guidelines, construction companies can save resources on issues common to BIM implementation in infrastructure construction.

In the InterCity Project, the client formally requested BIM via the consultant contracts, which provided a solid foundation for BIM implementation. Furthermore, the client appointed a BIM manager to coordinate project consultants so that traditional barriers could be overcome and a BIM handbook for railway construction could be prepared. This collaboration saved time by solving repeat issues by leveraging BIM experience of the project consultants. In this way, the InterCity Project team created a unified approach to using BIM in future railway projects.

Similar to the InterCity Project, the client of the Thu Thiem 2 Bridge project also stated terms for BIM application in consultant contracts and offered a budget for applying the new technology. Since the Vietnamese government had no regulations related to the expenses of applying new technologies in construction, the costs of BIM implementation hindered the process. The client and the consultant team presented the benefits and costs of BIM implementation to the ICE, the government agency in charge of controlling construction cost regulations. The effort resulted in the ICE's consent. Based on that, the client officially allocated a budget for BIM. In this way, the client supported the project team in overcoming a barrier posed by traditional regulations. In addition, the project team also joined the government's pilot program of preparing BIM guidelines for the Vietnamese construction industry. Since the Thu Thiem 2 Bridge was the first bridge construction project in Vietnam to use BIM, the experience was considered useful to the development of national BIM guidelines.

The InterCity and the Thu Thiem 2 Bridge cases present two suggestions to clients implementing BIM. First, they should specify BIM outcomes through contractual terms and provide a budget for implementation. A lack of regulations on the cost of applying new technologies is a particular characteristic of the Vietnamese construction industry, and the case presented an example of how clients can support the project team in overcoming BIM barriers posed by traditional regulations in a developing context. Additionally, clients need to appoint BIM champions to secure BIM competences and lead the implementation process.

(2) BIM champions are essential: Along with a demand for BIM, clients require solid BIM knowledge to enforce its use in their projects (Bosch-Sijtsema et al., 2017). They therefore need BIM champions who possess the technical skills, knowledge, and motivation to lead the implementation (Azzouz & Hill, 2017). BIM champions support clients in securing predefined BIM outcomes (Dakhil et al., 2019). In their study of 213 projects at Arup (a British multinational consultant firm), Azzouz et al. (2016) found that the involvement of BIM champions leads to better implementation. The roles of BIM champions include training staff, guiding the implementation, promoting BIM activities and the related vision within the organization, and communicating BIM strategies to partner companies (Almuntaser et al., 2018; Baldwin, 2019). In both of my implementation studies, the clients hired a BIM champion to lead the implementation. The BIM champion in the Norwegian project led InterCity Project team in preparing a BIM handbook for railway construction. The handbook includes an open approach to data exchange. This is an example of how a BIM champion can promote BIM strategy within an organization. In the Vietnamese case, the BIM champion not only led training and the implementation process but also supported the client in communicating with the authorities, which led top management to assist in overcoming regulatory barriers.

The InterCity BIM champion had worked for a BIM software company for more than 20 years. Her main tasks were consulting on BIM implementations and offering BIM software training. In the InterCity Project, she led the reference group and involved consultants who shared their experiences and developed a BIM handbook for railway projects. All the InterCity partners were asked to use BIM tools that offered free data file readers, which constituted an open approach to data exchange. In this way, the InterCity Project team took a unified direction to fulfil traditional quality requirements with BIM tools. Since Norway had no BIM guidelines for railway construction before the InterCity Project, the BIM champion's leadership was essential.

The BIM champion in the Thu Thiem 2 Bridge project was the project manager who worked for the Finish consultant and had extensive experience leading BIM implementation in infrastructure construction. He not only led the project team but also demonstrated the benefits and requirements of BIM to the authorities. Based on their new BIM awareness, the authorities agreed with the client in offering the budget for BIM in the Thu Thiem 2 Bridge project. The agreement from the authorities was the legal basis for the budget.

The InterCity and Thu Thiem 2 bridge projects highlight the essential role of BIM champions in implementation. The implementation process requires expert leadership. This positive influence of BIM champions on internal training and leading project teams is reminiscent of what was reported in studies in Saudi Arabia, Australia, and New Zealand (Almuntaser et al., 2018; Davies et al., 2017). Additionally, this case revealed that BIM champions can also influence external stakeholders, such as clients and authorities, which is important because such stakeholders influence the adoption decisions made by top management. The influence of BIM champions on top management proved useful to BIM implementation in Vietnam. This might also be true in other developing countries.

(3) Project members can acquire innovative solutions to BIM implementation barriers from construction communities: Experience sharing in communities helped project members to find good practices. Project members frequently attended conferences and industry workshops to stay abreast of industry developments. It is quite common for engineering consultants to attend these events and present their work. Some examples of community activities mentioned by interviewees were national buildingSMART events, events hosted by Norway's BIM network, Nordic BIM collaboration workshops, and events held by software vendors. Other BIM discussions happen on online channels, such as YouTube and the Autodesk Community. Additionally, project members can benefit from training courses and community documents. The Vietnamese case revealed how the BVC localized foreign BIM standards and guidelines. Furthermore, BVC members offered free Revit add-in programming courses to other members. These courses enabled the participants to develop Revit add-ins to automate parts of construction tasks. The reference documents and programming skills gained from the community increased project members' BIM competence, and they had more options to resolve BIM implementation barriers. In particular, they had more resources to choose or develop BIM guidelines and use programming skills to cover the gaps between BIM tool capacity and local requirements.

Communities also benefited from innovative solutions. The bSN case presented openLab hackathons as good examples of communities generating innovative solutions. In the E39 Highway hackathon in Norway, Statens Vegvesen invited bSN members to provide ideas about applying open standards to the planning and execution phases of the E39 Highway project.

The cases revealed that project members can gain BIM implementation insights from community activities. However, community participation can consume considerable amounts of time. Furthermore, community activities, such as seminars and workshops, might occur during office hours, making it difficult for project members to participate. Therefore, support from clients and companies is necessary for project members to join community activities.

6.1.2 BIM Innovation in Construction Communities

In addition to research institutions, communities are another arena for innovation. Community members can develop technical standards, commercialize ideas, and share their experiences with the latest technologies (West & Gallagher, 2006), thus supporting implementation practices. Further, construction communities are aware of problems with BIM use that arise from discussions among members. This awareness is the foundation for generating innovative solutions to increase BIM uptake. Community deliverables, such as standards, implementation support, best practices, and innovative solutions, are valuable to community members. These deliverables motivate members to participate in community activities.

In the cases, the Norwegian and Vietnamese construction communities (1) illustrated how to motivate members and (2) created new BIM solutions. The key findings below constitute suggestions to construction community organizers and practitioners for better BIM innovation.

(1) Members must be motivated to build business relationships: Several factors motivated members of the Norwegian and Vietnamese BIM communities to participate in community activities. Significant motivations included business benefits, and members also focused on relationship building, which can result in future job offers or contracts. Community members created connections by sharing experiences, providing solutions, and offering training. These three key types of activity happened in both bSN and the BVC. While bSN had noncommercial and openBIM-oriented principles, the BVC had no limitations on its discussions.

In building relationships, trust is an important ingredient. For example, bSN's principles prevented its members from presenting their own products and services. Members recognized that they could better build trust in a noncommercial environment, and trust among members drives cooperative innovation. This finding is in line with other studies in which a trustful climate facilitated innovation (Savolainen & Ikonen, 2018; Srinivasan & Elley, 2018). Since members worked together on bSN activities, they built relationships with one another.

This thesis's findings suggest that building business relationships is an influential motivation for members participating in construction communities. Community leaders should focus on activities with a high level of interaction to attract members. Furthermore, a trustful climate is important to innovation.

(2) The free flow of knowledge among members must be facilitated: Both bSN and the BVC had open access to community knowledge. The flow of knowledge occurred in two directions: inside out and outside in. Since joint production is an important indication of a successful community (West & Gallagher, 2006), supporting knowledge sharing to create collective products might be an effective strategy for developing BIM communities.

Inside-out flows occur when community members use their expertise to contribute to the community. bSN members developed openBIM standards at the international level. With the expertise of the members involved in standardization, openBIM standards have become more effective in Norway as well as worldwide. In addition, bSN organized openLab hackathons, which were arenas for innovative solutions. In these hackathons, problem owners raise their requests for specific BIM applications and other participants proposed innovative solutions. BVC members, meanwhile, participated in presentations of new tools, translations of foreign standards, and the development of Revit add-ins. In these activities, members used their expertise to support others in their implementations of BIM.

Outside-in flows occur when members use community knowledge to develop their capacity. bSN members used IFC and the buildingSMART dictionary to develop BIM-related products. For example, Catenda built a web portal to facilitate BIM collaboration, and CoBuilder prepared a product data template to define a common structure for construction product properties. These members had been offering those products as business services. BVC members used translated standards shared in their community to define BIM requirements in business contracts. Some members applied the community add-ins to automate 3D model inputs.

In both communities, the free flows of knowledge indicated open innovation approaches (Chesbrough & Bogers, 2014). Open innovation can reduce development costs and allow access to underused patents (Chesbrough, 2007). Therefore, open innovation might be a means of developing BIM applications with limited resources. In the developing country context, this open approach might be promising. For better BIM innovation, community leaders should encourage members to share knowledge and organize activities that lead to the collective creation of products.

Table 6 summarizes this thesis's practical implications, including how BIM implementation in infrastructure construction can be improved and how BIM innovation in construction communities can be improved.

BIM implementation in infrastructure construction	
Clients are crucial	• Support in overcoming the barriers of traditional construction approval requirements. • Formally request BIM applications. • Appoint a BIM expert to lead the implementation. • Support budget allocation for BIM implementation. • Support project members in their development of BIM standards.
BIM champions are essential	• Lead implementation and internal training. • Lead BIM guide preparation. • Direct efforts to overcome implementation barriers. • Provide BIM knowledge to authorities.
Innovative solutions from construction communities are helpful to the implementation	• Acquire best practices from workshops, seminars, online channels, and online professional forums. • Prepare BIM guidelines and standards for BIM implementation at work. • Acquire programming skills through training courses to automate construction tasks and narrow the gap between BIM tools and local regulations. • Obtain innovative solutions through hackathons.
BIM innovation in construction communities	
Members must be motivated to build business relationships	• A focus on building business relationships. • The ability to create a trustful environment by promoting noncommercial activities.
The free flow of knowledge among members must be facilitated	Inside-out flows: • Facilitate knowledge sharing by presenting new tools, organizing seminars on BIM applications, etc. • Provide access to community knowledge, including standards and patterns. • Facilitate innovation by supporting student theses, issuing best practice awards, etc. Outside-in flows: • Invite members to suggest solutions to BIM challenges. • Develop business competences based on community knowledge.

Table 6. Practical contributions

6.2 Contributions to research

This section presents the theoretical contributions that arose from my application of the institutional isomorphism framework (Dimaggio & Powell, 1983) and the

Institutional Intervention Model (King et al., 1994). These contributions extend the understanding of institutional effects on BIM implementation and institutional actions on BIM innovation.

This thesis contributes to the BIM implementation literature. Its focus has been on how to implement BIM in different settings with limited experience of it and how construction communities can contribute to BIM practices. The focus arose from the systematic literature review of the BIM studies presented in Paper 1. The review identified BIM-related research gaps in developing countries, particularly in infrastructure construction and professional communities.

I used institutional isomorphism (Dimaggio & Powell, 1983) to analyze BIM implementation in Vietnamese and Norwegian infrastructure projects (Paper 2 and Paper 3). In these cases, institutional pressures pushed project members to implement BIM. Furthermore, institutional pressures motivated them to overcome the barriers traditional regulations pose to the adoption of new technology.

I used the Institutional Intervention Model as a theoretical foundation for exploring how construction communities pursue BIM innovation in Norway and Vietnam (Paper 4 and Paper 5). Responding to various institutional actions, the communities displayed different ways of connecting members and encouraging them to innovate together.

6.2.1 Institutional pressures on BIM implementation

The InterCity and Thu Thiem 2 Bridge projects were BIM implementation pilots in their construction domains. The project teams could not find similar projects that had used BIM. Therefore, the application of the institutional isomorphism framework provided insights into the institutional pressures a pilot project faces when experience is limited. I selected the isomorphism framework because it explains the innovation adoption behaviors of individuals and organizations (Lounsbury, 2008).

Researchers have applied the isomorphism framework to examine innovative practices in construction industry innovation. For example, mimetic pressures are the reason Turkish construction engineers use CAD technology (Kale & Arditi, 2010), and following innovative companies is the reason Singaporean construction companies adopt new technology (Dulaimi et al., 2003). In the context of BIM implementation, researchers have applied the isomorphism framework on national and organizational scales (Cao et al., 2014; Edirisinghe et al., 2016). This thesis builds on the innovation discourse in construction by reporting three key findings: (1) how team members exert mimetic pressures in pilot cases, (2) how clients and authorities exercise coercive pressures to support implementation, and (3) how demands for professionalization support implementation.

(1a) Mimetic pressures direct BIM implementation: Mimicking experience from similar projects is a solution for BIM implementation in pilot projects. This discovered importance of mimetic pressures on BIM implementation aligns with findings in other studies in Sweden and Hong Kong (Bosch-Sijtsema et al., 2017; Chan, 2014; Lindblad, 2016).

In the InterCity Project, the client's BIM manager played the leading role in implementing BIM. Under the leadership of the BIM manager, all InterCity consultants shared their experiences in the project reference group meetings to develop a BIM handbook for railway construction. In these meetings, project members had the opportunity to learn from one another and find the best way of implementing BIM.

In the Thu Thiem 2 Bridge project, the Finish and Vietnamese consultants learned from one another to fulfill local requirements by the 3D modeling technology. On the Finish side, the project manager organized the training and implementation procedure. However, the drawings exported from the 3D model required customization to match local requirements. With experience in the local market, the Vietnamese consultant helped the Finish team understand the requirements and upgraded the exported drawings. In this way, the Thu Thiem 2 project team successfully applied BIM in Vietnamese infrastructure construction for the first time.

In both implementation studies, the project teams had no official guidance. Therefore, the implementation took place with a high level of uncertainty. In this ambiguous environment, members of the InterCity and Thu Thiem 2 Bridge projects mimicked the successful practices from similar projects. The influence of mimetic pressures on the project teams happened as described in the isomorphism framework (Dimaggio & Powell, 1983).

(1b) Mimetic pressures from BIM champions can become coercive pressures: BIM champions can exert mimetic pressure on clients and authorities, who in turn put coercive pressures on project teams. This finding indicates how coercive pressures that are crucial to BIM implementation can be created, and the client's decision-making process for adopting BIM in the Thu Thiem 2 Bridge project is the foundation of this finding.

Since Thu Thiem 2 Bridge was the first infrastructure construction project in Vietnam to apply BIM, the client needed knowledge of it and agreement from the ICE. The ICE is a government unit in charge of controlling construction costs. In this context, the Finish BIM manager on the consultant team conducted various seminars to show the benefits and provide knowledge of BIM to the client and the ICE. These seminars were held before the client decided to apply BIM to the project. With the given information, the ICE and the client officially agreed to include BIM in the project. Furthermore, the ICE issued an instruction to estimate the cost of BIM. Therefore, the Finish BIM manager's sharing resulted in an official request for BIM from the client, thus creating coercive pressures.

(2) Coercive pressures from clients and authorities are prerequisites: The role of top management in support BIM implementation is vital (Bui, 2019; Bui et al., 2018; Chan et al., 2019; Tsai et al., 2014). In the case studies, top management included the clients and authorities who exerted coercive pressures through decisions, contracts, and regulations. The coercive pressures were the main reason BIM was implemented and project teams were asked to customize the 3D modeling technology to local requirements. In both implementation studies, the 3D models supported the design and creation of drawings that had to be approved.

In the InterCity case, the management board used contract terms to officially request that BIM be applied. This was the reason the consultants had to be ready for the technology. Furthermore, the InterCity client hired a BIM manager to lead the implementation process. With these supporting actions from top management, the InterCity Project team gradually developed a library of 3D objects and a handbook for railway projects in Norway. These deliverables will become a basis for 3D modeling in railway projects in the future.

In the Thu Thiem 2 Bridge case, the explicit requests in the consultant contracts was the main reason the project team applied BIM. However, the client did not have a BIM expert to define detailed requirements. Therefore, the quality of the 3D model depended on the BIM manager from the Finish consultant, who was the BIM champion in the project. Additionally, the traditional approval process required 2D drawings. The project team relied on a local consultant to customize the exported drawings to the required quality. The 3D model was used for reference.

In both cases, the influence of coercive pressures was crucial to BIM implementation. Coercive pressures were also the reason for customizing the use of the 3D modeling technology. However, the projects would have benefitted more from the technology if the leading role was occupied by a BIM expert on the client team. I argue that BIM expertise is essential for clients to exert coercive pressures and obtain benefits from BIM.

(3) Normative pressures inspire project members to professionalize: This thesis's data revealed that project members want to keep up with technological development in construction. Therefore, they seek BIM knowledge through various channels outside of their work environments.

Normative pressures primarily stem from professionalization, which is "the collective struggle of members of an occupation to define the conditions and methods of their work" (Dimaggio & Powell, 1983, p. 152). Professionalization happens through formal education and professional improvement. While education from universities and training institutions has an important role in internally developing organizational norms, associations contribute to defining professional rules and behaviors through interorganizational networks (Dimaggio & Powell, 1983).

In this thesis's cases, professional and social networking activities were sources for normative pressures exerted on project members. The interviewees updated their knowledge and found solutions for work issues via networking activities. Interviewees updated their knowledge by surfing social network newsfeeds on the way to work or registering for email lists for webinar invitations, reports, and so on. Interviewees found solutions by searching the internet for specific problems and following relevant discussions in BIM-related communities.

Through networking, the interviewees also perceived normative pressures from market competition and job requirements, and they recognized the competitive pressures in the local market. If their companies were unable to deliver 3D modeling services, they would lose to the competition. Furthermore, the interviewees believed that working in the construction industry requires both engineering and modeling skills as well as familiarity with BIM tools. Getting a job without 3D modeling skills is not possible.

To avoid becoming outdated, interviewees took short BIM-related courses. These courses were from Lynda.com, seminars, and other online channels. However, certificates seemed less important than skills. To obtain fresh knowledge and follow the latest trends of BIM development, project members also pursued formal education, such as master's degrees.

6.2.2 Institutional pressures for stasis on BIM implementation

From an institutional perspective, BIM implementation can be seen as a digital transformation process that arises amid tension between change and stasis (Hinings et al., 2018). The previous section discussed institutional pressures for change. To provide a more holistic view of BIM implantation, this section describes institutional pressures that oppose it.

The data revealed the sources of institutional pressures that opposed BIM implementation, which stemmed from construction regulations and traditions. In this thesis's cases, construction regulations related to paper-based approval and construction costs exerted coercive pressures on BIM implementation. Although the InterCity and Thu Thiem 2 Bridge project teams perceived the benefits of BIM use, they had to prepare paper drawings for approval. The paper-based approval made the 3D model an extra burden to the project teams. Further, strict regulations related to construction costs required permissions from clients and authorities for implementing BIM. Without these permissions, BIM use would have been impossible.

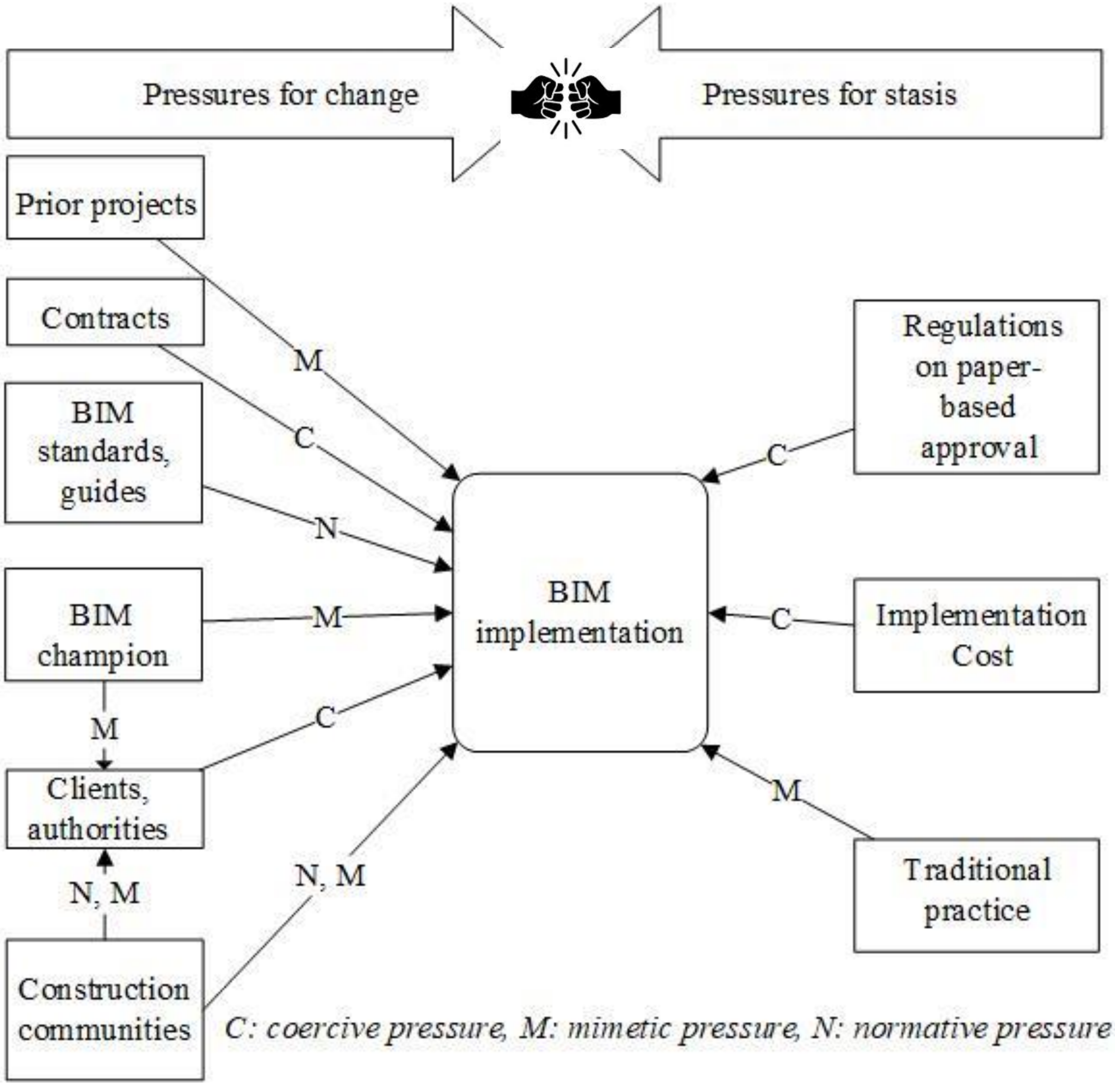

Figure 4. Institutional pressures for change and stasis on BIM implementation

In addition to construction regulations, traditional practices created mimetic pressures that hindered BIM applications. The project teams applied a traditional design method to tasks that BIM had yet not supported. Some examples of these tasks were signaling, catenary design, and land acquisition. Since the project members were unclear about obstacles to using BIM in infrastructure, they tended to follow a traditional design method to fulfil the design contract. In the constraint of time, the Thu Thiem 2 Bridge team prepared its design for approval the old way. The 3D model was used as a reference or to communicate with the authorities. Figure 4 illustrates institutional pressures for change and stasis on BIM implementation in this thesis's cases.

6.2.3 Institutional actions in BIM communities

The BIM innovation studies in this thesis include one community in Norway and one in Vietnam. These communities were in different developmental stages. Norway was among the global pioneers of BIM. In 2010, the Norwegian government mandated open BIM standards in public construction projects. At the time of data collection, Norway already had BIM handbooks for building and transportation projects. Vietnam, on the other hand, was still in an early phase of BIM implementation. The Vietnamese government planned to use BIM nationwide by 2021. Furthermore, bSN, following the management of buildingSMART International, had been holding activities since 2010. The BVC, established in 2015, was a discussion hub for BIM practitioners and had no management structure. My application of the Institutional Intervention Model to bSN and the BVC provided insights into how construction communities innovate. The data revealed that construction communities pursue BIM innovations by (1) creating new knowledge, (2) providing resources for activities, (3) promoting BIM use to other construction practitioners, (4) standardizing, and (5) creating demand for BIM use.

(1) Knowledge building leads to innovation: bSN organized different innovation activities, including the openLab hackathon in which its members invited BIM practitioners to develop innovative solutions to specific problems. For example, hackathon participants were asked to find creative solutions to building a digital twin for a ferry construction project (Project Ferry E39). Further, bSN awarded prizes for outstanding BIM-related student theses. This award scheme encouraged students to develop new BIM applications. Through these activities, bSN supported the development of new BIM knowledge.

The BVC, on the other hand, organized small projects to localize foreign BIM standards or develop Revit add-ins for members. The focus was catching up with ongoing development at the international level and automating some daily tasks.

(2) Subsidy provides resources for community activities: Subsidy is the key to keeping communities running. With subsidies from members, the communities in this thesis appointed management boards to organize activities. bSN and BVC members contributed through working hours, sponsoring events, and paying membership fees. With its budget from membership fees, bSN hired four full-time staff to manage community activities. These staff members effectively organized activities in Norway and connected bSN members to international organizations.

The BVC had a steering board of 24 members who joined voluntarily. To gain more resources for activities, the BVC's steering board collaborated with commercial companies and experienced BIM users. As a result of this collaboration, BVC members were exposed to new products, services, and information, such as free BIM tool licenses, presentations of good BIM practices, and BIM standards.

(3) Knowledge mobilization and deployment encourage other construction practitioners to use BIM: bSN supported the dissemination of openBIM in Norway and other countries via presentations and networking with the members of other construction communities. These members either led working groups in buildingSMART International or supported openBIM implementation in Norway.

Additionally, bSN posted a repository of open standards on its website, which construction practitioners could use to find relevant information, including an overview of openBIM, events, annual competitions, open standards, and competence services, such as teaching curricula and certifications, training courses, and an online portal for certification. The website also provided student theses on openBIM. These published theses represented what students can do with openBIM in their educational programs.

Mobilization actions require significant interactions with potential users. bSN u undertook such actions to persuade potential users of openBIM's capacity. Further, mobilization can be combined with deployment actions in community activities. For example, bSN encouraged construction practitioners to adopt openBIM through its website and offline events. The offline events included annual conferences, meetings, and workshops. There was no restriction on joining the discussion, and anyone could use bSN's communication channels to discuss the adoption of openBIM with the community. In addition, bSN used educational awards to inspire students to apply openBIM in their projects.

The BVC provided shared BIM standards, case studies, and training to its members. It used a Facebook forum or personal connections among members for sharing. Some BVC members offered free BIM tool training to others. In addition, the BVC connected with BIM tool vendors to present them with new applications.

(4) Set standards to develop consensus on BIM guidelines: A standard can be used as a guideline for a consensus-built and repeatable way of doing something (European Committee for Standardization, 2019). Since construction practitioners use BIM as a digital collaboration tool, standards are necessary and help users consistently apply it, thus facilitating collaboration. In this way, standards can support BIM innovation (Parkinson, 2017). bSN and the BVC were involved in standardization and introduced standards to their members in different ways.

bSN participated in international standardization organizations, such as the International Organization for Standardization (ISO), buildingSMART International, and the European Committee for Standardization (CEN). This active participation at different geographic levels resulted in two positive consequences. First, bSN members were familiar with European and ISO standards of BIM during the preparation phase of those standards. Therefore, bSN members found it convenient to do business in countries with the same standards. Second, bSN could gain experience from the standardization processes and resources of CEN and ISO to improve the quality of its community standards.

The BVC had been active in translating and introducing foreign standards to its members. It also supported their members in applying foreign BIM standards, such as PAS 1192-2:2103 and BS1192:2007. Although the BVC had no official standardization activities, some of its members participated in the Vietnamese Ministry of Construction's BIM consultant team. This consultant team was responsible for the development of national BIM guidelines.

(5) Innovation directive creates demand for BIM: This institutional action happens through direct commands or requirements (King et al., 1994). The data in my research showed how the communities undertook this action.

Some bSN members formally requested BIM use. Statsbygg mandated BIM applications in its projects in 2010 (Merschbrock & Rolfsen, 2016), and Bane NOR decided to implement BIM in the InterCity Project (Paper 3). These adoption decisions created demand for BIM use and therefore encouraged construction practitioners to innovate with it.

This thesis builds on understandings of institutional pressures, which both advocate and oppose BIM implementation in infrastructure projects. Further, a description of the institutional actions that motivate BIM innovation in construction communities has been provided. Table 7 summarizes this thesis's theoretical contributions.

Institutional pressures on BIM implementation
• Increased the understanding of mimetic pressures on the BIM implementation process. (a) Experience from similar or previous projects creates mimetic pressures. (b) A BIM champion is essential to leading the project team's response to mimetic pressures. • Explained how mimetic pressures turned into coercive ones. (a) Exerting mimetic pressures on clients and relevant authorities can create coercive pressures. • Increased the understanding of coercive pressures on BIM implementation. (a) Clients, authorities, and approval requirements are sources of coercive pressures. (b) Coercive pressures from approval requirements make project teams customize implementation processes and model outputs. • Increased the understanding of normative pressures on project members in infrastructure projects. (a) Networking activities exert normative pressures on project members. (b) Normative pressures force project members to upgrade their knowledge.
Institutional actions on BIM innovation
• Increased the understanding of knowledge building, which generated innovative solutions for the implementation process. • Explained how subsidies, such as membership and working hours, provided resources for community activities. • Provided an understanding of knowledge deployment and mobilization on BIM diffusion. (a) Mobilization action encourages construction practitioners to use BIM through professional presentations, seminars, discussions, etc. (b) Deployment action provides knowledge of BIM to interested and potential users through different communication channels. • Increased the understanding of standard-setting actions in the implementation process. • Explained how innovation directives promote BIM use.

Table 7. Theoretical contributions

7 Conclusion

This thesis has explored BIM implementation in a developed and a developing countries. Through a cross-case analysis of BIM implementation in Norway and Vietnam, suggestions for better BIM implementation in infrastructure construction in a developing context have been proposed. Additionally, I examined BIM community cases from each country. I applied the isomorphism framework to analyze BIM implementation in infrastructure construction, and I applied the Institutional Intervention Model to explore BIM innovation in construction communities.

This chapter answers the research question put forward in Chapter 1 and discusses this thesis's main limitations and suggestions for further research.

7.1 Responding to the research questions

This thesis's primary research question is: how can BIM implementation be improved to support infrastructure projects in developing countries? I responded to it by addressing the three sub-questions below.

SQ1: What is the status of BIM implementation in developing countries?

SQ2: What are the institutional influences on BIM implementation in infrastructure projects?

SQ3: How do construction communities innovate with BIM?

Table 1 in Section 1.4 maps the individual thesis articles to the sub-questions. The results of these articles are the foundation for answering the sub-questions, as summarized below.

SQ1: What is the status of BIM implementation in developing countries?

Paper 1 and Paper 3 focused on BIM implementation in developing countries. Until 2015, China, India, and Malaysia were pioneers in BIM research, while other countries were underrepresented. Furthermore, the scope of this research was mainly focused on technology transfers, importing technologies, standards, and collaboration. After a systematic literature review, Paper 1 identified research gaps related to infrastructure construction, facility construction, and BIM innovation in professional communities.

As of 2016, some developing countries have established national standards and guidelines for BIM adoption. Paper 3 reported that Vietnam is an example of such a country. In 2016, the Vietnamese government approved a BIM adoption plan and decided to perform various pilot projects. The goal is nationwide BIM use by 2021. As a result, Vietnam had 20 BIM pilot projects by the end of 2018. At the same time, legal construction frameworks have been updated. In September 2019, the Ministry of Construction issued Circular 09/2019/TT-BXD, which was about construction cost estimations. This circular included a guide to estimating BIM-related costs in Vietnam. With support from the government, construction practitioners in Vietnam are finding solutions to traditional barriers in the approval process of applying for BIM technology. In October 2019, the University of Transportation organized CIGOS 2019 in Hanoi.

Other BIM studies can be found in Malaysia, Pakistan, and Nigeria. Researchers have focused on reducing cost overruns (Muhammad et al., 2019), managing construction companies (Musa et al., 2019), and BIM adoption and implementation (Akdag & Maqsood, 2019; Babatunde et al., 2020; Saka & Chan, 2020). This thesis aligns with these BIM studies and similarly expands the understanding of BIM in developing countries. The insights from this thesis can be useful in improving digital collaboration in construction, thus supporting developing countries in building the infrastructure necessary for them to meet their Sustainable Development Goals by 2030.

SQ2: What are the institutional influences on BIM implementation in infrastructure projects?

Paper 2 and Paper 3 described BIM implementation in infrastructure projects in a developed and a developing countries, with one case study in Norway and another in Vietnam. The case studies revealed the strong influences of mimetic and coercive pressures on implementation, while normative pressures were also found to be significant.

Mimetic pressures influence how project members develop BIM guidelines, obtain support from top management, adapt BIM to local requirements, and gain BIM knowledge from communities. Mimetic pressures can stem from BIM champions, project members, and construction communities.

First, BIM guidelines are essential to successful implementations. This thesis found that the role of BIM champions is important to the development of BIM guidelines. In the InterCity Project, the BIM champion led the reference group of consultants working in the project in the development of a handbook for BIM implementation in railway construction. This handbook was expected to become a BIM guide for railway construction in Norway. By leading the collaboration, the BIM champion provided the direction and leveraged the consultants' BIM experience from other types of projects.

Paper 3 also documented the significant influence of a BIM champion on the development of BIM guidelines in the Thu Thiem 2 Bridge project. The BIM champion had experience from other projects and led the project team in adapting Finish BIM guidelines to the Vietnamese bridge construction context.

Second, the BIM implementation study revealed an interesting example of how mimetic pressures turn into coercive ones. In the Thu Thiem 2 Bridge project, the BIM champion presented BIM benefits and processes to clients and authorities via various seminars before the project started. This effort motivated the client to officially adopt BIM and provide the necessary knowledge to authorities. With this knowledge, the authorities approved BIM implementation in the project. One of the important agreements was the approval of implementation costs, which were in violation of construction regulations at the beginning of the project. Without support from the client and authorities, BIM implementation in the Thu Thiem 2 Bridge project would not have been successful.

Third, BIM implementation has to account for traditional requirements, such as paper-based drawing submissions. In the BIM implementation studies, the project members used their experience to harmonize the approval requirements and outputs from the BIM models. The models supported communication with the authorities and exported 2D drawings. The project members customized the 3D model outputs to match the approval requirements. Without the experience of project members, BIM implementation seems unlikely to succeed.

Fourth, acquiring BIM knowledge from construction communities might have positive effects on implementation. Construction communities are another source of mimetic pressures. The cases of bSN and the BVC show that project teams learn from construction communities when implementing BIM in infrastructure projects (Paper 4 and Paper 5). In Norway, Statens Vegvesen, a member of bSN, used a hackathon to gain innovative solutions for applying open standards in the planning and execution phases of the E39 Highway (Paper 4). This hackathon is an example of using external knowledge to resolve internal challenges. In Vietnam, BVC members held small courses to transfer knowledge to others using BIM tools and programming add-ins in Revit and Tekla (Paper 5). The acquired programming skills helped participants automate parts of construction tasks. Since some of the instructors had worked in bridge and road projects, they also shared their experiences of applying BIM tools to infrastructure. These activities revealed that mimetic pressures from other community members can have positive influences on infrastructure construction. By participating in relevant communities, project members can achieve benefits they can use in implementation.

Coercive pressures from top management are prerequisites for BIM implementation. Coercive pressures stem from official requests or support for BIM implementation. The clients in the InterCity and Thu Thiem 2 Bridge projects formally requested BIM in consultant contracts and appointed BIM champions to lead the implementation. In the Norwegian case, the appointed BIM champion directed the consultant teams of sub-projects to share their experiences and develop a common BIM handbook. In the Vietnamese case, the BIM champion was the BIM manager in the Finish consultant’s organization. He guided the project team through the Finish method of BIM implementation. In both cases, the BIM champions received client support for the implementation. Furthermore, for the Thu Thiem 2 Bridge, the project team could only adopt BIM after the ICE agreed with the implementation cost proposal. The ICE’s agreement is an example of support from top management.

In addition to adoption decisions in projects, clients and authorities can also mandate BIM. The case of bSN revealed that Norwegian construction companies have invested more in implementing open standards after Statsbygg requested openBIM in their projects in 2010. After that decision, Norwegian construction companies began to adopt BIM to participate in Statsbygg projects.

Normative pressures urge project members to professionalize by upgrading their BIM knowledge. Better BIM knowledge improves implementation. Project members professionalize to meet job requirements, be competitive in the construction market, and follow technology trends. The interviewees in both implementation studies believed that construction jobs in the ICT era require civil engineering knowledge and 3D modeling skills. Furthermore, a company that does not use BIM is not competitive. The project members working on the consultant team wanted top-level BIM skills. The desire for high-level BIM skills pushes project members to keep abreast of recent industry developments.

Professional communities are sources of professionalization, and the knowledge deployment and mobilization activities of construction communities put strong normative pressures on project members. Some examples of these activities are professional conferences, workshops, seminars, webinars, and social media newsfeeds. Other means of disseminating BIM knowledge to community members are newsletters, BIM repositories, and presentations. By participating in these community activities, members not only keep track of recent BIM developments, they also feel pressure to professionalize. Finally, formal education and short courses are other sources of professionalization. Examples of such courses include higher education degrees, online courses, and BIM training courses provided by professional communities.

SQ3: How do construction communities innovate with BIM?

This thesis has described six institutional actions and their influences on BIM innovation in construction communities. The key actions are knowledge building and subsidy, while other actions help to request, propose, and spread best BIM practices in the construction industry.

Knowledge building is an institutional action that drives innovation. As documented in Paper 4 and Paper 5, construction communities engage in BIM innovation on a voluntary basis. bSN's members pursued innovation with BIM implementation solutions and focused on methods or platforms for collaboration. The community management board played an important role in organizing events, such as hackathons, that generated innovative solutions. The BVC's management board, meanwhile, maintained an active communication channel on social media. Through this channel, it created BIM knowledge in informal ways, organizing small project groups that either localized foreign standards or developed add-ins for BIM tools. These add-ins, such as quantity take-offs and auto naming, support the automation of local construction processes.

Subsidy is important to communities. This action provides resources to other institutional actions and the management of the organization. Community members voluntarily contribute to their communities through membership fees, the sponsoring of events, and working hours. With funding from membership fees, a community can have full-time dedicated administration staff who can effectively organize activities. Additionally, communities need voluntary steering boards to direct innovation activities. Apart from joining these steering boards, community members can contribute by delivering BIM presentations, translating standards, and sharing their BIM-related experiences with others.

Knowledge deployment and mobilization are necessary to diffuse and encourage construction practitioners to use BIM. In addition to knowledge building, construction communities conduct BIM-related seminars, meetings, and awards programs for student theses. These activities introduce BIM to other construction practitioners and encourage them to use it. Further, a community's output is available to its members, including work done on standards, templates, and free add-ins, which reduce the costs and risks of using BIM.

Directives to innovate can trigger BIM investment from community members, especially when clients insist on BIM applications. The bSN case was an example of how a community member's request for openBIM drove the use of buildingSMART standards in Norway. Since Statsbygg's 2010 decision to use openBIM, open standards have been increasingly applied in the Norwegian construction market. Construction companies have to use openBIM to participate in Statsbygg's projects, and bSN supported its members in their effective implementation of openBIM.

Standard must be set to develop industry guidelines for BIM implementation. Standards are consensus-based guidelines for repeatable practices (European Committee for Standardization, 2019) and are a prerequisite of innovation (Blind, 2016). In the construction industry, community members can use BIM standards as resources for implementation guidelines, and BIM standards can be seen as innovations of construction communities in using the 3D modeling technology. In the bSN case, the development of open standards was an important task, and members contributed to standardization organizations at the domestic and international levels. Furthermore, members participating in standardization processes gain access to the markets that apply the standards (Paper 4).

Main Research Question: How can BIM implementation be improved to support infrastructure projects in a developing context?

Middle and low income economies have large knowledge gaps and limited technological capacity (World Bank, 2015a). In developing countries, technology transfers are influential in BIM implementation, while financial resources for research and investment are limited. This thesis contributes to BIM implementation in infrastructure projects in developing countries by proposing means of successfully implementing BIM and reducing the costs and risks of using it. The research results have revealed that BIM implementation requires (1) localized BIM guides, (2) BIM champions in a lead role, (3) the provision of BIM-related knowledge to clients and authorities, and (4) proper BIM tools.

First, localized BIM guidelines are necessary for BIM implementation. Paper 2 provided an example of Finish BIM guidelines applied to a Vietnamese construction context. In this case, the technical documents and expertise of the Finish consultant were essential. However, the guidelines had to be localized to satisfy local regulations and receive government approval. The experience of the local consultant team was therefore important. A bridge design in Vietnam requires three consecutive approval steps, and each step has a different level of detail. In the case, the local consultant team consulted the Finish BIM manager to adjust the guidelines to local requirements. Paper 3 also presented an example of how to develop BIM guidelines. In the InterCity case, the client organized a reference group of consultants who participated in the project. They used their BIM experiences from other projects to develop a handbook to implement BIM in the InterCity Project. The handbook included detailed requirements of 3D railway components and collaboration processes involving 3D models. The handbook was later developed into BIM guidelines for Norwegian railway projects.

Second, BIM champions are essential to implementation. A BIM champion from a client team is more effective than from other partners in leading BIM use in infrastructure projects. With decision-making power from the client, the champion can direct the development of BIM guidelines, organize necessary training, collaborate with the authorities to acquire the support of top management, and connect with professional communities to acquire necessary BIM knowledge.

Third, clients and authorities require BIM knowledge to support its implementation. Paper 2 and Paper 3 explored the active participation of clients and authorities in BIM-related seminars, collaborations, and workshops. These activities can be pursued by project teams or construction communities BIM champions and local partners must collaborate to disseminate BIM-related knowledge. Champions prepare content and local partners connect stakeholders to share BIM knowledge. Once equipped with relevant knowledge, clients and authorities are likely to support implementation.

Fourth, project teams should choose BIM tools that support local regulations. Paper 2 and Paper 3 revealed that traditional requirements, such as paper-based approval, are barriers to BIM implementation. There still exists a gap between the 2D drawings exported from 3D models and approval requirements. To meet approval requirements, project teams have to manually modify exported drawings. Furthermore, BIM tools still have limited support in some areas, such as signaling and landscaping. In the cases studies in this thesis, the project teams had to use BIM models as references to support the approval of 2D drawings. Since BIM tools’ add-ins can automate parts of construction tasks, programming skills will help reduce manual modifications. Equipping project members with programming skills improves the success of implementation.

Additionally, construction communities can provide resources for implementing BIM in infrastructure projects. By acquiring benefits from communities, project teams have better chances of reducing the costs and risks associated with applying BIM. Indeed, communities can assist the implementation by (1) providing updated knowledge and (2) proposing innovative solutions.

First, participation in professional community activities encourages project members to professionalize, and they tend to acquire new knowledge and apply BIM. The bSN and BVC cases presented construction communities as fruitful resources for BIM practices. BIM discussions helped community members keep abreast of the latest technological trends and practices, thereby facilitating technology transfers in infrastructure projects. However, participation can be time consuming. Choosing relevant activities and acquiring support from top management are necessary to get the most out of communities.

Second, clients can approach construction communities and request innovative solutions to implementation challenges in infrastructure projects. The hackathon organized by Statens Vegvesen for the E39 Highway asked participants to propose how open standards could be used in the project, which constituted an outside-in knowledge flow. By letting the outside knowledge flow in, clients benefit from reduced risks and costs when solving implementation issues. Project teams therefore have better chances of conducting a successful implementation.

7.2 Limitations

This thesis adopted a multiple case study design with semi-structured interviews to explore BIM implementation. The case study method was chosen because it provided a proper approach to address “why” and “how” questions (Walsham, 1995). Additionally, it helped me develop thick descriptions (ibid.). However, it has limitations in terms of generalizability, difficulty in establishing cause and effect connections, and ethical issues, particularly related to confidentiality (Queirós et al., 2017).

The compositions of interviewees is another limitation. In the BIM implementation studies, 7 of 10 InterCity interviewees held managerial roles and came from both client and consultant teams. Similarly, the Thu Thiem 2 Bridge case included the perspective of managers, coordinators, and the consultant's 3D modelers. The voices of contractors and authorities are necessary to gain a more holistic view of the implementation process. In the BIM innovation studies, the majority of the interviewees were managers with more than five years of experience. Opinions from junior engineers would contribute to an improved understanding of innovation. This limitation should be considered when interpreting the research results.

Second, the interview recordings from the Vietnamese cases were translated into English, and the participants in the Norwegian cases used English as a second language. There could have been discrepancies between the interviewees' statements and the translated transcripts. To minimize the possibility of errors, the data also included other information sources, such as newsletters, online posts, and articles about the cases. No modifications to the interview data were necessary.

Finally, the two BIM implementation studies might not adequately represent the infrastructure construction domain. For instance, Vietnam had more than five infrastructure projects that were in the pilot stages in 2015. Norway also has other infrastructure projects that use BIM. Regarding the BIM innovation studies, Norway and Vietnam have other construction communities operating in parallel with bSN and the BVC. The data from bSN and the BVC thus only documents part of the construction community activities in these two countries. However, bSN and the BVC were the most active communities at the time of data collection.

7.3 Further Research

Notwithstanding the limitations mentioned in the previous section, this thesis expands the understanding of BIM implementation and provides suggestions for better BIM use in developing countries. To support construction digitalization, the following topics are worth pursuing further.

First, this thesis explored BIM implementation in a developing context with an interpretive multiple case study design and interviews as the main method of data collection. Other research methods on a larger scale or over a longer time, such as survey and action research, could provide more insights into the research topic. Since I intended my research to support BIM implementation in developing countries, the transferability of the results is essential, and surveys in other developing countries are necessary to determine whether the results can be transferred.

Second, this thesis presented a BIM implementation pilot project involving a bridge in Vietnam. Because different types of construction involve different approaches to adopting technology, further studies on BIM implementation in other infrastructure projects, such as ferries, roads, and airports, are recommended. The obtained insights could contribute to a broader understanding of BIM implementation in developing countries.

Third, this thesis explored institutional pressures on BIM implementation, including those that oppose it. More studies on institutional pressures that hinder BIM implementation or maintain the status quo of construction projects would contribute to a better understanding of the topic.

Fourth, further studies on how authorities influence digital innovation in construction could provide insights into supports for implementing BIM in infrastructure projects. The implementation studies demonstrated that authorities, such as municipalities and government agencies, strongly influence implementation. Without support from the authorities, BIM implementation will be unsuccessful.

Fifth, the research results revealed a misalignment between foreign BIM guidelines and local requirements. Localization is required to meet approval requirements. What influences project teams in localizing foreign BIM guidelines is an interesting topic for further study. Addressing the localization issue would be useful when it comes to importing BIM practices to developing countries.

Finally, the construction innovation cases presented an open approach to BIM innovation. Since open innovation can reduce the costs and risks of technological development, this approach is relevant to BIM innovation in developing countries, where resources for research and investment are limited. Research on how construction communities pursue BIM innovation with an open approach would not only benefit technological development but also the construction industry in developing countries.

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Appendix A. Interview guide of BIM implementation studies (The InterCity and the Thu Thiem 2 Bridge cases)

Introduction: 3D modelling, time, location, person to interview

A. Background – 10 mins

1. Please tell me your discipline and experience in construction?
2. Do you have any experience or training on 3D modelling?
    - Organizer, outcomes, software, procedure, standards…
    - Previous and after you join your current project
3. How do you work with your colleagues on the 3D model?
    - Procedure, meetings, reports…
    - Updating, integrating, commenting, sharing data…

B. Regulations on 3D modelling implementation - 15 mins

4. Is there any requirement of 3D modelling in your project? Is it fixed through a contract? Is there any consequence if you don’t follow the requirement?
5. If there is disagreement or conflict on performing these 3D modelling regulation or agreement, how is it handled?
6. Besides the requirement from your project, is there any other mandatory requirements on 3D modelling you must follow? From whom, how to follow?
7. Is there any difficulty in following these requirements?

C. Good practice from other projects or friends - 15 mins

8. Do you know how other similar projects apply 3D modelling? Which, how?
    - If no, do you think it necessary to know? Why?
9. Is this practice applied in the whole project or your work?
    - If yes, how was it decided? If no, do you think it is appropriate?
10. Is good practice from the other projects difficult to apply? Why or why not?

D. Standards and certificates on 3D modelling (normative) - 10 mins

11. Please tell me if you know any 3D modelling standards, requirements, or certificates outside of your project. How do you know? If no, do you think it is necessary? Why?
12. Do you think 3D modelling standards, requirements, or certificates necessary? Why?
13. Is it difficult to follow or archive these standards, requirements, or certificates? Why?
14. How do you look for the information related to 3D modelling?

E. Other suggestions – 10 mins

15. According to you, why is 3D modelling applied in the project?
16. Could you tell me about the benefits and difficulties of 3D modelling?
17. Any other suggestion on 3D modelling in your project?

Coding categories of BIM implementation study
F. Other opinions
F1. General fact
F2. 3D
F3. 3D advantage
F4. 3D disadvantage
P. Coercive
PC1. Contract
PC2. Technical-3D requirements
PC3. Government
PC4. Strategy
P. Mimetic
PM1. Experience previous
PM2. Experience from others
PM3. Experience sharing
P. Normative
PN1. Conference, workshop
PN2. Online forum, website, class
PN3. Country, industry level
B. Background

Examples:

"The standards, they are coming from the discipline. The people who are responsible for different issues, they are doing a lot of training and practicing within their own departments outside of the project (PN1). Their experience beforehand is what we are taking and dealing with in the project (PM1). They are very important. We did not start from zero when we established the project. We are offering a lot of experienced personnel with necessary experience from all the parts (PM1)".

"When they created InterCity, it was decided as a main goal from the management within that organization that we should use 3D models (PC4). So, I was one of the people they recruited in that process. It is more established now. It was the management's decision that we should use the model (PC4) but actually, no more than that".

Appendix B. Interview guide of BIM innovation in construction communities (Example in the bSN case)

1. Background
    - Firm, education, discipline, experience
    - BIM-related experience and skills
    - Which company are you working for?
2. Institutional actions
    - What are the community communication channels?
    - What have you discussed about BIM in the community?
    - Mandatory or encouraging? Providing or requesting?

    2.1. Knowledge building
    - Q1. Does bSN create new knowledge?
    - Q2. How does bSN do it? Is there any specific procedure?

    2.2. Knowledge deployment
    - Q3. Does bSN introduce standards such as IFC to members?
    - Q4. How does bSN do this?
    - Q5. Does bSN have any certificate? Have any members of bSN requested certificates on modelling skills?
    - Q6. Does bSN provide any BIM training, BIM education program?
    - Q7. Does bSN organize any BIM pilot case?

    2.3. Subsidy
    - Q8. Does bSN provide support for implementing BIM?
    - Q9. Does bSN have any award for BIM implementation?
    - Q10. Does bSN have any requirement for BIM implementation?

    2.4. Mobilization
    - Q11. Does bSN have any campaign to advertise / raise awareness on BIM?
    - Q12. Does bSN promote openBIM in other organizations?

    2.5. Standard setting
    - Q13. Does bSN prepare any standard for BIM?
    - Q14. How does bSN prepare such standards?

    2.6. Innovation directive
    - Q15. Does bSN request any organization to build BIM software or implementation procedure?
    - Q16. Does bSN request the organizational members to apply BIM, to invest personnel on BIM or use any specific software?
    - Q17. Does bSN have any mandatory requirement to apply its resources such as standards?
    - Q18. Does bSN represent its members to negotiate with software vendors, governments…?
3. Other opinions
    - Q19. Why did you join bSN?
    - Q20. What should bSN do to improve BIM implementation?

Q21. What can/should you contribute to bSN?

Coding categories of BIM innovation study
01. Knowledge building
02. Knowledge deployment
03. Subsidy
04. Mobilization
05. Standard setting
06. Innovative directive
B. Background
O. Other opinions

Examples

"*All of us have a sort of grounding belief that open standards are the only way to have innovation flourish (O)*. *We didn't believe in any proprietary standard or industry standards. We believe in open standards (O)*"

"*We engage the universities and vocational schools. We have a good relationship with most of the vocational schools that educate people with BIM technology and we have a relationship with NTNU with a new digital building process and we have relations with OsloMet (04). We do try, I would like to have much more of that but the bandwidth of the company at the moment is too small. So, we can't do all of that but eventually I like it to happen better. I'm from academia myself.*"

"That might be the need for new standards of patent development or creating totally new ideas for solutions or workflow. That brings me over to another thing that we are doing. We are now creating an innovation programme for this network for innovating and developing for digitized way of working together in the whole industry actually. We need to innovate in solution and standards (01). We can do innovation initiatives in different levels in our program such as to create new ideas, test pilot and implement new solutions or standardization, standards"

Appendix C. Research publications

1. Bui, N., Merschbrock, C. & Munkvold, B. E. (2016). A review of Building Information Modelling for construction in developing countries. *Procedia Engineering,* Vol. 164**,** 487-494.

2. Bui, N. (2019). Implementation of Building Information modeling in Vietnamese infrastructure construction: A case study of institutional influences on a bridge project. *The Electronic Journal of Information Systems in Developing Countries*, Vol. 86, Issue 4.

3. Bui, N., Merschbrock, C., Munkvold, B. E. & Lassen, A. K. (2018). An institutional perspective on BIM implementation – a case study of an intercity railway project in Norway. *27th International Conference on Information Systems Development (ISD2018).* Lund, Sweden.

4. Bui, N., Merschbrock, C., Munkvold, B. E. & Hjelseth, E. (2019). Role of an innovation community in supporting BIM deployment: the case of buildingSMART Norway. *WIT Transactions on The Built Environment,* Vol. 192**,** 329-342.

5. Bui, N., Merschbrock, C., Munkvold, B. E. & Hjelseth, E. Understanding open innovation in BIM implementation: A cross-case analysis of construction communities in Norway and Vietnam. Under review for *Construction Management and Economics*.

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A review of Building Information Modelling for construction in developing countries

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Abstract

Building Information Modelling (BIM) is widely seen as a catalyst for innovation and productivity in the construction industry. BIM can assist a more sustainable construction process that in turn may contribute to eradicating poverty in developing countries (United Nation Millennium Goals). While BIM is increasingly being adopted in developed countries, implementations in the developing country context are rare. Research has established how construction firms struggle from several limitations having to do with the socio-economic and technological environment found in developing countries. Examples of issues preventing BIM adoption include a shortage of IT-literate personnel as well as an absence of national BIM implementation programs. Based on a review of recent research, this article addresses some of the hurdles and solutions for BIM implementations particular to low- and middle-income economies. Findings include that developing countries' construction firms rely on outsourcing of IT services or developing tweaks or workarounds, like using 'fake' IT licenses, for saving cost and enabling BIM. The article highlights shortcomings of existing research on BIM implementation in developing countries, and may serve as a starting point for researchers interested in how BIM technology can be adopted in a developing country context.

Keywords: barriers; Building Information Modeling; construction; developing countries; implementation strategy

1. Introduction

According to the World Bank [1, 2], there exist 135 middle- and low-income economies referred to as developing countries. These countries face large knowledge gaps and can be characterized by limited and occasional technological innovation [3]. In developing countries, construction is a labor-intensive industry. Wells [4] reported that the average

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construction output per person in low-income countries is just about one-ninth of that in high-income countries. Besides, construction is also considered as the most material intensive [5]. A variety of existing challenges lead to delays, poor site environments, poor working conditions, low quality, and accidents in developing country construction [6]. The low efficiency of construction in developing countries implies a promising area for development. Because construction could assist a more effective employment of human and material resources, the industry is often considered as a driver for growth and achieving development goals [7-9].

Like other industries, the construction companies benefit from a range of information and communication technology (ICT) solutions when delivering their projects. It has been suggested that construction projects will be more effective and productive with ICT applications [6]. One of these ICT applications is Building Information Modelling (BIM), which could have many benefits in supporting construction. In terms of more effectiveness and productivity, BIM yields advantages for scheduling, design, implementation, and facility management. From a stakeholder perspective, BIM helps owners, designers, contractors, and management teams to collaborate, visualize and manage construction work better [10]. Consequently, BIM technology receives significant attention from practitioners. In the light of improvement, increasing the use of ICT could help to address some of the currently experienced challenges. The implementation of construction ICT in general and of BIM in particular should be considered in the developing country context. Based on a review of recent research, this article thus focuses the following research questions: What is the current state of BIM implementation in developing countries, and what further research is required for advancing this? Addressing these questions is worthwhile for researchers and practitioners focusing on construction firms operating in developing countries, seeking to reap BIM's benefits.

1.1. ICT implementation in developing countries

Information and Communication Technology for Development (ICT4D) is a research area in the information systems (IS) literature. Examples of this research include the study of healthcare systems, the internet, and e-procurement systems in developing economies. What unites this research is the focus on overcoming the recurring limitations and barriers for ICT adoption in developing countries. Some of the frequently mentioned ICT implementation challenges typical for developing countries are management related, including qualified personnel, financial support, strategic perceptions, market support, socio-cultural environment, and security concerns. In addition, there are challenges such as lack of framework, policies and procedures for adoption. Lack of research and development also hinders ICT implementation [11-14].

While many of the managerial and technical barriers would seem familiar from the study of ICT implementations in developed countries, some appear unique for developing countries. Security concerns are likely to be the most noticeable case, since software piracy is widespread in developing countries. Aleassa et al. [15] reported that the 25 countries with highest piracy rates are exclusively developing countries. Using cracked software, organizations may unintentionally be exposed to viruses and hacker attacks that could lead to unexpected disruptions and unmanageable damages.

In addition to the inherent challenges of ICT implementations in a developing country context, BIM implementations are generally of a complex nature. BIM involves shared information space technology used for collaborative digital design work across several organizations. Thus, a range of organizational and technological barriers for BIM implementation have been reported [16, 17]. Frequently experienced 'BIM implementation barriers' [16, 17] range from lack of top management support, low awareness of BIM benefits, staff resistance to change, and cultural misfits, to creating new processes for BIM and interoperability issues. Many of the BIM barriers reported in the literature resemble implementation challenges familiar from the wider information systems literature [18]. For understanding BIM in the context of developing countries, we will identify implementation barriers typical for developing countries. This is done by informing our study in a broad theoretical framework focusing people, organizations and technology in BIM implementation [19].

1.2. BIM implementation framework

The framework chosen for structuring the literature review was suggested by Jung and Joo [19], and developed from an application of IS planning methodology in construction. In the attempt to assess the effectiveness of IS in construction, the authors stressed managerial and technical issues, aiming to address all relevant BIM issues. The framework can be summarized as follows:

Table 1. The BIM implementation framework (adapted from Jung and Joo [19])

Technical (T)	Perspective (P)	Construction Business Function (C)		
1. Data Property 2. Relation 3. Standards 4. Utilization	1. Industry 2. Organization 3. Project	1. R&D 2. General Admin. 3. Finance 4. HR. mgt. 5. Safety mgt.	6. Quality mgt. 7. Cost control 8. Contracting 9. Materials mgt. 10. Scheduling	11. Estimating 12. Design 13. Sales 14. Planning

- [T1] Data Property covers the technical aspects of geometric and non-geometric BIM data, their arrangement in databases, and their metadata with construction material objects being classified.
- [T2] Relation deals with the technical interdependency of data properties in parametric BIM objects. Moreover, this category deals with technical aspects of file exchange (i.e. industry foundation class file exchange format)
- [T3] Standards include BIM studies exploring technological aspects of file exchange and related standards such as ISO, Uniclass, and MasterFormat.
- [T4] Utilization entails studies seeking to develop the technological aspects of BIM to better support practical project level use of BIM. Here the different construction disciplines contribute studies on how to make BIM a technologically better system for its respective purpose.
- [P 1, 2, 3] Perspective covers overview studies focusing the industry, organizational and project wide diffusion of BIM.
- [C 1-14] Construction Business Function covers studies focusing on BIM's effect on organizational performance and work in different aspects of the construction supply chain. This stream of research takes into account how BIM and IS influence the day-to-day operations in the construction industry and projects.

2. Methodology

Table 2. Scopus search summary

Keywords	[1] ((Building information modelling) OR (Building information modeling)) AND ((developing countries) OR (developing country)) [2] ((Building information modelling) OR (Building information modeling)) AND ((countries*))		
Database and date assessed	[1] Elsevier SciVerse Scopus assessed 15.12.2015 [2] Elsevier SciVerse Scopus assessed 15.12.2015	Return	2 37
Scopus search strings	[1] (TITLE-ABS-KEY({Building information modelling} OR {Building information modeling}) AND TITLE-ABS-KEY({developing countries} OR {developing country})) AND DOCTYPE(ar) AND (LIMIT-TO(LANGUAGE,"English")) [2] (TITLE-ABS-KEY({Building information modelling} OR {Building information modeling}) AND DOCTYPE(ar) AND (TITLE-ABS-KEY(countries*)) AND (LIMIT-TO(LANGUAGE,"English"))		
Number of relevant articles: 27			
* names of 135 developing countries as defined by the World Bank.			

A literature review is an extensive reference providing background and justification to the conducted scholarly works in a specific research field [20]. This paper contributes an update of BIM implementation in developing countries. To collect relevant literature, a 6-step literature search process was adopted [21]. (1) The search focused on peer-review outlets. Moreover, as conference papers usually are of lower quality and less mature than journal articles, only journal articles were considered [22]. No restriction to specific journals was made, to provide an overall view of scholarly work in the area. (2) The search was conducted in the Elsevier Scopus database, the largest database for peer-reviewed abstracts containing over 57 million records. (3) The topic keywords informing the search were "Building information modelling" and "Building information modeling". Geographical keywords were "developing countries" and the specific names of 135 developing nations. Topic keywords were connected to each other by using the Boolean operator "OR". Likewise, we linked the geographical keywords by "OR". Only English language articles were considered in our study leaving aside potentially relevant work published in other languages. (4) A limitation of this work is that we did not consider the impact and influence of articles in terms of citations. (5) The initial return of the search were 39 articles. However, through initial screening for topical relevance we excluded articles not having to do with BIM in construction (i.e. biomedical engineering etc.), leaving a total sample of 27 articles (6). This was followed by a full text evaluation to categorize the collected articles according to the BIM implementation framework presented in Table 1. After step (6), two more articles were excluded. One article was about a hospital BIM design case study in the Middle East, but the task was outsourced to a design team in the US [23]. The other excluded article was an on-going study by Enegbuma et al. [24], because their latest work was included in the sample. Thus, a total of 25 articles were classified. For articles covering several topics, only the main focus was used for classification. The main focus was identified by reading what specific purpose was stated in the article. Table 2 summarizes the search conducted.

3. Findings

Sixty-four percent (16/25) of the articles were published in the last two years. This can be viewed as an increasing interest in BIM implementation in developing countries. Among the 135 developing countries, BIM implementation studies were only reported in China (13), Malaysia (9), and India (3), indicating a research gap regarding the other 132 countries. Figure 1 shows the distribution of articles by country over time. An overview of the classification results based on the framework by Jung and Joo [19] can be found in Table 3. Table 4 presents frequently mentioned keywords classified by article topic area. In the following, the results of our review are presented by these topic areas.

Fig. 1. BIM studies in developing countries

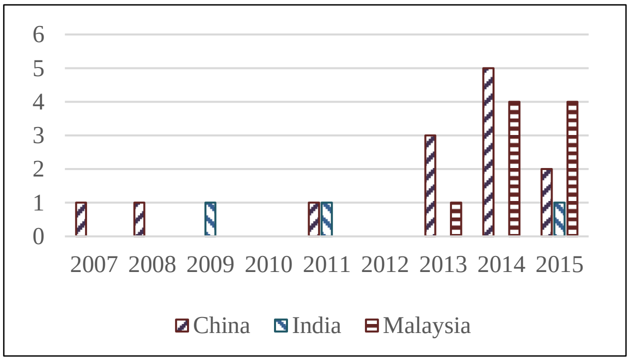

Table 3. Classification of articles

Dimension	Articles	Percentage
Technology	12	48 %
T1-Data property	1	4 %
T2-Relation	0	0 %
T3-Standards	4	16 %
T4-Utilization	7	28 %
Perspective	7	28 %
Construction Business Function	6	24 %
Total	**25**	**100 %**

Table 4. Mentioned terms

T1-Data property	As-built, cloud computing, construction management, data management, facility management
T3-Standards	Cost estimation, engineering contract, Industrial foundation classes
T4-Utilization	As-built, carbon footprint, construction management, construction safety, facility management, geographic information system (GIS), terrestrial laser scanner (TLS)
Perspective	Construction management, industrialized building system, information technology strategy, participant involvement, Structural equation modeling, sustainable construction
Construction Business Function	Innovation adoption, innovation diffusion theory (DOI), Institutional theory, integrated project delivery (IPD), lean construction, parametric modeling technology (PMT), technology acceptance model (TAM)

3.1. Technical

Viewing all technically focused articles together (T1-T4), we find a relatively strong focus on technology in developing countries (48% of all articles). Maybe not surprising, there are several studies focusing on the alignment of technological standards, taking into account national, regional and local regulations and legislation. Moreover, making BIM a technically better tool to support its utility for developing country construction firms receives much research attention. From the classification of the articles it appears that technological relation (T2) topics receive no research attention in developing countries.

<u>T1 – Data property:</u> Claiming that data management in construction and facilities management is challenging, Jiao et al. [25] suggest a “cloud application model”, namely LubanWay, enabling data sharing and gathering. This cloud computing model was applied and developed for facilities management in the Shanghai Tower. LubanWay can be used to combine engineering and management data, collect data, and proves “particularly effective in cost control” [25].

T3 – Standards: The identified studies focused on transferring BIM standards to the developing country context. This includes studies on how international BIM standards (e.g. AEC/UK or openBIM) can be adapted to the Chinese national context. There are presently no legal barriers for utilizing such standards in China as long as these are specified as contract addendum to the tender document [26]. Scholars have studied how industry foundation class file exchange (IFC) following the openBIM method can be employed in developing country civil engineering projects [27, 28]. This would allow for tighter integration across several different engineering systems [28], as well as aligning different estimation methods [27]. The findings are promising as they show that BIM has the potential to "significantly reduce" workloads and errors in civil engineering projects in developing countries [29].

T4 – Utilization: When implemented in projects, BIM provided design support resulting in overall reduction of design time [30, 31] and clashes [30]. However, it was evident how issues of low data quality and poor coordination may hinder effective BIM utilization [32]. How Terrestrial Laser Scanning and Geographic Information Systems data could be merged with BIM for creating 3D as-built visualizations has received attention from developing country researchers [31]. Other areas focused in this category include: BIM's utility for increasing construction safety [33], how to drive construction efficiency by deploying BIM [33], and how to overcome hurdles for BIM-based collaboration across companies [31]. Finally, sustainable or green construction is another area of BIM research, and "energy saving and carbon reduction" [34] as well as "energy conservation" in the early construction design stages are studied in the developing country context [35].

3.2. Perspective

BIM implementation surveys in developing countries can be found at industry, organizational, and individual levels. A survey of the Chinese industry surfaced that BIM was primarily viewed as useful for promoting contractor competitiveness [36]. Organizational BIM adoption levels in Malaysia and China remain low, with less than 20% of the surveyed construction organizations applying BIM in practice [37-39]. Moreover, even when BIM has been implemented in individual construction companies, its usage is limited and still in its infancy with many barriers to be tackled [38]. Taking a technical view, practitioners would need to improve "the compatibility and integration" between BIM and current construction software [38, 40]. Moreover, BIM use would need to be in alignment with daily construction activities [38]. Presently, BIM is viewed to be fairly complex and difficult to use [41]. In addition, developing country firms view BIM as a 'risky' investment since its business value remains unclear [36]. While practitioners appear interested in BIM adoption, they seem unwilling to change the status quo in their firms [41]. Drivers such as "economic benefits" and "effectiveness and efficiency" could motivate these practitioners [40]. BIM needs to be supported from clients, contractors and government before it will become used in developing countries [36, 41]. Moreover, technical training is viewed as important to drive BIM implementation [40].

3.3. Construction business function

Theories frequently applied in IS research such as Institutional theory, TAM and DOI are also used to investigate how to implement BIM in practice. A survey of 92 construction projects in China revealed that coercive or "authoritative pressures" have a great impact on the attitudes of clients/owners towards BIM adoption, while architects and contractors were mostly motivated by mimetic pressures seeking to imitate "successful conduct" of others [42]. Furthermore, practitioners' BIM adoption intentions were influenced by their "willingness and interest" [43]. Entrepreneurs viewed IPD based on PMT as promising avenues for improving their ways of doing business. IPD was considered a good approach for achieving tighter integration in developing country construction projects [44]. PMT was viewed as an essential basis for a better alignment of design technologies [45]. Utilizing relational database systems allows graphical and non-graphical data to be managed in one system. Such information infrastructure will support managing, capturing, and representing project data in a dynamic way [45]. Moreover, BIM systems still allow users to continue generating traditional two-dimensional paper drawing sets [45]. However, BIM adoption continues to be low in developing countries [38]. An attempt to develop a model for evaluating construction IT application in general, and BIM implementation in particular, has been presented in the literature [46].

4. Discussion

Most of the articles included in the review have been published in the last two years, showing how researchers have just begun to explore BIM topics in developing countries. When comparing the extent of this work to the BIM research efforts undertaken in developed countries over the past two decades, it is reasonable to claim that this work is still in its infancy. Moreover, research interest so far appears to be limited to China, India, and Malaysia. Thus, the findings presented in this article need to be viewed against the background that there exists little BIM related research from other developing countries. The key review findings of our review are presented using the BIM implementation framework introduced in section 1.2 (Table 5 and following paragraphs).

Table 5. Current state of BIM implementation in developing countries

Technical (T)	Perspective (P)	Construction Business Function (C)
• Technology transfer focus • Vanilla implementations • Few 'localized' BIM solutions • Focus on open file exchange formats	• BIM uptake unknown • Lack of BIM standards • Little government support • Few professional bodies and industry clusters • Legal status of BIM unclear • Outsourcing of BIM services	• Inexperienced modelers • Unclear benefits of BIM • Lack of financial resources • Low data quality in design

Technical - The articles have the main focus on transferring available BIM technology to the developing country context. Researchers focus their inquiries mainly on 'vanilla' implementations of commercially available BIM software packages made by software vendors located elsewhere. A notable exception from this trend is the LubanWay [25] software developed by a local Chinese software developer. Evidence from developed countries indicates that off-the-shelf BIM solutions will need some degree of customization and/or 'add-ons' to best fit the realities of local legislations and building traditions. Taking Norway as an example, there exists a range of commercially available BIM add-on software packages providing Norwegian construction companies with digital object libraries featuring construction materials typically used in Norway. Moreover, software packages for energy or costing solutions are developed to fit the realities of the Norwegian national context. However, developing local BIM solutions taking the national contexts of developing countries into account, may have ramifications for technological interoperability [36-43]. Researchers debate how this could be accomplished by focusing open file exchange formats, like the industry foundation classes (IFC), in software development [27, 28]. Judging from the articles reviewed, there appears a need for researching and creating local BIM software adaptations customized for the various developing countries. This constitutes an important area for further research.

Perspective - There are relatively few instances of practical BIM use reported in the developing country context. However, in China, India, and Malaysia, there are cases of BIM use similar to what is done in advanced projects elsewhere (e.g. the Shanghai Tower). However, in terms of industry wide BIM diffusion, China has fewer than 20% percent of its AEC firms reporting BIM use, whereas the US has BIM adoption rates of above 70% [47]. In absence of data on BIM diffusion in other developing countries, we also draw upon the insight from the first author, after working several years for a Vietnamese metro administration. According to his experience, in Vietnam there are very few cases of BIM use, and if ever used it is by Japanese and Korean consultants working in the projects. This indicates a need for further research mapping BIM uptake in other developing countries. This could be done based on existing BIM capability and maturity indicators. An intriguing question is how BIM diffusion in developing countries could be accelerated. One way would be to attain governmental support for BIM in developing countries. This has proven effective in Norway where several large construction clients demand BIM in open formats in all or most of their projects. Moreover, disseminating BIM knowledge to AEC firms operating in developing countries is important for further diffusion. Doing so would result in increased understanding of BIM's benefits and increase the technical expertise required for implementation. Succeeding with this knowledge dissemination would require concerted efforts involving professional bodies, industry, and academia [48]. Examples from countries such as Finland, Norway, Denmark, and Singapore show how these three players may contribute in promoting BIM. For example, Norway has an active research community, governmental building authorities, and the local organization buildingSMART Norway (representing 25% of the Norwegian construction industry) all focusing on national BIM development [49, 50]. The Norwegian buildingSMART chapter is an industry cluster focusing BIM capability development, development of training syllabi, and open file exchange [51, 52]. The result of this concerted effort is that all the large and also several of the small and medium sized Norwegian contractors have hands-on experience from using BIM. An intriguing avenue for further research would be to identify how developing countries can learn from successful practice elsewhere for increasing BIM knowledge and implementation.

Construction business function - The research classified under this sub-topic studies what can be gained by BIM implementation in different parts of the building construction supply chain in developing countries. Like their peers in developed countries, scholars from developing countries have argued for how sustainability, construction management and logistics could all benefit from increased BIM use. While conceptual studies from India and Malaysia debate BIM, GIS, and TLS integration [31, 33], studies exploring BIM use in transportation (roads, bridges, metro, etc.) and facilities (water pipes, sewers, etc.) projects are absent. Considering the importance of transportation and facilities projects for development, researchers should consider conducting further work in this area. Further, the business context in developing countries poses a range of challenges for BIM implementation: scarce financial resources, low quality in building design, lack of national BIM standards, and inexperienced personnel [32, 38, 53]. Against this background, many executives are not convinced that BIM usage will provide appropriate returns [36]. This amplifies the importance of governmental BIM support in developing countries. Ding et al. [40] suggested that public sectors should demand BIM or initiate the first BIM projects to lead construction industry. Construction organizations in developing countries appear to expect financial and technical support and guidance from their governments [43]. We propose that governments of developing countries should be more active in promoting BIM implementation. It is somewhat surprising that there are relatively few studies seeking to address the major barriers for BIM implementation in developing countries, similar to what is done in ICT4D research. This can be viewed as a limitation of the present work that would need to be addressed before BIM can be implemented successfully.

5. Conclusion

Based on a systematic literature review, this article has presented an overview of BIM research in developing countries. Almost no research on BIM in developing countries exists prior to 2013, and the focus of the present work is limited to the three countries of China, India, and Malaysia. Further, the scope of the research appears to be limited to topics related to technology transfer, seeking to import technology, standards, and collaboration approaches from developed countries to the context of developing countries. Limited attention is given to BIM implementations in infrastructure and facilities projects in developing countries. This leads us to conclude that more work is needed to develop new BIM solutions that better address the context of the local construction industries in developing countries.

In general, more studies are required to cover the gaps identified in this paper. Technological and managerial aspects in enhancing BIM implementation should be focused in further work. We propose to conduct research in developing countries on the framework dimensions (T1 and T2) that are under-represented. Moreover, further studies on how professional communities and industry clusters promoting BIM practice can be cultivated in developing countries are recommended. From a technical view, approaches or requirements for collaboration such as openBIM will be essential to focus in further studies. From the managerial view, development of an effective strategy for BIM implementation in developing countries should be targeted. In this pursuit, in-depth comparison between developed and developing contexts is required.

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RESEARCH ARTICLE

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Implementation of Building Information modeling in Vietnamese infrastructure construction: A case study of institutional influences on a bridge project

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Abstract

Many of today's building designs are created based on three-dimensional modeling technology. Architects and engineers use so-called building information modeling (BIM) systems to create digital representations of buildings. Inspired by the improvements in building construction projects, a Vietnamese construction project team decided to use the system to model a large-scale bridge crossing the Saigon River in Ho Chi Minh City, Vietnam. This paper provides an understanding of how the project team adopted BIM as the first BIM pilot project in Vietnamese infrastructure construction and analyzes the influence of institutional pressures. The findings reveal how the BIM champion of an international engineering consultancy led the project team to overcome challenges posed by local construction requirements and how the local partner adopted BIM technology under strict time and quality constraints. The case study presents an example for other infrastructure projects that involve BIM.

KEYWORDS

building information modeling, developing country, infrastructure, institutional pressures

1 | INTRODUCTION

Building information modeling (BIM) systems are viewed as a technology capable of transforming design and construction processes, ultimately resulting in better buildings quality (Azhar, 2011; Bryde, Broquetas, & Volm, 2013). A BIM system is a "shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from the inception onward" (National BIM Standard – United States, 2015). There is a broad consensus that BIM will be an essential cornerstone for digitalizing and modernizing the architecture, engineering, and construction industry. However, some scholars have commented on the challenges of implementation and limitations of the technology (Dainty, Leiringer, Fernie, & Harty, 2015; Vass & Gustavsson, 2017).

It has been argued that BIM practices are limited to large, highly information technology (IT)-literate firms capable of capitalizing on BIM technology (Hosseini et al., 2016). Other scholars find that BIM is primarily used in building construction projects, leaving behind other parts of the sector, such as transportation (Dongmo-Engeland & Merschbrock, 2016). Furthermore, most developing countries have considerable knowledge gaps and limited, occasional technological innovation, which has caused their construction sectors to miss out on BIM (Bui, Merschbrock, & Munkvold, 2016). This situation resembles what has been reported for healthcare systems, the internet, and e-procurement systems, which all prove difficult to implement in developing economies (Adams, 2004; Anaman & Osei-Amponsah, 2007).

In developing countries, building infrastructure is essential for economic growth (Giang & Pheng, 2011; Inderst & Stewart, 2014), and more research on technology adoption in project implementation is necessary to increase construction efficiency. Project owners have begun to demand visualization at a lower cost and better risk management (Ofori, 2007; Ogwueleka & Ikediashi, 2017). A potential solution to these problems is integrating BIM into the construction life cycle (Al-Btoush & Ahmad Tarmizi, 2017). There have been some encouraging recent developments in Asia, where several countries, including China, India, and Malaysia, have accumulated experience from work based on BIM (Bui et al., 2016; Ismail, Chiozzi, & Drogemuller, 2017). The application of BIM, and information and communication technology (ICT) in general, has reportedly brought benefits to the construction industry in developing countries. For example, ICT can improve the quality of quantity surveying services, facilitate decision making, and reduce costs on construction projects (Musa, Oyebisi, & Babalola, 2010; Oladapo, 2006). However, as documented in the case of Vietnam, this requires specialists with technology infrastructure development skills and versatile IT professionals who can apply their ICT skills in other work domains (Khanh & Winley, 2018; Winley & Lau, 2012). In addition to the inherent challenges of ICT implementation in a developing country context, BIM implementations are typically complex. BIM involves shared information space technology used for collaborative digital design work across several organizations. This paper sets out to explore the challenges and opportunities of BIM implementation in a developing country construction context. Institutional theory is adopted to understand how BIM emerges, diffuses, and sometimes vanishes during the project (Colyvas & Jonsson, 2011; Mignerat & Rivard, 2009). The research focuses on how institutional effects shape organizational behavior in BIM implementation. The research question asked in this paper is *Which important factors explain the emergence and institutionalization of BIM in the construction context in a developing country?*

The research question is answered by conducting a case study of the Thu Thiem 2 Bridge project in Ho Chi Minh City, Vietnam. This project constitutes Vietnam's first BIM implementation in a transportation project. The project can be viewed as successful because the design team was awarded an international prize for its BIM work (Tekla, 2017) and provides an example for other project teams who want to implement BIM technology in their transportation projects. This paper also contributes to the information systems development literature by studying how BIM can be institutionalized and thereby increase construction firms' efficiency in a development context. Furthermore, the BIM work was achieved via collaboration among companies from both developed and developing countries, and mutual learning enabled the BIM work to be completed successfully. Data were collected through semi-structured interviews with 11 BIM subject matter experts working on the project and by assessing project documentation.

The next section explains the IT artefact at the core of our study and the local Vietnamese context, as well as how institutional theory was utilized in this paper, followed by a presentation of the research method. The following sections present and discuss the findings, which provide insights obtained from analyzing the data through the institutional lens and relate the research outcomes to previous studies. Finally, the conclusion section summarizes key findings and makes recommendations for further research.

2 | INDUSTRIAL CONTEXT

In Vietnam, several major consultant companies have begun using BIM systems. For example, Hoa Binh Corporation, Contrexim, VNCC, Polysius Vietnam (Tran, Nguyen, Ta, & Le, 2014). However, it appears modeling is primarily used within individual disciplines, and few projects incorporate significant model-based interchanges between different firms and disciplines (Tran et al., 2014). Thus, when assessed using the "BIM capability stages," Vietnamese industries seem to have several firms operating at stage 1 maturity where only minor process changes have occurred, and traditional contractual relations, risk allocations, and organizational behavior persist (Succar, 2009).

Tran et al. (2014) state that BIM implementation in Vietnam is in its infancy and faces a range of challenges, including high investment costs and the lack of requirements from authorities, skilled personnel, and BIM training. The existence of these substantial challenges corroborates prior research, and it appears these types of challenges do not completely disappear even after a country advances its BIM work (Bosch-Sijtsema, Isaksson, Lennartsson, & Linderoth, 2017). To address some of the challenges and strengthen BIM implementation, the Institute for Construction Economics prepared a BIM roadmap for 2015 to 2020. This roadmap facilitates a review of BIM implementation practices worldwide to suggest an adoption plan for Vietnam (Bosch-Sijtsema et al., 2017).

The Vietnamese private sector and research institutes have been active in BIM implementation. For example, the Vietnamese software vendor Harmony Soft has made add-on packages for mainstream BIM software that include local Vietnamese building components in the models that reflect Vietnam's culture (Tran et al., 2014). In academia, local researchers from the National University of Construction and the Institute of Construction Economics have begun focusing on BIM. These two institutions have collaborated on organizing several BIM seminars to increase BIM awareness in Vietnam. By participating in these seminars, government agencies, research institutes, universities, and construction practitioners in Vietnam update themselves on ongoing trends and good practices in BIM (Tran et al., 2014).

The Vietnamese government has contributed to BIM adoption by preparing legal frameworks and promoting BIM use. In 2014, the updated construction law recognized BIM implementation as a construction management task. In December 2016, the Vietnamese government approved a BIM adoption plan that set a goal of completing at least 20 BIM pilot projects in 2018 to 2020. The outcomes of the pilot projects constitute the foundation for nation-wide BIM implementation, which will begin in 2021. Furthermore, the Ministry of Construction issued Circular 06/2016/TT-BXD, which allows including BIM implementation costs in construction budgets (Mui & Giang, 2018; Vietnam BIM Steering Committee, 2017). In 2017, a national BIM steering committee was formed to develop BIM implementation strategies and advocate BIM use.

This committee's work includes introducing an online information portal, as well as coordinating and guiding government agencies in BIM implementation (Vietnam BIM Steering Committee, 2017). In 2018, the Vietnamese government launched its adoption plan by selecting 20 pilot projects to experiment with BIM implementation (Decision 362/QD-BXD). These projects include the following projects: residential and office buildings (11), transportation (5), hospitals (3), and a water reservoir (1). The project owners will apply BIM during the design, implementation, hand-over, and operation phases. The relevant government authorities, especially the BIM steering committee, will support these pilot projects to overcome BIM-related challenges in regulation, procedure, training, and procurement.

3 | THEORETICAL LENS

This paper aims to understand institutional effects on the success of the Thu Thiem 2 Bridge project, which included BIM implementation. In the IS literature, scholars have used institutional theory to examine innovation adoption phenomena in organizations. In 2009, Mignerat and Rivard (2009) identified and reviewed 53 articles published in 20 IS outlets, all of which used institutional theory. These articles focus on institutional effects and the institutionalization of innovation (Mignerat & Rivard, 2009). While the institutionalization literature mentions different formation stages of institutions, the term institutional effect refers to the external environment's influences on a specific organization (Mignerat & Rivard, 2009). In a similar review, Weerakkody, Dwivedi, and Irani (2009) examined 210 peer-reviewed journals and found 511 articles published between 1978 and 2008 that address institutional theory. Among those scholarly works, 28 articles used institutional effects as a central analytic tool in IS studies. These IS articles were classified into three general themes related to IT: innovation (a), development and implementation (b), and adoption and use (c).

Institutional theory helps researchers explain organizational change in the innovation adoption process (Colyvas & Jonsson, 2011). Organizational change happens because organizations seek acceptance within socially constructed systems (Scott, 2014). Institutionalists study an organization within its environment, which consists of its relationships with other organizations (Scott, 2014). The analytic framework of institutional theory consists of three pillars as presented in Table 1 (Scott, 2014). Regarding institutional effects, the three pillars present the mechanism forming institutions through institutional pressures, which are coercive, normative, or mimetic (Scott, 2014). Coercive pressure relates to explicit regulatory processes that organizations must follow (Dimaggio & Powell, 1983). Normative pressures derive from professionalization, such as having interorganizational networks, similar educational backgrounds, and mimetic behaviors in a profession (Dimaggio & Powell, 1983). Mimetic pressure leads organizations to follow other organizations' practices that are perceived as being more successful (Dimaggio & Powell, 1983). Construction project teams work within a network of related organizations, such as clients, administrative agencies, and other teams working on similar projects. These related organizations exert different types of influences on project teams. The construction project environment is similar to what is described in institutional theory. Combined with the explanatory power of the theory, this similarity makes institutional theory an appropriate lens through which to understand a project team's behavior.

Regarding innovation adoption, Chan (2018) evaluate previous studies of how institutional pressures have made construction practitioners change their working habits to adopt innovative practices. For example, Kale and Arditi (2010) note that Turkish practitioners in their study applied CAD technology and ISO 9000 because they were afraid their competitors would gain a competitive advantage via these innovations. In a similar study, Dulaimi, Ling, and Bajracharya (2003) found that Singaporean construction companies innovate because they tend to mimic others in their supply chain. Since BIM is an innovation in construction, construction researchers have focused on institutional pressures to examine BIM implementation phenomena. Studies of institutional effects on BIM implementation range from the national scale (Cao, Li, & Wang, 2014) to case studies (Edirisinghe, Kalutara, & London, 2016). In these BIM implementation studies, the authors identified the key factors influencing innovation adoption in construction. The scholarly works described here document the explanatory power of institutional effects. Therefore, this paper focuses on institutional pressures to explain BIM implementation in the Thu Thiem 2 Bridge project case study.

TABLE 1 Three pillars of institutions (Scott, 2014, p. 60)

	Regulative	Normative	Cultural—cognitive
Basis of compliance	Expedience	Social obligation	Taken for granted
Mechanism	Coercive	Normative	Mimetic
Logic	Instrumentality	Appropriateness	Orthodoxy
Indicators	Rules, laws, sanctions	Certification, accreditation	Prevalence, isomorphism
Basis of legitimacy	Legally sanctioned	Morally governed	Culturally supported, conceptually correct

4 | METHODOLOGY

As this paper aims to extend the understanding of BIM implementation in the developing economy context, the case study approach was selected. The case study approach fits the research purpose well because this approach can provide an in-depth description of social phenomena (Yin, 2017). In particular, this paper presents a case study of a construction project in Vietnam.

4.1 | Case description

The setting of our case study is a large infrastructure construction project in Vietnam. The 1473-m-long bridge is one of five connections crossing the Saigon River in the center of Ho Chi Minh City. The cable-stayed bridge is set to become a landmark in the region with its pylon rising to 111 m above water level. The bridge, linking the Thu Thiem district to the old city center, features six traffic lanes and two pedestrian walkways on either side of the bridge deck. In 2008, the Ho Chi Minh city council (HCMC) allocated €80 million to fund the project. Once enough land was acquired to begin construction in February 2015, a private corporation, Dai Quang Minh (DQMC), was appointed to oversee the bridge design and construction activities. The agreement included deploying BIM technology throughout the design and execution phases (Tuoi Tre Newspaper, 2015). DQMC has played the client role since the agreement was signed. The city's intention was to embrace BIM use following a wider national strategy seeking to increase digitalization in the Vietnamese construction industry. An example of the BIM models used in the project is depicted in Figure 1. In addition to requests from the city, DQMC must also comply with national construction regulations monitored by relevant authorities, such as the Department of Transportation, Ministry of Construction, Ministry of Transportation, and Institute of Construction Economics.

A Finnish consultancy (WSP Finland Øy) was appointed to work alongside the local consultant (TEDI South) to deliver the engineering design of the bridge. The Finnish engineers had a track record of working with BIM software in their projects. Finland is renowned for its highly digitalized construction sector, which delivered its first BIM projects nearly twenty years ago (Kam, Fischer, Hänninen, Karjalainen, & Laitinen, 2003). However, BIM use in infrastructure projects is a relatively recent development in Finland (Bradley, Li, Lark, & Dunn, 2016; Kivimäki & Heikkilä, 2015). Although TEDI South is a leading infrastructure consultancy in Vietnam, they had no prior experience working with BIM technology. Thus, the Finnish engineers supported their local counterpart in its BIM work. In turn, the Vietnamese consultant ensured local regulations were followed and that the project was delivered on time and within budget. The BIM vendors supplying the software and IT support were from Finland, Viasys VDC, and Tekla companies. All these project partners had to follow Vietnamese regulation enacted by relevant authorities.

The Thu Thiem 2 Bridge project was selected for several reasons. First, this case constitutes Vietnam's first BIM technology implementation in an infrastructure project, and the institutional context of BIM software implementation in Vietnam is poorly understood. Second, this project is viewed as internationally leading, signified by the team winning the international Tekla BIM Awards for the bridge design in 2017, which indicates that studying this advanced practice may yield important insight for companies elsewhere. Moreover, international collaborators on this project seem to have worked well together, with the Finish consultants being named "creative company of the year" by the Embassy of Finland in Hanoi

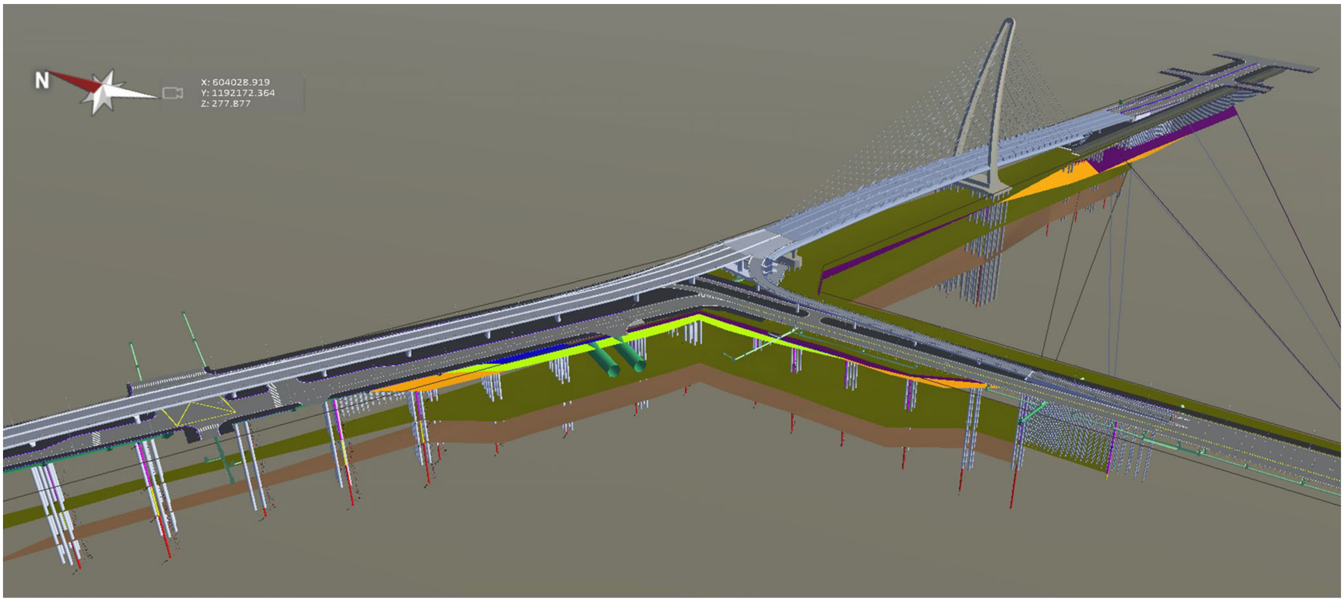

FIGURE 1 Thu Thiem 2 Bridge, Ho Chi Minh City, Vietnam (Courtesy: TEDI South)

TABLE 2 List of informants

#	Position	Organization	Discipline	Experience (years)
1	Technical Manager	Dai Quang Minh Corp.	Structure	10-15
2	Project Director	Dai Quang Minh Corp.	Management	15-20
3	Project Manager 1[a]	TEDI South	Management	15-20
4	Bridge Engineer 1	TEDI South	Structure	5-10
5	Bridge Engineer 2	TEDI South	Structure	0-5
6	Survey Engineer 1	TEDI South	Geology	+20
7	Survey Engineer 2	TEDI South	Geology	+20
8	BIM Coordinator 2	Viasys VDC	Structure	0-5
9	BIM Coordinator 3[c]	WSP Finland	Management	10-15
10	Technical Manager 2	WSP Finland	Structure	15-20
11	Project Manager 2[b,c]	WSP Finland	Management	+20

[a]Project-level BIM coordinator.
[b]Project-level BIM manager.
[c]Foreign engineer.

for their contribution to Finnish-Vietnamese relations. Finally, the knowledge and experience gained by the local engineers are likely to shape the development of Vietnam's national BIM standard for infrastructure.

4.2 | Data collection

An interview guide was prepared based on institutional theory with a focus on the pillars of institutions, similar to what Scott suggested in his work on institutions and organizations (Scott, 2014). The interviewees answered 17 open-ended questions, allowing them to share their experiences with the BIM-based work. The opening questions were aimed at learning about their professional background and role in the project. The next three thematic areas were designed to capture the regulative, normative, and cognitive elements experienced in BIM work (Scott, 2014). The questions captured how institutional pressures manifested in day-to-day project activities (eg, experience sharing and training), work materials (eg, certificates, standards, models, and procedural guidance), and in the actors' documentation related to BIM. The interviews concluded by asking the engineers to identify the principal elements that inspired them to adopt BIM technology. In addition to the interviews, a range of BIM-related project documents informed this paper. This includes the written investment decision, BIM guidelines, training materials, meeting protocols, a simulation model of the project, and materials presented online.

Data collection began in May 2017 by contacting the director of Viasys VDC Vietnam, the software vendor that provided virtual design programs for the project. At this point, the design process had been underway for 2 years. Following this initial contact, a letter of intent was sent to the project director, who consented to the research being conducted. The first interview with WSP Finland's project manager took place at the end of June 2017. WSP's manager, who oversaw the design work on the project, identified the key actors performing managerial, coordination, and modeling tasks with BIM. From June to July 2017, a total of 11 interviews with the design team members responsible for implementing BIM were conducted and recorded. Then, the recorded interviews were transcribed and analyzed based on important concepts in institutional theory. An overview of the interviewees, their position, professional discipline, and construction work experience is presented in Table 2.

Notably, most interviewees had extensive experience in bridge construction. Only one bridge engineer and one BIM coordinator had less than 5 years of experience. However, these two engineers possessed strong BIM modeling skills. The other Vietnamese or local engineers had just begun exploring modeling programs a few months before the project was initiated. The interviewees consisted of two foreign and nine local engineers. While the foreign engineers only work for WSP Finland, the local or Vietnamese engineers represent the client, the WSP Finland office in Ho Chi Minh City, TEDI South, and Viasys VDC. The interviewees' strong professional backgrounds allowed them to reflect on both traditional practices and emergent BIM use.

4.3 | Data analysis

All interview transcripts and collected documents were imported into NVivo 11 software and coded. The coding nodes follow Scott's three pillars of institutions, which allow classifying quotes into coercive, normative, and mimetic pressures. The quotes support the explanation of how institutional pressures influenced the project team.

5 | FINDINGS

5.1 | Coercive pressures

The project members commented that they had to deal with three main barriers during the process. These barriers were traditional paper-based work practices, cost estimate regulation, and technological capacity. Without the support of the relevant authorities, it might seem impossible to use BIM in the project. Figure 2 presents keywords that were repeated the most from the interviewees. Some of the common keywords are BIM, project, construction, design, think, know. It indicates the data include opinions and experience of the interviewees on applying BIM in construction projects.

The first barrier is that construction authorities only accept 2D paper-based drawings for approval. This requirement applies to all projects submitted for approval in Vietnam. The project director refused to make an exception and approve a 3D model: "Everybody in Vietnam wants the 2D drawing and documents." As stated by Survey Engineer 1, "The Ministry of Transportation agencies always want to see physical signatures and stamps in all submissions." The paper-based tradition also influenced TEDI South's design sequence during the project. Instead of beginning with a 3D model, the local consultant prepared the design on paper. Then, a 3D model was produced based on the 2D design to meet the requirements of the engineering contract with the client so that TEDI South could satisfy the local requirements and meet the deadline. Since this project was the first BIM experience of TEDI South, the project manager 1 was afraid that the local consultant would be unable to complete its assignment on time while learning to use the new technology. For WSP Finland, it was an unusual practice. After successfully creating the 3D model, the WSP Finland team had to prepare 2D drawings for submission. It seemed they had to "go 100% back [to paper-based documents] to finalize the design," as stated by BIM Coordinator 3. Since the drawings must comply with Vietnam's construction regulations, and the software was unable to export these accordingly, the WSP Finland team manually modified the drawings exported from the 3D model. This modification consumed a considerable amount of time. When the authorities requested changes, the WSP Finland team updated the 3D model and then produced the modified 2D drawings. The consultant team perceived the 3D model for TEDI South and the 2D drawings for WSP Finland as additional tasks they had to perform to incorporate BIM into the project: "We [had] to prepare both the 2D drawings and the 3D model…, so it took a lot of time" (BIM Coordinator 2).

FIGURE 2 The common keywords repeated the most by the interviewees

Another barrier was the regulations for cost estimates include no items for applying new technologies, which meant individuals in charge of the state budget would refuse to reimburse for such items. Thus, the clients focused on the total cost more than innovation because they wanted to keep the construction costs as low as possible. Since the Thu Thiem 2 Bridge belongs to Ho Chi Minh City, the bridge was a state project, and the construction had to strictly follow the cost estimate regulations. According to the project director, it was difficult to get reimbursed for software license and computer purchases as cost items in the project's budget because the consultants could use these ICT tools on other projects. Thus, it was unreasonable to depreciate the whole investment amount on one project. Although the consultant could increase its fee a little if new technology was used, no extra points for innovation were given in the bidding process. According to the Technical Manager 2, consultants or contractors could use the project budget for software licenses and computers, but they had to transfer ownership of such items to the client after the project was completed. It was an asset management regulation. Unfortunately, a project might require several years to complete, at which point the software and computers might be outdated. Thus, the client would be unwilling to receive them. Even when BIM could show proven benefits, the Project Director insisted “the cost has to be approved.” A decision from a higher level of authority is necessary in this case.

The technological capacity of Vietnamese construction companies was another barrier. The local consultant team recognized that its company had to invest in staff training, software licenses, and computer system upgrades, as well as implement new work processes to implement BIM, which could be a long process and require considerable effort. Thus, the management board seemed reluctant to adopt BIM and simply encouraged its staff members to upgrade their knowledge themselves. After the engineering contract was signed, TEDI South had more motivation, but it also had to deliver a 3D model. They used part of the contract money to buy software licenses, provide staff members with training by external lecturers and allow staff members to try different BIM programs during working hours. Before the contract was signed, interviewees from TEDI South commented that they were busy with other projects and did not have time to learn about BIM. From the client side, the Project Director noted that other parties, such as the contractors and government agencies, should also implement BIM to provide the greatest benefit to the project.

Furthermore, BIM implementation happened only after the HCMC officially approved it in the build-transfer agreement with DQMC. However, the decision to apply BIM seems to have been influenced by the Institute of Construction Economics' consent. In the beginning, not all authorities agreed with the proposal, but consent from the higher authority level was more important. In this case, the Department of Transportation, the HCMC agency for infrastructure, refused the proposed estimate for BIM, but the Institute of Construction Economics agreed. This consent was given approximately 2 years before the Vietnamese government officially approved the national BIM adoption plan in December 2016. It meant the Institute of Construction Economics perceived no coercive pressure for BIM at that time. The project owner, HCMC, made the decision based on the Institute of Construction Economics' comment. The reason, the Institute of Construction Economics recommended BIM use, will be further discussed in the mimetic pillar section.

Regarding the BIM expectations from the client side, the project members had different opinions. The WSP Finland team were surprised because the client indicated no desire include BIM in the project. Project Manager 2 understood that “the client didn't know what to do [with BIM,] so they often agreed with what we [the consultant] proposed.” The Project Director explained that he considered cost as the most important criterion. In addition, the technical manager admitted that his team had no experience with BIM. Thus, the client team was unable to prepare requirements and monitor BIM implementation. Regarding BIM implementation, the consultant team felt the largest part of the coercive pressures were from the Institute of Construction Economics to showcase innovation benefits in the Vietnam context.

At the company level, the demand for BIM expertise was low. The members could join the project team without any advanced knowledge of BIM. No partners set formal recruitment requirements, such as BIM certificates or experience. Indeed, DQMC, WSP Finland, and TEDI South only encouraged their employees to explore software and BIM on a self-study basis. BIM implementation relied solely on the Finish consultant. From TEDI South's side, Survey Engineer 1 noted that “the management board only requested us to master the program for which the company has licenses, and the board preferred [taking on] more projects to adopting new technologies.” DQMC considered the project to be temporary as members and technologies might vary from project to project. Moreover, HCMC would receive the bridge after the implementation in about three years. Thus, DQMC was unable benefit from BIM in the long-term. It led to the client being unmotivated to pursue BIM adoption. In this context, the local project members obtained BIM knowledge from seminars, conferences, and online channels. This environment, which provides knowledge of trends and the status of BIM applications, exposed them to normative pressures. The following section uncovers the effects of normative pressures on the Thu Thiem 2 Bridge project.

5.2 | Normative pressures

The local project members from TEDI South and the WSP office in Ho Chi Minh City had the desire to follow modern trends in construction, resulting from normative pressures from information sources and the competitive environment. This desire became another motivation to implement BIM in their work without the management board's request. Thus, BIM implementation could remain in their companies in the long-term. “Eventually, BIM, building information modeling, is a piece of digitalization progress in building industry” (Project Manager 2).

In fact, the local project members knew about BIM through short courses, formal education, seminars, conferences, and online channels. The local modeling team prepared themselves in advance by attending short courses on modeling programs as illustrated by the following quotes: “I studied some BIM tools myself and have tried to apply these new skills in practice” (BIM Coordinator 2), and “I think we have to study by ourselves to be ready for new demands at work” (Project Manager 1). After the project began, TEDI South also organized similar courses for its employees, including the Thu Thiem 2 Bridge project team. The courses demonstrated new capacities of modeling programs and introduced new trends in BIM technology. However, Bridge Engineer 1 commented that those courses were ineffective because most of the tutors were from academic institutions and had little practical bridge modeling experience. The knowledge gained from these courses was unable to help them solve modeling issues encountered in the Thu Thiem 2 Bridge project. Thus, they had to search for solutions on online channels, such as YouTube and Autodesk Community. Conferences and seminars on BIM applications outside of the project were an additional information source. Furthermore, the WSP Finland project manager had completed his master's thesis on BIM in 2014. The fresh knowledge he gained during his degree program provided the latest trends to the local engineers through internal project training. The WSP Finland project manager also led the establishment of expectations for BIM use in the project. Referring to the BIM levels in the United Kingdom (British Standards Institute, 2013) as a measurement, he directed the Thu Thiem 2 Bridge project from level 0 to 3. In the later phases, he expected to combine all digitalized project information in the model. The short courses and these information sources provided an understanding of the new capacities of software and new trends in construction. The more the local project members knew about BIM, the more they wanted to update their knowledge. They wanted to match the level of BIM practitioners in other developed countries, such as the United Kingdom, the United States, Singapore, and Finland. This motivation encouraged them to implement BIM: “If you are a consultant, you must lead the market in terms of technology” (Survey Engineer 1).

Competition in the Vietnamese construction market was another pressure to apply BIM. The WSP Finland project manager noted that his company wanted BIM experience in Vietnam to compete with other international consultants in the future. Regarding the local companies, the TEDI South team knew that other companies were trying to adopt BIM. They mentioned Hung Nghiep, VTCO, and TEDI Hanoi as companies that are applying BIM. However, they had no discussion or information regarding the status of BIM implementation in these companies. Survey Engineer 1 insisted that “an engineer needs both engineering and modeling skills.” With only an engineering background, an engineer needs other people to prepare the model. With only the modeling skills, he might not be confident in his work. Thus, if they had no BIM skills, they might be outdated soon. Besides, the local team understood that the Ministry of Construction would prepare regulations for BIM implementation based on pilot projects, including the Thu Thiem 2 Bridge. These regulations could be mandatory for the whole industry within a few years. They surmised that other companies were already preparing for this development and were afraid of losing their competitive advantage. Although all local members believed that Vietnam would adopt BIM, most of them presumed that the adoption would take five to ten years. This guess was much longer than that of the government plan, which set 2021 as the milestone to apply BIM throughout the country.

5.3 | Mimetic pressures

In addition to coercive pressure from the authorities, mimetic pressure from the Finish consultant, who had the most extensive BIM experience on the project, played an important role in making the implementation successful. Since mimetic pressure influenced related parties and project members, the pressure assisted the project team in overcoming the strict regulation of construction costs and gradually changed from a paper-based to model-based design process.

Regarding cost regulation, the project director mentioned that the authorities had to approve the costs, but no one in Vietnam had prior experience with BIM in a bridge project. Thus, it was difficult to prepare and approve the estimated BIM-related expenses. In the Thu Thiem 2 Bridge project, WSP Finland was the only partner who had competence in and experience with BIM implementation. In 2012, the Finish Company began approaching the Ministry of Construction, Ministry of Transportation, Institute of Construction Economics, Department of Transportation, and other relevant authorities and began organizing BIM seminars. In these seminars, the WSP Finland project manager presented case studies from the United States and Finland to introduce the benefits of BIM: “Our role would be bringing something new here, so I started to discuss with the ministries and many departments” (Project Manager 2). The authorities perceived the potential and wanted to achieve such advances. Thus, the Ministry of Construction prepared a program for pilot BIM projects in Vietnam. In 2014, WSP Finland prepared the estimated cost for BIM as a design task in the Thu Thiem 2 Bridge project. The BIM implementation cost increased the total design fee by 10%. HCMC almost declined the proposal. Fortunately, the Institute of Construction Economics, the Ministry of Construction's agency in charge of construction economics, agreed with the proposal because it supported the Ministry of Construction's pilot program. The Institute of Construction Economics expected evidence of BIM's benefits in Vietnam on the Thu Thiem 2 Bridge project. With consent from the Institute of Construction Economics, HCMC formally requested that the client apply BIM in the project, leading to implementing BIM in the project at the beginning of 2015. It is noted that the government approved the pilot program in the BIM adoption plan in 2016 (The Prime Minister Office, 2016). In this process, WSP Finland placed mimetic pressures on the relevant authorities to remove the traditional barrier of the cost estimate. In particular, WSP Finland obtained approval for BIM implementation by presenting the benefits of BIM to the relevant authorities, which indicates that the mimetic pressure became coercive. During the design phase, the project team showcased BIM use in the Thu Thiem 2 Bridge project through seminars. In these seminars, the project team invited a representative from the Institute of Construction Economics, the Department of Transportation, and other relevant authorities. This communication channel maintained mimetic pressure on the authorities, who held coercive power in the project.

Mimetic pressure also encouraged the local team to gradually change the local consultant's design process. Through its partnership with WSP Finland, TEDI South received on-the-job training and seminars. This cooperation helped increase BIM knowledge and skills among the Vietnamese engineers. In this project, the experts from WSP Finland guided TEDI South's engineers in following the BIM execution plan, as well as preparing the model. WSP Finland also introduced typical BIM projects to the local consultant team. Since the project had a tight deadline, TEDI South decided to prepare the traditional 2D drawings for submission. Then, they created the 3D model from the 2D design and used it for reference. They felt that they were not ready for BIM in the Thu Thiem 2 Bridge project. Their purpose for using BIM in the project was to study how to use BIM rather than make the best use of the new technology. However, because TEDI South knew how to use BIM, they were able to utilize the 3D model to identify problems in the paper drawings. When the 3D modeling team found problems, they checked and modified the drawings: "The 3D model helped us to identify so many mistakes and clashes in the drawings, especially complicated structures" (Bridge Engineer 2). As can be seen in Figure 3, the steel bar placement, pipes, anchors, and other structural components were merged in the 3D model. The design team used a BIM software tool to prepare this simulation and automatically detect conflicts between the components and then adjust the design accordingly. Before they prepared the 3D model properly, traditional 2D drawings of related components in Figure 3 were submitted to meet the tight deadline. The conflicts identified from the 3D model were transferred to the later design step. Since the relevant authorities still demand traditional drawings, the BIM technology was not leveraged to its full capacity. In the traditional procedure, a senior engineer would review all papers based on his experience. However, many conflicts remained until the implementation. Bridge Engineer 1 added that "sometimes we don't know how the contractor can build from the paper drawings, some parts are almost impossible to imagine." With the 3D model, the local design team seemed more confident with their product and decided to adopt 3D designs in the future. "The company [TEDI South] is looking for big projects to implement BIM"," according to Survey Engineer 1. The experience of the local design team in the Thu Thiem 2 Bridge project was important in this process. It implies there were mimetic effects that made TEDI South modify their design process.

Moreover, the data reveal the influence of members who had more advanced modeling skills and BIM knowledge. In the Thu Thiem 2 Bridge project, the design team relied on BIM coordinators from WSP Finland and the software vendor to solve modeling issues. These coordinators mastered the modeling programs and had engineering backgrounds. Since this was the first bridge project with BIM built in Vietnam, the project members found many required components, for example, the handrail, to be difficult to model. In this case, the BIM coordinators searched the available solutions and solved the problems with them. This support was useful for the local consultant since it worked with the modeling programs for the first time. When the local engineers had gained more experience with the software, they began to write some add-ins that were tailored to their work. An add-in is a piece of code or mini-program that can be used as a function in specific software to provide extra features. Most of the add-ins were created to input data or visualize the components. For example, Survey Engineer 1 wrote a Revit add-in to input the displayed values for the boreholes in the model. This add-in could enter the data from the geological survey into the model. It saved considerable time compared to entering the data manually. Survey Engineer 1 commented that "It took much time to familiarize with the software in this project, but we could do it faster in future projects when we have libraries and tailored add-ins." In this learning process, the local engineers not only familiarized themselves with the modeling programs but also customized these for their own sake. The customization helped the design team meet local requirements. Although the customized add-ins only supported survey information in the Thu Thiem 2 Bridge project, these mini-programs might be the key to removing the traditional barriers and meeting the local requirements on other BIM projects in Vietnam.

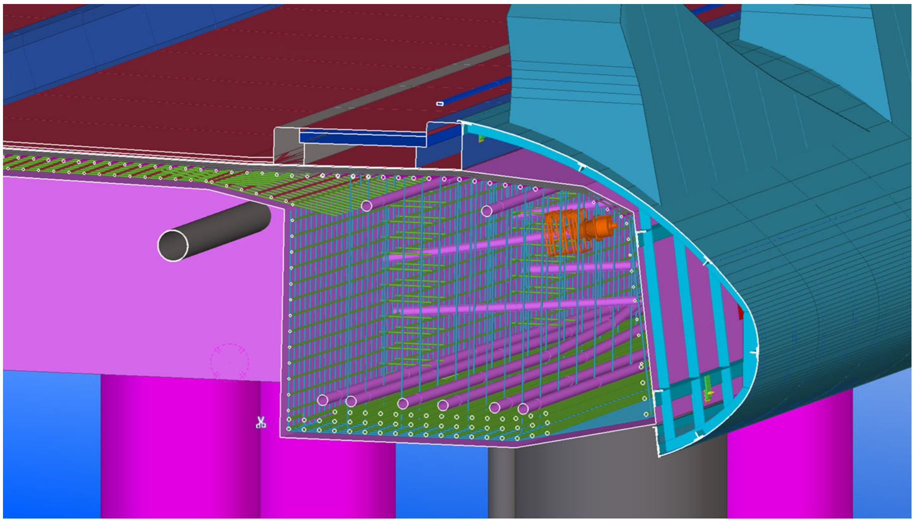

FIGURE 3 A 3D simulation of complicated structures to identify conflicts (Courtesy: WSP Finland Øy)

6 | DISCUSSION

This paper has described how the effects of institutional pressures lead to successful BIM implementation in the Thu Thiem 2 Bridge project. The main factors were support from the relevant authorities and guidance from the BIM champion on the project. A BIM champion is a person with the required technical skills and motivation to lead the organization implementation of BIM (Messner & Anumba, 2013) who, in this case, was the WSP Finland project manager. Also, the project team had to overcome three barriers that hindered innovation on the project. These barriers derived from mandatory construction regulations regarding paper-based submissions, cost estimate regulations, and the technological capacity of Vietnamese companies. However, the project team managed to implement BIM successfully. Through the institutional lens, this effort represented a mutual effect of institutional pressures, which are summarized in Table 3. In the case study, the mimetic pressure became coercive. After the relevant authorities acknowledged BIM's benefits from presentations they had attended at workshops and seminars, they recommended the project owner formally request BIM. Since the local members had to apply BIM, they had stronger motivation to seek related knowledge. They collected knowledge not only from other project members but also from outside sources, such as short courses, workshops, seminars, conferences, and online channels. This environment provided them an overview of BIM's implementation status worldwide. During this information seeking process, they exposed themselves to normative pressures. Thus, they felt it necessary to obtain new BIM skills. Otherwise, their skills could be outdated soon. The case study also explains how companies gradually change their working processes during innovation adoption, with the local consultant team shifting from paper-based to 3D modeling design.

Furthermore, the interviewees referred to the existing paper-based tradition as the most time-consuming issue in implementing BIM. Since the software was unable to generate 2D drawings that could meet the local requirements, the project team had to modify them manually after they were exported from the 3D model. This indicates a gap between the local requirements and the software's capacity. In the Thu Thiem 2 Bridge project, project members used add-ins to reduce the number of manual tasks. These customized mini programs might decrease the gap. However, it seems difficult to resolve this issue without the involvement of authorities and software vendors. These agencies define the local requirements and develop the software. How local requirements might be harmonized with software capacity might be an interesting topic for further research.

In the case study, coercive pressure from government authorities, the project owner, and the client were low. They requested BIM in the project only because the consultant presented good practices through various seminars and had no specific expectations for BIM. In contrast, coercive pressure from clients and government authorities has been reported as the major reasons for BIM in Hong Kong (Chan, 2014) and China (Cao et al., 2014). However, none of these studies reveal why government authorities and clients request BIM. Since these organizations have decision-making power on construction projects, identifying what influences the BIM adoption decisions of government authorities and clients requires further study.

The Thu Thiem 2 Bridge project confirms the importance of a BIM champion. The WSP Finland project manager acted as the major change agent to implement the BIM innovation in the project. The importance of a BIM champion has also been documented in other studies in Norway (Bui, Merschbrock, Munkvold, & Lassen, 2018) and Sweden (Lindblad, 2016). In a similar vein, Bosch-Sijtsema et al. (2017) found that clients need solid knowledge to enforce BIM implementation in their projects. Unlike these studies, the BIM champion on the Thu Thiem 2 Bridge project worked for the consultant's team. This position provided the Finish manager with less coercive power than a BIM champion on the client's team. Thus, coercive pressure might be important, but it is not necessarily the root of the innovation adoption initiative. Moreover, the client teams of public projects in Vietnam have low salaries compared to the consultant or contractor teams because these salaries have to follow the national scale for state officers. Thus, it might be difficult to recruit competent BIM champions to the client team. This context raises the question of how BIM champions from the consultant team influence BIM implementation on public projects. The answer to this question might reveal practical contributions to public projects not only in Vietnam but also in other developing countries that have a similar situation. Furthermore, studies addressing this question could contribute to a better understanding of institutional effects on BIM implementation in construction projects that have a low level of coercive pressure.

In a BIM implementation study conducted in China, Cao et al. (2014) found normative pressure had no influence on BIM implementation. However, the interviewees in the case study provided a different perspective. Through seminars, workshops, conferences, and online channels, project members perceived innovative trends in the construction industry. The trends made the project members want to learn new BIM skills for their own sake; otherwise, their skills could become outdated. This is the result of normative pressure on the project team. Most of the project members knew about BIM trends through discussions in professional communities. Thus, how construction communities support BIM implementation in infrastructure projects deserves further study.

TABLE 3 Overview of the findings classified based on the three pillars of institutions

Regulative pillar	Normative pillar	Cultural-cognitive pillar
• Project owner demand • Relevant authorities' consent/ decision • Construction regulations • National BIM pilot plan • BIM execution plan	• Participation in seminars, workshops, conferences, and short courses • Online channels • Competitive construction market • Government initiatives	• Mimicking others' processes at work • Receiving training from others • Mimicking examples from online communities

This paper provides practical contributions to BIM implementation in infrastructure projects where BIM applications are still in the early stage. By describing the responses of different partners under institutional pressures in the Thu Thiem 2 Bridge project, the paper explains how the project partners overcame various barriers to make BIM implementation possible. The practical contributions can be useful for innovation adoption in infrastructure projects for government agencies, project owners, design consultants, and contractors: (a) government agencies and project owners can create discussion channels for innovations in construction, coordinate inter-project experience sharing, prepare frameworks for testing new technologies, and may want to consider changing building regulations for BIM; (b) project design teams can staff their projects with BIM experts in key roles, create environments where novice BIM users learn from experts, and employ recent university graduates with strong IT/BIM skills; and (c) contractors can participate in professional forums and seminars to remain abreast of the latest technology and can collaborate with partners who have a greater technological capacity. The first contribution mentions about generating discussions among policy-makers and BIM experts. In this way, the policy-makers have better understanding of BIM technology, while BIM experts are aware of local requirements. As a result, updated regulations to leverage BIM capacity and customized BIM implementation processes will be available for construction practitioners. The second and third contributions present suggestions to address the technological capacity of local construction companies. Better technological capacity and better regulations can benefit BIM implementation in a developing context.

Regarding institutional effects, the consultant team exerted mimetic pressure by presenting the benefits of BIM to the relevant authorities. The main actor was the BIM champion, the Project manager from Finland. The Finish BIM champion showed BIM benefits to relevant authorities in various seminars and workshops. This effort motivated decision-makers in these agencies to support the project team to implement BIM in the Thu Thiem 2 Bridge project. Since the authorities acknowledged the benefits, they decided to allow BIM use in the case study. Furthermore, the project team not only adopted BIM but also customized modeling programs to make these programs fit the local regulations. The findings might also be valuable to other projects in similar contexts.

The case study presents an example of how construction companies in a developing context collaborate with their counterparts from developed regions for BIM implementation. The experience of the local consultant might be useful for other developing countries which want to increase the uptake of BIM. In the Thu Thiem 2 Bridge project, the main barriers for implementing BIM, as a new technology, in Vietnam infrastructure projects derived from the local regulations. These barriers were the paper-based approval and the cost estimate regulations. To overcome these barriers, the supports from relevant government authorities are essential. For successful implementation, the local consultant connected the Finish consultant to relevant authorities. In this way, the project team could present the benefits of BIM to these authorities and have their consents for BIM implementation.

Regarding the IS discipline, IS scholars have studied response strategies to institutional pressures for many years (Mignerat & Rivard, 2009). Thus, strategic responses of construction organizations to institutional pressures on BIM implementation is a relevant topic for IS scholars. The paper also makes a theoretical contribution by providing an understanding of institutional pressure on BIM implementation in an infrastructure project within the context of a developing country. Since knowledge from developed countries might be invalid in developing ones (Khanna, 2015), more studies in developing contexts are necessary to improve our understanding of institutional theory. The findings illustrate how different institutional pressures combined to ensure the implementation of innovation in the case study.

The major limitations of this work lie in the context of the case study. The Thu Thiem 2 Bridge project is the first BIM pilot project in an infrastructure context in Vietnam. In this context, the influence of similar projects or companies was limited. Furthermore, the interviewees included the managers, coordinators, and 3D modelers. This combination helped to provide data on the managerial and collaboration processes, which are the key focus of this paper. However, the data does not include the local 2D bridge designers' opinions. Thus, a part of the BIM implementation in the Thu Thiem 2 Bridge project might remain uncovered. Furthermore, the case study identified the influence of the consultant team on the decision of the project owner, but the data include no interviews with the project owner or the relevant authorities. Therefore, the data might only reflect the opinions of the consultant. Despite these possible limitations, this paper documents relevant findings regarding BIM implementation in the Thu Thiem 2 Bridge project.

7 | CONCLUSION

In summary, this paper presents a case study of the first BIM pilot project in the Vietnamese infrastructure domain. Analyzed through the institutional theory lens, the collected data reveal important factors for successful BIM technology adoption. Although the project team faced barriers in the local traditional working process and context, the experienced partner from Finland supported the team in successfully implementing BIM. The description of institutional effects in this paper contributes to the understanding of BIM implementation in the IS discipline. The experience of the project team reported in this study might be transferable to other projects in similar contexts. Also, this paper suggests some suitable topics for further study, such as the gap between local requirements and software capacity, the influence of relevant authorities, the role of BIM champions on the consultant team, and last but not least, the role of the construction community in adopting new technologies in the local context.

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AN INSTITUTIONAL PERSPECTIVE ON BIM IMPLEMENTATION – A CASE STUDY OF AN INTERCITY RAILWAY PROJECT IN NORWAY

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Abstract

Architecture and engineering offices around the world increasingly replace their dated Computer-Aided-Design (CAD) solutions with Building Information Modelling (BIM) solutions. There is a profound IT-enabled change in the way in which commercial and residential buildings are designed and produced. However, parts of the industry remain largely excluded from this trend, as roads and railroads continue to be designed based on two-dimensional CAD systems. This paper reports from a case study of BIM implementation in a Norwegian railroad project Based on institutional theory, we identified how institutional pressures affected the BIM implementation of the project team in the InterCity railway project. The cases study highlights the important role of the client's BIM manager in enforcing these pressures in practice. Furthermore, the paper provides useful insights not only for construction project teams seeking to implement BIM in infrastructure projects but also for other organizations adopting new technologies.
Keywords: Institutional pressure, building information modelling, infrastructure, railway.

Introduction

"*Using BIM [Building Information Modelling] as a planning tool improved our process on nearly every front. With BIM, we could reduce the environmental impact of our project, optimize designs across disciplines, and increase democracy and transparency in our planning*" BIM Manager, Bane NOR [1]

The statement above appeared on Autodesk's web page after the Norwegian "InterCity line" railroad project had been awarded the software vendor's prestigious Architecture, Engineering, and Construction Excellence Awards in 2016. The project was lauded for having succeeded in using BIM technology effectively to attain approval from more than one-hundred project stakeholders. Bane NOR, the national Norwegian railroad administration, stated that using BIM software was influential in reducing the adverse environmental impact of the railroad project, ensuring good communication with the project stakeholders, and explaining the project to the wider public. InterCity, the largest ever infrastructure construction project Norway, is positioned to become a national role model for BIM use in transportation projects.

Building Information Modelling software packages have been developed, as the name implies, for supporting the design of buildings. It is only recently that software vendors have begun offering similar solutions for transportation projects. Moreover, the processes for BIM-based work in transportation are just beginning to emerge. Thus, exploring the results of an early implementation of this new software in its industrial context affords an opportunity for understanding the implementation process. Moreover, the recent technological advancements in the architecture, engineering, and construction industry would seem to be an area in need for further information systems (IS) research [2]. There is a well-established knowledge base in IS research that can be drawn upon for studying the implementation of information systems. Moreover, the existing potential to contribute to transforming a major industry such as infrastructure construction is a worthwhile undertaking.

The motivation of this paper roots in the difficulties occurring when new technologies are implemented in a transportation project. Since McKinsey Global Institute [3] reported that the construction labour-productivity growth lagged behind that of the total economy from 1995 to 2014 worldwide, contributions to technology implementation in construction could support to solve this problem. With this notion in mind, we looked for a framework helpful for understanding technology adoption and found institutional theory, which has proven value for explaining change processes and innovation adoption [4], to be an appropriate theoretical lens for the study. Institutional theory considers the processes by which rules, schemas, norms, and routines are formed to become stable foundations for social behaviors. Institutions are routinized social behaviors that are continuously reproduced by a set of actors. Therefore, institutional theory is a worthwhile theoretical view for exploring how BIM technology use in transportation projects can be turned in to a taken-for-granted and continuously self-producing social behavior. The theory is useful for understanding what makes an IT innovation "stick" in organizational settings [4].

Understanding the institutional effects on the BIM-based work in this railroad project is a good starting point for other construction project teams seeking to implement this technology in their projects, through insights into what motivates project teams to work based on BIM. Since there are few examples in the literature reporting in depth on how to make BIM work in railroad projects, we contribute by asking the following research question: *What are the institutional effects on the BIM implementation in the InterCity line railroad project?*

To address this question, we present a case study conducted in the InterCity project, analysing how the multiple actors organized and used BIM in their project. The theoretical lens guiding the data collection is institutional theory. The intended contribution of this paper is twofold. First, we argue that research taking an institutional perspective can broaden the theoretical understanding of BIM implementation in transportation projects. Second, the practical contribution of this paper is to showcase some of the influencing factors for successfully implementing BIM in transportation projects.

Building Information Modelling: The Artifact Explained

The crucial difference between BIM and earlier non-object-based 3D CAD solutions is the concept of object-based design. BIM joins object-based design, relational databases, and parametric manipulation. Object-based design or solid modelling technology allows for the description of geometric objects in 3D space fully. Relational databases fused with the solid objects allow for linking building product specifications to the objects represented in the model. Parametric change engines make the objects "smart" by enabling their automated modification. In other words, "Doors will fit automatically into a wall [and] a light switch will automatically locate next to the proper side of the door" [5]. In essence, the software allows for creating virtual prototypes or so-called "digital twins" of buildings and/or infrastructure. Moreover, BIM serves as a design space where multiple organizations engage in collaborative dialogue [6, 7].

Rapid advances in building information modelling offer new opportunities for improving processes in the architecture, engineering and construction industry. BIM aids project teams to cut costs, achieve higher productivity, accuracy, better communication, and efficiency [8]. However, Cheng, Lu [9] point out that there is a tendency for construction practitioners to think that BIM's benefits are limited to building construction projects. In fact, there is a belief in some quarters that transportation projects differ substantially from buildings and that BIM technology would not yet yield benefits for these types of projects (ibid.). While BIM has become widely diffused in building construction, transportation is left behind. Transportation projects include bridges, roads, railways, tunnels, ports and harbors [9].

Arguably, there are several differences between building and transportation projects having to do with their structural components. Moreover, they are executed by different communities of practice whose technical language differs considerably. For instance, a column in a building is equivalent to a pier in a bridge. Furthermore, railroads, roads, and bridges have their components arranged horizontally based on central or reference lines. This is why BIM for infrastructure is frequently referred to as "horizontal BIM" whereas BIM in building construction is referred to as "vertical BIM" [8]. Thus, the logic on which infrastructure projects are based is almost the diametrical opposite to that of generally vertical building design [10]. In the US the implementation of BIM technology in infrastructure projects is about three years behind BIM implementation in building projects [8].

Theoretical lens

We adopt institutional theory to identify and understand what helped the InterCity project team succeed in their implementation of BIM technology. There is a legacy of IS studies using institutional theory to identify the driving forces behind technology implementation in organizations. To illustrate this, a recent review of the literature identified 53 articles published in 20 IS outlets using institutional theory in the period from 1989 to 2009 alone [11]. In fact, institutional theory has been used to study innovations in organizational settings since the end of the 1970s [12, 13]. These types of studies focus both the institutional effects and institutionalization of innovations [11]. Institutionalization is about different formation stages of institutions. Institutional effects refer to the influences of an institution on other institutions, organizations, or organizational entities (ibid.).

Table 1. Three pillars of institutions [12]

	Regulative	**Normative**	**Cultural - cognitive**
Basis of compliance	Expedience	Social obligation	Taken for granted
Mechanism	Coercive	Normative	Mimetic
Logic	Instrumentality	Appropriateness	Orthodoxy
Indicators	Rules, laws, sanctions	Certification, accreditation	Prevalence, isomorphism
Basis of legitimacy	Legally sanctioned	Morally governed	Culturally supported, conceptually correct

The theory is also a powerful tool to explain individual and organizational behaviors in technology adoption [14]. According to Dimaggio and Powell [15], an organizational field includes "those organizations that, in the aggregate, constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar services and products". The concept of organization field allows institutionalists to craft relationships between a given organization and its environment [12]. In these relationships, organizations desire for legitimacy for not only survival but also social acceptability and credibility in their environment in the long run. Therefore, organizations will strive for legitimacy, and their behaviors are controlled and constrained by institutions. Scott [12] suggests that "institutions comprise regulative, normative and cultural-cognitive elements that, together with associated activities and resources, provide stability and meaning to social life". Regulative, normative, and cultural-cognitive pressures result in social structure either imposed on or upheld by organizations and individuals. These social structures are then translated into 'scripted' organizational and/or individual behavior which on the long run may become taken for granted and institutionalized [12]. In short, organizations follow institutions to achieve legitimacy [11]. Legitimacy is defined as “a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions” [12]. Institutional theory has proven its value in IS research and scholars have shown how institutional effects work on distinct phases of the IT/IS implementation process, identified response strategies to institutional pressures, and explained the interaction between IT artifacts and institutions [11]. However, institutional theory is not without criticism and it has been argued that it fails to adequately theorize differences across organizations [13].

As can be seen in Table 1, institutions are formed by three pillars, namely regulative, normative, and cultural-cognitive pressures. The three pillars form or support institutions in different dimensions and could be used as an analytic framework to understand institutions. The regulative pillar contains regulatory or rule-setting activities by institutions [16]. In effect, this pillar gives prominence to explicit regulatory processes such as rule-setting, monitoring, and sanctioning activities (ibid.). Normative systems “define goals or objectives (e.g., winning the game, or making a profit), but also designate the appropriate ways to pursue them” [16]. Values or norms may be applicable to all or at least several members of a collective (ibid.). In plain English, this pillar is about following guidelines imposing constraints on social behaviour. Cultural–cognitive systems are more about constructing a common meaning in the collective. This dimension is not so much about the objective conditions in a social environment, but the actor’s subjective interpretation of them (ibid.). Moreover, this pillar is concerned with cultural aspects, symbolic aspects of social life, and belief systems that exist in a collective (ibid.). A good example of how such meanings are formed are isomorphic mimetic pressures [15].

In construction projects, the project team performs its tasks in a relationship with other organizations such as clients, administrative agencies, contractors, consultants and other similar project teams. This leads us to argue that institutional theory could be a suitable lens to understand a project team’s behaviors, which in the case of this paper is the implementation of BIM as an information system [14, 17]. Understanding the change from traditional drawing to model-based design is important to explain the BIM implementation process. Understanding change might also reveal “how things stick” [4], i.e. how to retain innovation in the organization. More explicitly, this paper utilizes institutional theory to explore the mechanisms that shape BIM implementation in the case study. We use the three pillars of institutions as depicted in Table 1 to inform the analysis part of this paper.

Methodology

The setting of our case study is the 270 km InterCity railroad project including 25 new stations connecting the cities of Oslo, Lillehammer, Halden, Porsgrunn and Hønefoss in eastern Norway. We collected our data during the design stages of the Dovrebanen line, a 75-km double track railway from Sørli to Lillehammer in the second quarter of 2017. This part of the project has been chosen based on several selection criteria. The first criterion was that the project participants should resemble a rather typical constellation of actors involved in the design of railway projects to ensure that we would capture how institutional pressures influence their BIM-based work. The second criterion was to choose a project where digital modelling technology was used in the project design stage. The third criterion was that we needed a railroad project where BIM had been implemented with some success. The Dovrebanen project fulfilled this criterion since the project team won the Autodesk 2016 AEC Excellence Awards, recognizing their successful BIM application. The project benefited from BIM usage when determining the characteristics of the physical alignment of the railroad. BIM was influential for integrating existing railroad tracks, harmonizing crossings with existing main streets, and protecting valuable landscapes from adverse environmental impacts. Furthermore, BIM was used as a medium to facilitate communication across the 120 internal and external stakeholders of the project [1].

For capturing how BIM-related practices were adopted by the organizations participating in this project and how and why individuals conformed to the new practices, we informed the data collection by institutional theory. More precisely we structured our interview guides based on the three institutional pressures as suggested by Scott [16] namely: regulative, normative and cultural cognitive (ref. Table 1). The questions posed to the individuals participating in our study aimed to reveal the activities (experience sharing, learning…), the materials (standard, certificate, model…) and information sources related to BIM in the experience of the project members. The interviewees went through seventeen open questions to tell their stories about BIM implementation in the project. At the end of each interview, the interviewees were asked to rank the reasons for BIM implementation. We expect to find causes that are outside of the institutional theory framework.

Fig. 1. Screenshot from the Dovrebanen BIM model (© 2017 Helga Nes, RIFs årsmøte, BaneNOR)

The data collection started in February 2017 by sending the letter of intent to the project director. After the administrative procedure, the first interview with the project's BIM manager took place in the end of March. Based on the background collected from this interview, we met members who hold managerial or coordinating positions for getting in-depth data on the BIM implementation process. From May to June 2017, a total of ten interviews were conducted and recorded. This included five informants from the client team and five from the consultant team, as profiled in Table 2. These actors were in charge of coordinating the BIM work in a design team comprising two hundred consultants and engineers.

Table 2. Overview of interviewees, their disciplines, and years of experience

Client organization			**Consultancy**		
Role	Discipline	Exp.	Role	Discipline	Exp.
BIM manager	Management	20 +	Project director	Management	10-15
Project manager 1	Management	20	BIM coordinator 1	Management	15-20
Project manager 2	Management	15 - 20	BIM coordinator 2	Management	10-15
Project planner 1	Planning	20 +	BIM coordinator 3	Management	5-10
Project planner 2	Planning	15 - 20	Discipline leader	Geology	20 +

The recordings were transcribed, and coded through the use of NVivo 11. The ideas were classified into nodes that belong to the background, regulative, normative and cultural-cognitive categories. We analyzed related ideas in each node to understand the institutional effects on the project team members in BIM implementation.

Findings

This section provides our analysis based on Scott's pillars of institutions as related to the BIM implementation in the case study. First, a brief overview of the collaborative design space as established in the case project is presented, followed by a presentation of our findings structured according to the three pillars, namely (1) regulative, (2) normative, and (3) cultural-cognitive. Thereafter, this chapter presents the interviewees' perceptions of which institutional pressures they found most influential for their digital work.

The collaborative design space

Right from the start, BaneNOR (the client) decided that the entire project should be modelled based on three-dimensional design technology. At the time, BaneNOR worked on developing a national BIM modelling handbook for infrastructure projects. This work was largely based on earlier handbooks for building construction projects prepared by Norway's governmental property developer Statsbygg. The project team found these guidelines to be too generic for use in the InterCity project. This is when BaneNOR, in collaboration with a reference group involving the project consultants, began developing project specific guidelines called "3D agreement". The "3D agreement" was intended to serve as a basis for the digital collaboration. It specified how to model, what to model and the level of detail that can be expected of the individual design contributions made to the model.

The client's BIM manager took a central role in developing the guidelines. She began by preparing the initial agreement, defined the filename format, the layers and colour codes to be used in modelling, and the level of detail that should be provided by each of the disciplines throughout the different phases of the design process. The reference group then added further detail based on their experience from earlier project work and new experiences made in the InterCity project. The client, who positioned InterCity as a partnering project, demanded close collaboration of the individual consultancies.

Regulative pillar

"Force, sanctions, and expedient responses are central ingredients of the regulatory pillar" (p.61) [12] these usually come in the form of rules and laws [16]. The institutional mechanism behind the regulative pillar is coercive pressure or the "formal and informal pressures exerted on organizations by other organizations upon which they are dependent and by cultural expectations in the society within which organizations function" [15]. Thus, the actors exercising these pressures are usually governments, regulatory bodies, large organizations, and industry associations [18]. In the context of a construction project, coercive pressure could, for example, be exerted by a client's organization downwards through the supply chain.

The contracts between BaneNOR and the engineering consultancies stated that BIM and 3D modelling was to be applied in the design of the project. By demanding the delivery of 3D models, the client exerted coercive pressure on the project team affecting the engineering consultancies' behaviours. Moreover, documents attached to the contract, i.e. "Bane NOR's infrastructure BIM handbook" and an early version of the "3D agreement", specified in depth how modelling technology was to be deployed in the InterCity project. These specific guidelines may also be viewed as coercive pressures. These pressures were however rendered weak since the specifications had not been tried out in the practical setting of a railroad project before, making their application and enforcement difficult. Nonetheless, all consultancies agreed to collaborate to help the client's organization to further develop these guidelines, which may be seen as results of coercive pressure.

Bane NOR's top management stated that BIM should be used in the InterCity project. This can be viewed as a form of coercive pressure working within the client's organization itself. Thus, the client's project managers had no choice but to enforce a BIM strategy in their project. Top management, however, was not very specific and, apart from demanding BIM to be used, the client's project management team felt that there was little active support by management: "*It was a management decision that we should use a BIM model but actually there was no more support than* *that*" (BIM manager, client). Consequently, several members of the client's project team had neither prior experience nor the computer systems required for active participation in the modelling in place. Thus, taken together, this coercive pressure can be viewed as somewhat weak.

Demanding BIM or 3D modelling technology to be used in the project, in conjunction with little related experience by many of the client's engineers, left some of the consultants puzzled: "*If our client doesn't require BIM use, we will not do it*" (BIM coordinator 2, consultant). Nonetheless, there were other voices stating that they would use modelling technology even in total absence of coercive pressures: "*I will still try to use 3D modelling but maybe some of the disciplines would not be so enthusiastic because they see it just as more work, stating that they don't have the resources for doing it*" (BIM coordinator 1, consultant). A general perception was that coercive pressures exerted by the client were important for initiating modelling activity by all parties: "*The projects where it is easy to implement BIM are those where the owner demands the use of BIM*" (BIM coordinator 1, consultant).

Beyond the aforementioned, we found no instances of regulative coercive pressures related to digital modelling in the project. This is also indicated by the client's BIM manager who stated that she could "*work quite freely*". Moreover, one of client's engineers stated that his management did not really display an interest in modelling activity: "*My manager, he doesn't use 3D and he never has a question about 3D*" (project manager 1, client). Overall, the consultants viewed the coercive pressures for using 3D modelling exerted by the client's organisation as rather weak: "*The demands from Bane NOR to the consultancies* [related to 3D modelling] *were not very high*" (Project manager 1, client). This same consultant stated, however, that this situation changed dramatically once the client's organization employed a senior BIM manager with twenty years of related experience. This indicates that a client organization's coercive pressures related to BIM and 3D modelling work only become effective by a combination of having rules in place and the right people to enforce them.

There were other coercive pressures affecting digital modelling work in the project. More specifically, the municipalities' approval processes still require 2D paper drawing sets to be delivered as a basis for decision-making. This meant that while the client's management team demanded from the consultancies to use 3D modelling to create their designs, there were demands to deliver 2D drawing packages at the same time. Thus, the coercive pressures working on both the consultants and client's design team can be viewed as somewhat ambiguous and counteracting each other. Unless municipal rules are changed towards allowing for 3D designs to be used as a basis for municipal approval processes, these mixed coercive pressures will continue to exist. According to one of the client's project managers, BIM is still quite new, and: "*Many people here are using paper and they will continue using paper*" (project manager 1, client).

Normative pillar

Normative pressures primarily derive from professionalization, which is "the collective struggle of members of an occupation to define the conditions and methods of their work" [15]. Professionalization can happen through formal education and professional improvement. While education from universities and training institutions has an important role in developing organizational norms internally, associations contribute to defining professional rules and behaviours through inter-organizational networks [15]. Therefore, the educational background, trainings, professional association activities, modelling standards and certificates were the foci of the section presented here. The normative section further focused on common practices or standards that can be applied to all projects, and the sources of information.

Some of the project team members attend conferences or industry workshops quite frequently to keep abreast of recent developments in the industry. It was quite common for the engineering consultants to attend conferences and even present their work in these. The consultants stated that they attended BIM and 3D modelling specific events such as national buildingSMART events, events hosted by Norway's BIM network or events held by software vendors such as Novapoint who develop modelling software for infrastructure projects. The client's BIM manager and one of the project managers both attended similar conferences. In addition to the industry-focused conferences, the client's representatives attended BIM workshops for governmental and state institutions such as the "Nordic BIM collaboration". Attending such conferences and workshops provided the project team with updated knowledge on BIM technology use and available systems. Moreover, this indicates that there appears indeed to be quite an active "collective struggle of members of an occupation" [15] to move towards 3D modelling and BIM in Norway.

There appear to be considerable normative pressures working on Norwegian engineers to begin using 3D digital modelling systems. The project team's activity in this direction indicates that this is taken seriously by all parts of the project organization. To illustrate this, one of the consultants' BIM coordinators stated, "*It's important mainly to keep up with what other people are doing and… being visible in the market...to sell our services*" (BIM coordinator 1, consultant). Not updating oneself on the recent developments could even mean exclusion from the occupation altogether: "*You won't get a job if you cannot use a 3D model*" (BIM coordinator 1, consultant). How powerful this normative pressure is and how not adhering to it could even weaken the market position of firms follows from this quote: "*If [company] didn't want to use BIM, I wouldn't want to work there because this would tell me very much [about the employer]*" (Project planner 2, client).

Professional and social networking activities appear to be another source of normative pressure working on the engineers. The interviewees take both active and passive roles in network activities. The passive access happens through surfing social network newsfeeds on the way to work or registering the email lists for webinar invitations, reports and so on. The active approach includes googling for certain problems and following discussions on BIM related communities. Also, this form of normative pressure pushes project members to study or take training related to BIM because "*I have to be on the top of the skill level all the time*", as stated by a BIM coordinator 1. This BIM coordinator often takes courses on Lynda.com when he wants to update his knowledge. In addition, the project members perceive BIM and 3D modelling training as important formal education, while certificates related to BIM are considered less important. In their opinion, such certificates are good "*for polishing your CV, but no one cares*".

Cultural - cognitive pillar

When organizations strive for ambitious goals, they tend to imitate other organizations to replicate their perceived effectiveness. This mimicking might happen unintentionally through employee transfer or formally through industry associations [15]. Moreover, Gholami, Sulaiman [19] suggest that envy of the success of competitors, suppliers, and customers could motivate mimetic behaviours. In the case study, a precise and detailed description of how to build the 3D model in a railroad project did not yet exist. The project team thus needed to consider mimicking available 3D knowledge from elsewhere, such as existing modelling handbooks from building projects.

The client's BIM manager started up the "3D agreement" initiative. She had the idea from a friend who worked with 3D modelling in another railway project. In that project, each discipline had an agreement document to define what and how to create the objects. Thus, this makes the use of the 3D agreement in the InterCity project a case of mimicking. This indicates that cultural cognitive pressures played a role in motivating the BIM-based work in the project, too. Moreover, there is evidence for mutual learning about BIM across the different project teams working on the four lines of the InterCity project. It is, however, true that the possibilities for learning from others were limited to the team, or as the client's project manager put it: "*We don't have many projects to relate or to look to because this project is so large in scale that this has not been done before based on a 3D model*".

How the team learned from others and from available knowledge within the team is maybe best illustrated by how the "3D agreement" evolved. First, it was written based on prior industrial experiences from the project team members. In fact, some project team members had extensive BIM experience from road projects. One example is the client's BIM manager having more than twenty years of experience from consultancy work and from working at a software developer making systems for infrastructure BIM. She was familiar with most of the commercially available BIM software solutions, and also taught design courses for some years. Similarly, one of the client's project managers had worked in road projects with 3D deliverables starting as early as 2003. The consultants had quite many experienced 3D designers specialized on road projects. Thus, while railroad BIM is totally new, there exists a knowledge base in road construction that can be drawn upon: "*We did not start from zero when we established the project*" (Project director, consultant).

Similarly, mutual learning across the InterCity project organization was influential for developing the "3D agreement". A reference group of BIM experts working on the different lines was formed to inform the development of the agreement. This coordination process required the consultants to share their expertise and experience. The project team identified good practice from other projects to mimic this in their project, with some modifications. The project director stated that "*a lot of people are asking for information and I will share it*" and "*if we see useful information …then we want to apply it as soon as possible*". He also stated that the key to this learning is cooperation: "*We are working with the others but maybe not as close as we would like to, we could have been working even closer*".

Moreover, from their experience and professional network participation, most of the interviewees have the feeling that BIM is an irreversible trend in the construction industry. They "*take it for granted*" that "*there is no way back*" to the traditional design with drawings, and that "*everybody is going to work based on the new 3D modelling programs*" in the future to come.

Priority of institutional pressures

At the end of each interview, the project members were asked to rank the following three different reasons for using BIM in this project: the request from the client, good practice from other projects, and the recent trends in the construction industry. This question also opened to other reasons from the interviewees. The answers revealed that the request from the client is not always the most important reason to apply BIM. Most of the interviewees agreed that they apply BIM because they find it useful for their work; they experience the benefits from other projects, and would like to replicate this in the case study (cultural-cognitive pressures). Some interviewees were somewhat passionate about discussing benefits of BIM. Second came that they viewed BIM to be an important trend in the construction industry (also cultural cognitive pressures)

Discussion

This paper has described how institutional pressures influence BIM implementation in the InterCity project. The analysis reveals that the project members have been exposed to all three institutional pressures, jointly influencing the implementation in different ways. An overview of the pressures is presented in Table 3. The contracts with the consultant expressed coercive pressure by requesting 3D model delivery. The contract terms provided a solid reason to apply 3D modelling, but the level of detail for the model was unavailable. Moreover, the client had initially no people with the necessary expertise to follow the contract before they hired the BIM manager. We found that the degree to which the client can influence BIM practices in projects depends on a combination of top management support, contracts and rules, and the degree of BIM expertise present in the client's organization. We found also coercive pressures exerted by the municipalities counteracting digital modelling work. Based on this we suggest for policy makers to revisit municipal approval practices and allow for delivery of digital models as opposed to 2D paper drawings.

Some of the normative pressures working on all members in the project team follow from participating in professional and social networks. There seems to exist considerable peer pressure in the Norwegian professional communities towards working based on digital modelling. The practitioners felt that BIM and 3D modelling are irreversible trends. While the project team found the reason and motivation for BIM implementation from coercive (regulative) and normative pressures, the detail of the BIM implementation is rooted in mimetic (cultural-cognitive) pressures. Therefore, we would argue that early adopters of BIM in infrastructure projects are unable to specify documents for BIM implementation without extensive experience sharing with other project teams. How experience sharing supports BIM implementation might be a promising research topic.

Within the infrastructure domain, inter-project coordination seems important for BIM implementation. This was similarly found in a recent Swedish BIM implementation study [20]. This indicates that mimetic pressures are of crucial importance for succeeding with infrastructure BIM projects. Reference groups appear to act as catalysts for mimetic pressures and seem influential for project teams seeking to work based on BIM. Our findings indicate that inter-project coordination is an important channel for experience sharing among construction practitioners. The important role of mimetic pressures as drivers for BIM implementations has been identified in earlier work [21-23]. In our view, there is a need for further work in this area to explore how experience sharing, as one type of mimetic pressure, can support BIM implementations.

Table 3. Overview of the findings classified based on the pillars of institutions

Regulative pillar	Normative pillar	Cultural – cognitive pillar
• Top management demand • Modelling contracts • Modelling rules • Champions enforcing the rules • Counteracting pressures from municipalities	• Modelling skills give “professional status” • Workshop participation and membership in professional communities • Modelling prominent in social and professional networks	• Mimicking others • Inter-project reference group

Some published surveys provide insights into the reasons for BIM implementation in different countries. In Hong Kong [22] and China [24], coercive pressures from the clients and government authorities are named as the major reasons for BIM implementations. However, none of these studies actually point to pre-existing coercive pressures working in the opposite direction of BIM-based work by enforcing 2D paper drawings instead. We argue that the balance of these two diametrically opposed coercive pressures is an interesting topic for further research.

Also, our findings would seem to confirm the importance of a client’s demand for digital work. However, similar to the recent Swedish study we find that client project managers act as change agents or champions for ensuring the use of BIM within their projects [20]. Based on our findings we would argue that coercive pressures only materialize when clients have BIM champions enforcing them. Bosch-Sijtsema, Isaksson [21] argue in a similar vein and state that solid BIM knowledge is a necessary precondition for clients to be able to enforce BIM in their projects. Cao, Li [24] found normative pressures not to influence on BIM implementation. Based on our findings we beg to differ and argue that in fact, informal, normative pressures originating in individual engineers’ social and professional networks would seem crucially important for successful 3D/BIM implementation in infrastructure projects.

The above discussion is a good example of how institutional pressures begin to play out in BIM implementations. In the IS discipline, response strategies to institutional pressures have been a research area for many years [11]. We argue that exploring how construction organizations respond to institutional effects and pressures in BIM implementations is a promising topic also worthwhile for IS scholars. Considering that IS provides a strong knowledge base that can be drawn upon for studying how these new types of artifacts may influence an important industry, we argue that we need more IS work in this area.

The practical contributions of our work are that we present some of the underlying institutional pressures that made the BIM implementation in this railroad project possible. These pressures are listed in Table 3. We argue that some of these pressures are transferable to other projects and countries. However, the national Norwegian industrial context here represents a limitation to transferability. We argue that especially the normative and cultural-cognitive pressures would be difficult to replicate in other countries. The normative pressures resulting in engineers believing that their professional future hinges on their modelling skills seem to be a result of Norway having a tight-knit infrastructure BIM community mutually enforcing these beliefs: "*The infrastructure BIM community in Norway is quite small, so we all know each other*" (BIM manager, client). Moreover, within the BIM community there seems to exist a culture where knowledge is freely and openly shared between and across companies and projects.

The theoretical contribution of our work is that we provide an initial understanding of the institutional pressures influencing BIM implementations within the industrial context of railroad projects. One intriguing finding is that there exist regulative pressures working diametrically opposed in railroad projects. Moreover, we found a hierarchy of institutional pressures. The interviewees informed the importance of cultural-cognitive, normative, and regulative pressures, in that order. We would argue for more studies in the hierarchy of institutional pressures to broaden the understanding of institutional theory. The case study also reveals close-knit professional communities represent "breeding grounds" for mimetic pressures would also seem to be an interesting theoretical finding. This would represent an interesting area in need for further research.

A clear limitation of our work is that our findings are influenced by the national Norwegian context, as argued above. Moreover, all the interviewees performed managerial tasks. This helps to understand the managerial aspects of the collaboration processes that were focused in this paper. However, the voices from technicians were absent, which might leave a part of BIM implementation uncovered. Notwithstanding these limitations, this paper does illustrate the institutional effects on BIM implementation in a railway project.

Conclusion

This paper identified how institutional pressures affected the BIM implementation of the project team in the InterCity railway project. Regulative pressures stem from top management, construction contracts, modelling rules, and municipalities. The client's BIM manager is important to enforce them in practice. Normative pressures include modelling as professional status, workshops, and social and professional networks. Cultural cognitive pressures include mimicking and inter-project reference groups. Further promoting successful BIM diffusion in railroad projects would require all three institutional pressures to be in place. This paper also provides insights on technology implementation that could be transferable not only to other projects, but also to other countries. From the theoretical view, the InterCity case study indicates a hierarchy of institutional pressure, which might be an interesting topic for further studies. Moreover, this paper suggests exploring the role of professional communities in technology implementation.

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ROLE OF AN INNOVATION COMMUNITY IN SUPPORTING BIM DEPLOYMENT: THE CASE OF BUILDINGSMART NORWAY

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ABSTRACT

The construction industry is notorious for being slow to adopt technological innovations. One way to support the industry and accelerate the uptake of technologies is to establish open standards. This paper examines how the buildingSMART community helped the Norwegian construction industry in their attempts to implement Building Information Modelling (BIM) with open standards. The interventions were identified by using the Institutional Intervention Model in the data analysis. Data were collected through interviews with industry experts affiliated with the Norwegian chapter of buildingSMART. The interviewees were selected for their central role in the community and for working hands-on with developing open standards, processes, guidelines and educational resources for BIM implementation. Our findings show that the community has succeeded in their efforts to further BIM-related competences in the industry. Moreover, we document how the interventions of non-profit communities have contributed to creating tangible business values for firms in the construction industry. The insights from this study have implications for other industries or countries which desire to develop innovations based on a community approach.

Keywords: building information modelling, construction industry, open community, open innovation.

1 INTRODUCTION

Innovation can help the construction industry to increase efficiency, corporate performance and sustainability [1]. However, the construction industry still lags behind other industries in innovation activities because of different barriers derived from its nature and context [2]. The low uptake of innovation adoption also happens when construction practitioners digitalise with building information modelling (BIM) technology. BIM supports the shift in construction projects from paper-based to model-based design [3], [4]. This technology also assists in the change from fragmented construction processes to an integrated and collaborative working style based on Information and Communication Technology (ICT) platforms [5], [6]. Besides development in separate organisations, construction practitioners also advance innovation through communities [7], [8]. We contribute by expanding the literature on construction communities and innovation, particularly in BIM development. Our research question is: “How do construction communities advance BIM technology?”.

To answer this question, we interviewed eleven industry experts affiliated with the Norwegian chapter of buildingSMART. Moreover, to understand how the community intervenes in industrial practice, we used the Institutional Intervention Model [9] to make sense of the interview data. This model helps to disclose how the community’s activities influence the adoption and use of BIM technology. The paper aims to broaden understanding of innovation activities in construction communities by describing the role of a professional association for innovation in the construction industry and explicating how construction companies can obtain business value from community work.

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The paper is organised into six sections. The first section introduces the research question and objectives. The second section briefly describes BIM technology, openBIM and the buildingSMART construction community. The third section presents the theoretical lens guiding the data collection and analysis. Then, the method section introduces the case study, followed by a presentation of the findings and discussion. Finally, the conclusion summarises key contributions and topics for further research.

2 BUILDING INFORMATION MODELLING AND INNOVATION COMMUNITIES

2.1 Building information modelling

BIM is an ICT innovation supporting data sharing and collaboration in construction projects. In such projects, different disciplines, such as architecture, structure and mechanics, perform various tasks, including design, implementation, maintenance and management, requiring extensive collaboration among the construction partners. BIM software provides a platform for this collaboration, integrating separate construction processes into an information model of the construction project. The model typically consists of non-geometrical and geometrical data of the building components. While geometrical data include physical measurements, non-geometrical data support construction management with information such as scheduling, costs, material types and relationships among components. The main idea of BIM is to create a digital object that includes all relevant data and make these data available for relevant parties within the construction life cycle. The results of BIM use include but are not limited to fewer errors, lower expenses and shorter duration [10], [11]. To gain benefits from BIM, construction organisations have invested in BIM development through various options, such as open innovation. An example of the open approach to BIM development is openBIM.

An initiative of buildingSMART, openBIM is "a universal approach to the collaborative design, realization, and operation of buildings based on open standards and workflows" [12]. Simply put, openBIM is a digital language for the open and free exchange of information on the built environment. With openBIM, construction partners can work together regardless of the software they use through a vendor-neutral data exchange format. Regarding "closed BIM", the BIM tools are from just one vendor [13]. Since construction involves different disciplines and tasks, it is difficult for a single software vendor to provide necessary tools that match all construction demands. Thus, construction companies use different software systems. These software systems should feature interoperability for effective collaboration. If construction data cannot be exchanged from one software system to another, then construction practitioners must process the data every time they are received. Gallaher et al. [14] reported that the cost of correcting software interoperability in the US was a financial burden to the construction industry. Construction owners and operators bore about two-thirds of this cost, while the remaining cost was borne by contractors, suppliers, architects and engineers. Reducing this type of economic waste was the main reason for establishing the Private Alliance in 1995 with 12 companies. The main purpose of this alliance was to achieve interoperability through full information exchange. The Private Alliance became buildingSMART in 2008. The core principles of buildingSMART are openness, neutrality and non-profit [15], together presenting an open approach to developing digital standards for the built environment. The products of buildingSMART are open standards, including the Industry Foundation Class (IFC), the International Framework for Dictionaries (IFD), the BIM Collaboration Format (BCF) and the Integrated Delivery Manual (IDM). Although some problems, such as data loss and misinterpretation, still happen [13], it is clear that the construction community has made progress on digital innovation in construction.

2.2 Innovation community

Open innovation, coined by Chesbrough [16], is an approach to innovation through communities. Open innovation has promoted technology development in various industries, such as chemical, ICT, consumer-product, automotive and retail industries [17]–[19]. Open innovation is "a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model" [20]. The open approach helps technology development overcome inefficiencies, such as rising development costs, shorter product life cycles and underused patents [21]. Open innovation facilitates knowledge to flow in and out of the company boundary, creating inside-out and outside-in types, respectively. Companies can also perform a so-called "coupled process" which allows knowledge to flow in both the inside-out and outside-in directions [20]. By facilitating knowledge flows, the open approach provides new development paths for underutilised ideas. This approach encourages companies to apply external ideas if they are considered better than internal ones [22].

A community can be a group of individuals and/or firms based on voluntary participation [23]. Communities play an important role in innovation by developing technical standards, organising interactions among members and encouraging members to create their own start-ups to commercialise newly developed technologies [24]. These interactions form the basis of a community. Through interactions, members can share their knowledge, form collective solutions and create joint artefacts [24]. The joint production is an important indication of a successful community [24].

3 THEORETICAL LENS

King et al. [9] reminded us that innovation is a process of turning an invention into a usable form, where an invention is a new idea or a new product. Innovation may also be a product developed from an invention. To explore how an organisation intervenes in ICT innovation, King et al. [9] proposed a model, referred to as the Institutional Intervention Model in this paper, which includes six forms of institutional actions across two dimensions (Fig. 1).

The first dimension is influence – regulation, expressing the extent of persuasive or compelling control. The second dimension is about supply-push and demand-pull forces driving the innovation. While the willingness of potential users to use the innovation generates demand-pull forces, the supply-push forces derive from the innovation itself [9].

	SUPPLY-PUSH	DEMAND-PULL
INFLUENCE	Knowledge building Knowledge deployment Subsidy Innovation directive	Knowledge deployment Subsidy Mobilisation
REGULATION	Knowledge deployment Subsidy Standards Innovation directive	Subsidy Standards Innovation directive

Figure 1: Dimensions of Institutional Intervention. *(Source: Adapted from King et al. [9].)*

Table 1: Six forms of institutional action. *(Source: Adapted from King et al. [9].)*

Form of action	Institutional action
Knowledge building	Creating knowledge bases that are necessary for innovative activity. Typically, conducting and funding basic research belong to this category. Governments may also mobilise large corporations or their agencies to conduct research on particular topics of national importance.
Knowledge deployment	Facilitating the dissemination of new knowledge. For example, introducing individuals and organisations to knowledge of an innovation, creating repositories of technical facts, providing training.
Subsidy	Using the resources of an organisation to reduce unavoidable costs and risks to innovators. This action includes the funding of prototypes, internally producing goods and services from an innovation, supporting complements for using innovation, and reducing barriers to the production of an innovation.
Mobilisation	Encouraging external individuals and other organisations to have the same opinion on innovations. The main instrument for mobilisation are promotion and awareness campaigns.
Standard setting	Establishing socially constructed agreements among organisations interested in using an innovation. The implementation of standards is voluntary, but it can become mandatory if enforced by law.
Innovation directive	A command to produce, use or facilitate innovations. Directives appear in requests for a particular technology, investment in research and development, requirements to use particular products, etc.

An organisation can increase the supply of a particular technology to the market through various actions, such as providing financial and personnel support for research and development [25]. These two dimensions provide four different contexts of innovation. Based on the context, an organisation can perform appropriate institutional interventions to facilitate innovation. Table 1 describes six forms of institutional actions.

Each innovation requires appropriate interventions for development, and organisations have different ways of adopting innovations [9]. Furthermore, an organisation can change its role in the innovation process depending on the context [9]. Since the Institutional Intervention Model can provide a framework to understand the context of ICT innovation, this model is a suitable theoretical lens to guide data collection on how the buildingSMART community advances openBIM in the construction industry. In the context of this research, the buildingSMART community and its member organisations use a combination of institutional actions to develop openBIM innovations. An individual organisation, for its sake, exerts the demand-pull force, such as requesting training programmes from the community. This organisation can also perform the supply-push force, such as funding prototype development to benefit the community. The actions which happen inside the network of the studied organisation and influence openBIM development will be considered as institutional actions.

4 METHODOLOGY

We conducted an interpretive case study of the buildingSMART Norway Chapter (bSN), a member of buildingSMART International. The establishment of bSN began from the visit of a Norwegian construction delegation to the Singapore Building and Construction Authority in 2003. During that visit, the Singaporean agency showcased how to use BIM and IFC for electronic plan checking. Impressed by this BIM application, the Norwegian delegation decided to promote openBIM in Norway by performing an establishment project. This project led to the establishment of bSN in 2010. Since then, bSN has conducted various BIM-related activities that seek to positively influence the dissemination of openBIM. These activities include participating in standardisation, organising hackathons, preparing openBIM training, organising annual conferences and meetings, arranging different discussion groups and providing BIM-related information [26]. In 2010, Statsbygg, the Norwegian Directorate of Public Construction and Property, began to request the use of openBIM in their projects [27], making Norway one of the first countries to request open BIM standards. Statsbygg was also an active member in the establishment of bSN. Besides Statsbygg, other Norwegian organisations have also adopted the open approach to BIM, such as the National Rail Administration (Bane NOR), the Defence Estate Agency, the Public Road Administration, and various software vendors and consultants. At the time of data collection, bSN had 131 organisation members, like government agencies, software vendors, contractors, consultants, universities and standardisation organisations. bSN is an example of openBIM promotion through the community. With diversified activities and different types of members, bSN is a suitable case to explore how a community advances BIM technology in construction.

We prepared a list of 20 potential interviewees and contacted them for appointments. The criteria for selecting interviewees were as follows: (1) Having experience with BIM and with bSN's activities; (2) Having experience with decision making on technology adoption in their organisations; (3) Being active within bSN and within construction community activities; and (4) Representing different types of bSN members. Our interview guide had two sections. The first section focused on the working experience and background of the interviewees. The second section consisted of nine open questions on the interviewees' activities related to BIM and bSN participation. Based on the Institutional Intervention Model, these nine open questions revealed different forms of bSN's actions. The interviewer also asked follow-up questions to get as much detail as possible from the experience of the interviewees.

Table 2 shows an overview of the interviewees. From November 2018 to January 2019, we conducted 10 interviews with a focus on the decision makers from the bSN members because they can influence the knowledge flow between their organisations and bSN. The contacted bSN members were from different organisations, including those in the private sector, in non-profit companies and in academia. Eight interviewees were at the director level, while three were company founders.

The recorded interviews were transcribed and analysed in NVivo 12. The Institutional Intervention Model formed the framework for coding, but we also arranged one category for any activity that was different from the six forms of action. Since this paper focuses on the open innovation community, the case study needed to have an open boundary. This means the analysis investigated any activity leading to openBIM innovation with the participation of bSN members, also including activities not organised by bSN. Other relevant documents and information from bSN were also part of the collected data.

Table 2: The list of interviewees.

Interviewee no.	Company type	Level	Experience (years)
Interviewee 1[i]	Construction association[n]	Director	+20
Interviewee 2	BuildingSMART Norway[n]	Director	+20
Interviewee 3[i]*	Software vendor	Founder, Director	+20
Interviewee 4[i]*	Software vendor	Founder, Director	15–20
Interviewee 5[i]	Software vendor	Founder, Director	+20
Interviewee 6[i]	Software vendor	Director	+20
Interviewee 7	Consultant	Manager, strategy lead	15–20
Interviewee 8	Standardisation[n]	Director	+20
Interviewee 9	Standardisation[n]	Project manager	+20
Interviewee 10[i]	University[n]	Senior engineer	10–15
Interviewee 11*	University[n]	Associate Professor	15–20

*Holds a PhD degree, i: Has experience from ICT projects, n: Non-profit organisations.
One group interview was conducted with both Interviewee 8 and Interviewee 9.

5 FINDINGS

In addition to institutional actions, the data also revealed what motivated the interviewees to engage in community work. This section describes the motivation of members and the institutional actions in bSN. bSN uses various communication channels, including annual conferences, forums, sub-forums, slack online forums, workshops, group meetings, Oslo BIM meetings, newsletters and websites. bSN members gather via these communication channels for discussions on openBIM use and development. The discussions happen at both the whole community and sub-group levels. The results are demands for new standards, experience sharing and joint products related to open standards. The joint products can be new applications of openBIM, new adoption processes, training programmes, etc. Therefore, these communication channels are essential for bSN to intervene in openBIM development.

5.1 Motivation to join the bSN community

The establishment of bSN was successful because of the strong leadership of the steering committee. The leaders of the bSN establishment project had extensive experience in various leading positions in buildingSMART international and different construction organizations. The leaders' reputation and management made the members contribute to the community:

> "There was a good sense of community across companies and organisations and there was a lot of willingness from each organisation and community to spend their own time and own money to get this going. So a lot of individual efforts combined into a big community level controlled by a reasonably strong leadership". (Interviewee 4)

Following the inspiration on openBIM from the bSN leadership, bSN members actively contributed to various buildingSMART activities, particularly IFD development, standardisation and summit organisation. The bSN members received no payment for their contributions to the community.

The bSN members saw the benefits for their business from contributing to the community, and the bSN community shared a belief in the advantages of openBIM, which benefited all parties in the construction value chain:

> "All of us have a sort of grounding belief that open standards are the only way to make innovation flourish". (Interviewee 3)

> "Why we have supported the dictionary [IFD] development is because we've seen the future value for the community and for us". (Interviewee 5)

Anyone with innovative ideas on buildingSMART deliveries can develop their products or services. Various members of bSN chose openBIM as their core competency and have invested in open standards; e.g., Catenda creates a cloud-based collaboration platform supporting IFC files, while CoBuilder develops product data templates based on IFD.

Although their work for the community might be different from their business, by showing their competence with openBIM, they gave other members the impression that they possessed good skill sets and thus associated their products with good quality. Thus, the interviewees believed their contributions to the community could create benefits for their business.

> "People in the buildingSMART community almost know us for the data dictionary. That is not what we are about… It's been a rough idea that we didn't want to be in the buildingSMART community pushing our product…We were trying to contribute in a good matter that creates trust".

> "I think people have seen that there are some good skill sets behind someone they can trust, and when they hear about our product, immediately they will think it must be a good product because there are good people behind it". (Interviewee 4)

Also, the bSN members wanted to take social responsibility by contributing to the construction community. According to Interviewee 6, improving efficiency in construction can bring benefits to society, such as affordable houses, a better environment and so on. He believed that digitalisation was the right solution to the construction efficiency problem.

> "The construction industry consumes 40% of energy use but creates 40% of solid waste because of bad communication and bad processes. That is the difference from other industries which are digitalised more and use more technologies to reuse the waste". (Interviewee 6)

Despite the mentioned advantages of bSN, some interviewees still expected changes for innovation to happen faster. They argued that bSN and buildingSMART were suitable for meeting people but inappropriate for making changes and decisions.

5.2 Knowledge building

bSN members have created new technical knowledge on openBIM in academic, industrial and collaboration projects. Regarding academic projects, the researchers in the bSN member universities have published research articles and guided student projects on openBIM. In 2018 and 2017, bSN introduced 113 student projects related to openBIM to the community. Besides academic knowledge, the guidance also includes connecting to companies for accessing data. The industrial projects create practical knowledge on openBIM, such as software tools, the Digital Roadmap and the results from the openLab hackathons. The Digital Roadmap is a strategy for digitalisation in the Norwegian construction industry with a vision towards the year 2025. This strategy suggests Norwegian construction organisations should digitalise together based on BIM and open standards. At the time of data collection, bSN was creating an innovation programme to push joint activities.

> "We are now creating an innovation programme for this network for innovating and developing digitised ways of working together… We need to innovate in solution and standards". (Interviewee 2)

A typical activity in this programme are the openLab hackathons, in which bSN supports the problem owners to organise a competing ground for innovative solutions. The results from the hackathons might lead to standardisation or practical solutions for the problem owners. Besides the project's focus on the Norwegian market, bSN also participates in the development of buildingSMART deliveries, particularly on the IFD. This serves as a way for bSN to share their experience and products on openBIM to the community.

In addition to conducting research in their domains, academia and industry members also collaborate for mutual benefits. On the one hand, the universities invite industrial practitioners to give guest lectures, which provide essential updates to the educational programmes. On the other hand, the industrial companies need researchers' expertise for their product development. In this way, the companies can absorb external knowledge for their innovations.

5.3 Knowledge deployment

bSN supports the dissemination of openBIM not only in Norway but also in other countries through presentations and networking among their members. These members are either leading working groups in buildingSMART International or they have experience with openBIM implementation in Norway.

Besides, bSN organises a repository of open standards on their website. Construction practitioners can find relevant information – including an overview of openBIM, events, annual competitions, open standards and competence services, such as teaching curriculums and certification, training courses and an online portal for certification. The website also provides student theses on openBIM. The website represents an archive to explore what students can do with openBIM in their educational programmes.

5.4 Subsidy

The bSN community has two schemes of funding for innovation. The first scheme, managed by the steering committee, focuses on bSN activities. With the funding from the membership fee, bSN employs four full-time staff for the administration board. This staff manages activities in Norway and participates in standardisation, maintenance of communication channels and the openBIM repository, as well as research collaboration with members and other organisations. With this full-time staff, bSN has become a formal entity dedicated to openBIM development in Norway. This has resulted in diversified channels for innovation and more members joining bSN.

The second scheme, derived from the organisational members, aims to create innovative solutions for the members' interests. The funding comes from the members' budget. For instance, based on a request from Statens Vegvesen – the Norwegian Public Roads Administration, bSN organised a hackathon to generate ideas on applying open standards for the planning and execution phases in road and bridge projects. Statens Vegvesen paid all expenses of the event.

> "A hackathon is an activity in a large project of Statens Vegvesen. Statens Vegvesen came to us and said they wanted to use open standards for model-based project planning and execution and see how they can use open standards…So bSN started a project, and hackathon is an activity in that. We also have other members who come to us, and they want direct support or use buildingSMART as an arena for innovation". (Interviewee 2)

Besides hackathons, bSN members also conduct their own research projects. The building research organisation, SINTEF Byggforsk, for instance, sponsored the creation of a cloud-based collaboration platform for seamless information flow in construction projects. The prototype of this platform served as the foundation for creating a start-up later on. The support from SINTEF reduced the risk and cost in the initial phase of the development, and thus stimulated innovation on openBIM.

5.5 Mobilisation

While deployment actions provide openBIM with knowledge, mobilisation actions require more interactions with potential users. bSN used this form of action to persuade potential users to believe in openBIM capacity. Mobilisation can be combined with deployment actions in the community activities. bSN encourages other construction practitioners to adopt openBIM through offline events. The offline events include annual conferences, meetings and workshops. There is no restriction on joining the discussion, and anyone can use the bSN communication channels to discuss how to adopt openBIM with the community. In addition, bSN inspires students to apply openBIM in their projects with education awards. bSN members actively approach students for promoting openBIM.

> "We engage universities and vocational schools. We have a good relationship with most of the vocational schools that educate people with BIM technology. We also have relationships with NTNU (Norwegian University of Science and Technology) and OsloMet (Oslo Metropolitan University) … We do try". (Interviewee 4)

5.6 Standard setting

The core of openBIM is about open standards. Therefore, developing standards is an important task of bSN, and the members understood that they should standardise together.

> "Instead of starting up an initiative here and there… they understand that if they want to influence their future in terms of profession or business, they should come together here [for making standards]". (Interviewee 8)

Besides buildingSMART International, bSN members hold leading positions in technical committees related to BIM in three other standardisation organisations, namely Standard Norway, the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO). According to Interviewee 8, Norway initiated the European standardisation in the BIM domain. The active participation at different geographic scales of standardisation resulted in two positive consequences. First, the bSN members were familiar with European and ISO standards on BIM in the preparation phase. Therefore, it was convenient for them to do business in countries that adopted those standards. Second, bSN could learn how to improve the quality of the standards by utilising standardisation processes and resources in CEN and ISO.

5.7 Innovation directive

Although the bSN community has been active in developing open standards, the application of openBIM was low until a client formally requested it. Interviewee 7 commented that “when Statsbygg said that all our projects would require openBIM from the year 2010, then the market changed, and the industry also changed”. In the case of bSN, Statsbygg supported the development of open standards and has become the market leader in using those standards. Interviewee 8 suggested an example model for the implementation of open standards, which was “Standard Norway develops standards, Statsbygg chooses which to apply, and bSN supports the implementation”.

6 DISCUSSION

Innovation communities focus on pushing innovation development through the voluntary contributions of members. We argue that the success of such communities relies on how members perform innovation together. Our analysis suggests that the members participate in the bSN activities because of inherent benefits from the community activities. The collected data shows that bSN performs six forms of institutional action for innovation (see Table 3).

6.1 How buildingSMART Norway contributed to openBIM development

Regarding innovation communities, leaders should have a strong technical contribution and be able to bind the community together [28]. In the case of bSN, the leader of the establishment project was successful in setting the digitalisation vision for the community as specified in the Digital Roadmap. This vision and the leader’s reputation made the members believe they should digitalise together and develop BIM innovation based on the open approach.

Table 3: buildingSMART Norway innovation activities.

Form of action	buildingSMART Norway innovation activities
Knowledge building	Creating the Digital Roadmap and product data templates, organising openLab hackathons, conducting academic studies and research projects, guiding student projects
Knowledge deployment	Attending various events as keynote speakers, publishing case studies, providing an online tool for certificates, advancing a training curriculum, creating the open standard repository
Subsidy	Providing funding for an administration board with four full-time positions, conducting projects to make BIM tools, sponsoring hackathons and research projects
Mobilisation	Organising education awards, presenting openBIM to different audiences, performing guest lectures, making marketing videos
Standard setting	Participating in standardisation in ISO, CEN, buildingSMART International, Standard Norway
Innovation directive	Requesting openBIM in public projects of Statsbygg, Statens Vegvesen

In addition to strong leadership, bSN members saw the benefits of participating in the community. The benefits have both commercial and social aspects. The commercial benefits come from the support for both the prototype and knowledge development. From the technology foundation, bSN members can perform further development to gain competitive advantages. This finding is in line with a study on the Linux Foundation community, where IT organisations not only adopted but also modified the Linux kernel to suit their business and strategic needs [29]. Furthermore, the technical contribution to the community can build relationships and trust among members, which might turn into business partnerships later on. Another benefit derives from social responsibility. We argue that social responsibility can be a promising driver for construction technology development in the digital era. How social responsibility supports digital innovation in construction might be an interesting topic for further studies.

bSN has performed six forms of institutional actions. However, knowledge deployment and mobilisation seem to be the key action forms to exert supply-push forces to the community. These actions from the community suggested that bSN members adopt openBIM. In return, bSN members demanded more support from the community to apply openBIM in practice. The members' requests resulted in knowledge building, subsidy and innovative directive. In the bSN case, the Norwegian community was aware of openBIM by early on participating in Private Alliance activities. After the visit to Singapore in 2003, the Norwegian delegates believed in the benefits of openBIM and decided to promote it in Norway. As a result, bSN members organised hackathons, supported BIM research, mandated openBIM use and performed other activities to apply openBIM. We argue that knowledge deployment and mobilisation are essential institutional actions to support the construction community in developing not only openBIM but also other innovations. We propose that further studies be conducted on institutional actions to broaden the understanding of innovation in the construction community.

6.2 Open innovation and construction communities

In the bSN community, the interviewees reported gaining benefits from open standards, such as the software companies that have built their business competencies from the community work. These companies have not only developed open standards but have also used these standards to build their commercial services. The openLab hackathons are other examples where bSN members organise events for creative ideas on problems raised in the community. The practice of the bSN community reflects how knowledge flows in and out of organisational borders. It also represents how companies can benefit from community work. More studies on this topic can contribute to the development of the construction industry and broaden the understanding of open innovation in another context.

If a company chooses open innovations as its core competency, then its management board must balance the tension between standardisation and customisation. Standardisation reduces fixed costs and offers efficiency, while customisation leads to high satisfaction but lower efficiency [30]. The more customisation an organisational member makes, the more active this organisation is in the standard development. For example, the software vendors that develop their openBIM tools often hold the leading position in the working groups for developing standards. Although the relationship between innovation and standardisation is still unclear [31], we would argue that the variety of standardisations might have positive influences on innovation. The relationship between how an organisation uses open standards and how this organisation contributes to innovation development might be an interesting topic to explore further.

6.3 Contribution and limitations

This paper contributes to the understanding of the influence of an innovation community on BIM development in the construction industry. Through the analysis and discussion, the role of bSN as a professional construction association was elaborated. The bSN members showed different levels of using open standards and participating in the community work. Also, the paper reveals how a construction company turns community contributions into business values. The following limitations of our study should be noted. First, our data collection did not include the voices of clients, contractors or research funding agencies. Second, all interviewees and interviewers used English as a second language, which might have affected the collected data. Third, all interviews took place in Oslo, Norway, and thus we could not identify any issues related to location constraints. Therefore, we propose expanding the study to include the remaining stakeholders and broadening the understanding of the impact of the open community on construction innovation in Norway and internationally.

7 CONCLUSION

In summary, this paper describes how the bSN community developed openBIM through different institutional actions. The bSN case study highlights the importance of the leadership as well as the motivation of members to contribute their resources for technology development. To support openBIM development, the bSN administration board might direct activities to knowledge deployment actions to form the foundation for innovative ideas. Besides, mobilisation actions are important to encourage construction practitioners to adopt openBIM. The bSN members, on the other hand, should consider subsidy actions for innovative solutions to their specific problems. Thus, innovations can flow into organisations and become new business advantages or core competencies of spin-off start-ups. To provide a better understanding of innovation communities, we have suggested topics of interest for further studies in the discussion. Although some limitations remain, this paper addresses the research question by providing an understanding of how a construction community advances BIM technology.

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Understanding open innovation in BIM implementation: A cross-case analysis of construction communities in Norway and Vietnam

Manuscript under review

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Innovation communities have taken various actions to accelerate the uptake of Building Information Modelling (BIM) in the architecture, engineering, and construction industry in Norway and Vietnam. A cross-case analysis of two construction communities, namely buildingSMART Norway and the BIM Vietnam Community, were carried out. These two communities represent different stages of development and thus vary in the practices deployed for supporting innovation. Data were collected based on twenty-one semi-structured interviews conducted with industry experts actively engaged in these two open innovation communities. The results were analysed based on the Institutional Intervention Model, which delineates institutional actions related to the adoption of new information technology. The findings show both similarities and differences in the way in which the communities intervened in industrial practice. The communities shared their experiences and ideas by using similar types of knowledge channels and repositories. The approaches differed with regards to innovation direction, knowledge building, knowledge deployment, mobilization, subsidy, standard-setting, and innovative directives. Moreover, the evidence suggests that communities can learn from others working with similar problem sets elsewhere. However, the transferability of interventions is limited by national building approval processes, legislation, and intellectual property rights.

Keywords: Building Information Modelling, innovation, communities, construction

1. INTRODUCTION

BIM has potential to become a disruptive technology in the construction industry (Morgan, 2019). Yet, firms often lack the resources to conduct the necessary research and development (R&D) work for software development, implementation, and use. Against this background, inter-organizational collaboration in the area of ICT related R&D work has become increasingly common. An inter-organizational R&D approach where firms freely share knowledge is referred to as "open innovation" (Chesbrough, 2003). Open innovation happens in a variety of inter-organizational networks such as alliances, communities, consortia, ecosystems, and platforms (West and Bogers, 2017).

BIM supports data sharing and collaboration in construction projects by using information and communication technology (ICT) platforms. In BIM projects, experts from different disciplines such as architecture, structure, and electricity perform various tasks including design, implementation, maintenance, and management based on a BIM software platform. BIM helps to create an information model of the on-going construction, its "digital twin". All relevant construction partners utilize the information model for effective collaboration. Construction projects can derive various benefits from BIM, such as fewer errors, reduced costs, shorter duration, better consultation process, and better information management (Wong *et al.*, 2010, Demian and Walters, 2014, Goedknegt, 2015, Dowsett and Harty, 2019). In recent years, construction companies have invested heavily in BIM R&D to gain a competitive advantage from this technology. In addition to company internal work, several open innovation communities, such as buildingSMART, have researched, developed, and advanced BIM technology across organizational boundaries.

However, transitioning to use of modern ICT like BIM requires substantial investment into R&D. This is challenging to accomplish in an industry where only the largest of firms have the capacity to run formal R&D programs (Blayse and Manley, 2004). Moreover, only one in four architecture, engineering and construction (AEC) firms have designated R&D budgets, and only three out of four firms have one or more employees on their payroll working with R&D (JBKnowledge, 2019).

Nonetheless, AEC is a project-based industry with a long-standing tradition of inter-organizational innovation (Rutten *et al.*, 2009, Vass and Gustavsson, 2017). However, inter-organizational innovation in AEC is often confined to single projects and seldomly translates into lasting industry-wide change (Rutten *et al.*, 2009, Ozorhon and Oral, 2017). Further embracing the concept of open innovation in the context of AEC is viewed as particularly important for driving lasting ICT based change in construction (ibid.). Recognizing this, practitioners have begun establishing open innovation communities in AEC. A prominent example of this trend is the nineteen buildingSMART communities in different countries, who provide forums for open innovation related to BIM technology implementation (buildingSMART, 2019a).

Despite its potential, open innovation as a concept for systematic change in AEC continues to be under-researched (Bonanomi, 2019). The study presented in this paper is motivated by a research review calling for developing a better theoretical understanding of open innovation in the context of construction (Rutten *et al.*, 2009). Moreover, studying open innovation in construction is worthwhile due to the industry's unique way of operating as a loosely coupled system (Dubois and Gadde, 2002). We seek to provide an improved understanding of how open innovation communities diffusing BIM technology influence and are influenced by the industrial context of AEC. Thus, our study is guided by the following research question: "*How do open innovation communities support BIM innovation?*"

To answer this research question, the paper presents a cross-case analysis of the buildingSMART Norway Chapter (bSN) and the BIM Vietnam Community (BVC) based on the Institutional Intervention Model (King *et al.*, 1994). The main advantage of a cross-case study design is that it allows for studying different examples of BIM-related community practice. The Norwegian case was selected as an example of a BIM community operating at a high level of sophistication with its 20 self-governing chapters (Rogers, 2019). The Vietnamese community was selected as an example of an emerging community run by volunteers. These communities were also selected for being in different stages of their development, whereby bringing out different examples of innovative community practice. The Institutional Intervention Model is used for explaining how open innovation communities influence and are influenced by the institutional context in a given industrial setting. The intended contribution of this paper is twofold: First, we argue that research based on the Institutional Intervention Model broadens the theoretical understanding of open innovation communities in AEC. Second, the practical contribution is to broaden the knowledge of how construction communities support innovation, and how members can benefit from the community work.

The organization of the paper is as follows. Section two provides the theoretical background on open innovation and the Institutional Intervention Model. Section three presents the method and the case studies examined in this paper, and section four describes the data analysis, followed by a discussion of the results in section five. Section six presents the conclusions and implications of the work.

2. THEORETICAL FRAMEWORK

Open innovation is an innovation development approach taking place in professional communities (Chesbrough, 2003). Open innovation has been defined as “a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization’s business model” (Chesbrough and Bogers, 2014). Figure 1 presents a model of an open innovation community where ideas are shared across organizational boundaries between competitors, users, suppliers, and software vendors. Organizations can benefit from open innovation by reducing development costs and by developing more innovative ideas through knowledge exchange with external sources (Chesbrough, 2007). By facilitating knowledge flows, organizations connect innovative problem solvers to available problems. This approach encourages companies to apply external ideas to solve larger problems (Winkel and Moody, 2008).

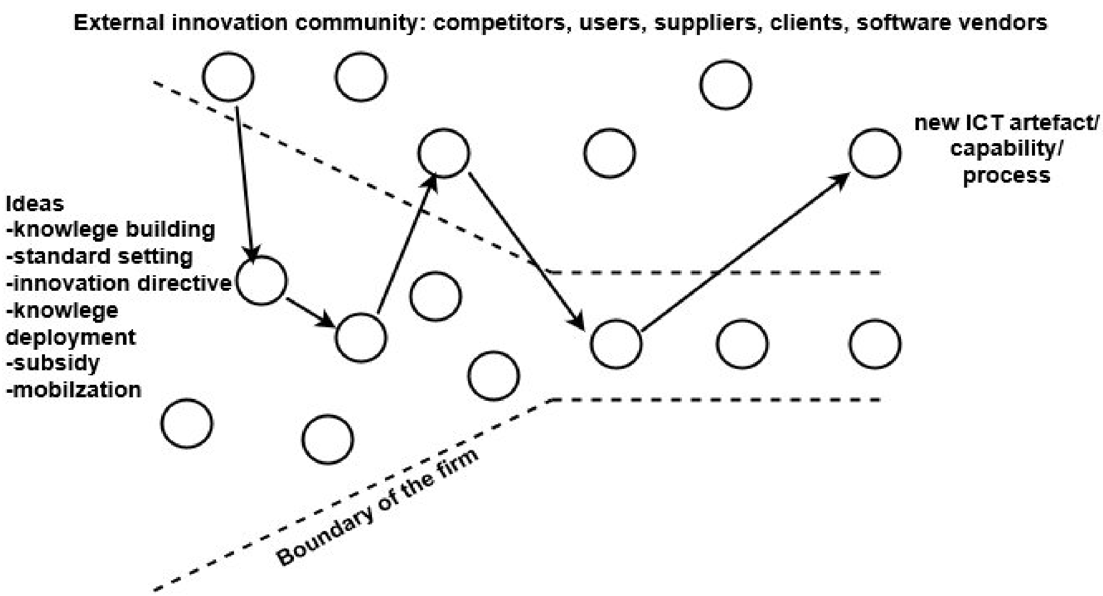

Figure 1. Open Innovation Model (adapted from Chesbrough (2003))

The Institutional Intervention Model (King *et al.*, 1994) is useful for understanding how social action can turn an innovation into lasting social practice. We considered this framework well suited for studying how open innovation communities develop ideas, technology, and processes to a stage where they become established in industrial practice. While it is difficult to claim a direct causal relationship between institutional interventions and the adoption of innovations, exploring the interventions undertaken by open innovation communities can result in transferable insight useful for others (King *et al.*, 1994). The Institutional Intervention Model has its origins in institutional theory and has been designed for the study of the institutionalization of ICT based innovations (ibid.). The model suggests six types of interventions useful for establishing ICT innovations as lasting social practice. These six interventions, as depicted in Figure 1, include knowledge building, knowledge deployment, subsidy, mobilization, standard-setting, and innovation directive, defined as follows in relation to open innovation communities (based on King *et al.* (1994)):

- *Knowledge building:* knowledge needs to be built as a foundation for innovation. The knowledge residing within the different parts of the community is combined into viable ideas. Ideas can be shaped and built upon by the entire open innovation community.
- *Knowledge deployment*: facilitating the dissemination of new knowledge through competent individuals and organizations, repositories of technical facts, providing education and training, etc.
- *Subsidy:* providing resources to reduce cost and risk for innovators. An organization can sponsor making prototypes, goods and services used to promote innovation and reduce barriers to innovation.
- *Mobilization:* using promotion and awareness campaigns to spread a common opinion on innovations. For instance, an academic taking on a mobilizing role to promote innovation.
- *Standard setting:* encouraging and establishing socially constructed agreements for using innovation. Participation in standardization and using standards are voluntary. However, if a government agency requests by law to use a standard, this standard becomes mandatory.

- *Innovation directive:* issuing direct orders to produce, use, or facilitate innovations. An organization can request a technology, investment in R&D, require using a particular innovation, etc.

3. METHOD

This paper presents a cross-case study of two open innovation communities in the construction industries of Norway and Vietnam, bSN and BVC. The case study approach was selected for this study since it provides an understanding of the "sticky, practice-based problems where the experiences of the actors are important, and the context of the action is crucial" (Benbasat *et al.*, 1987). The case communities were selected based on three criteria: (1) The community members should engage in cooperation with others across organizational boundaries; (2) the activities in the community should include R&D; and (3) BIM should be at the centre of the community work. These criteria ensured that the cases were instances of open innovation communities focused on developing BIM technology.

The two open innovation communities operate in different industrial environments distinguished by their economies, culture, and technology development. Norway is considered a global pioneer when it comes to the digitalization of its AEC industry. The Norwegian Directorate of Public Construction and Property (Statsbygg) started applying BIM technology in their projects in 2007. Since 2010, Statsbygg has mandated the use of IFC, an open BIM standard, in their projects (Smith, 2014). In addition, the Norwegian authorities have developed national guidelines for BIM use in building and transportation projects. Vietnam, on the other hand, is still in the early phase of BIM implementation. The Vietnamese government issued an adoption plan in 2016, targeting nationwide BIM use from 2021. When the data for this study were collected at the end of 2018, there still existed no official BIM guideline for the Vietnamese market. Thus, while the members of the Norwegian bSN community can draw from practical experience, their Vietnamese colleagues in the BVC community have yet little practical BIM experience to draw from.

The data were collected from September 2018 to January 2019. A total of 21 semi-structured interviews were conducted with members of the two communities. The interviewees work in the private sector, in non-profit organizations and in academia. The criteria for selecting interviewees were as follows: (1) Having experience with BIM; (2)

Having experience with decision making related to technology adoption; (3) Being actively engaged in community activities. Eleven face-to-face interviews were conducted with bSN members. All except two were at the director or manager level, and three were company founders. Two interviewees were from academia, who have supported students with BIM-related topics and connected other bSN members for guests lectures in universities. With BVC, two face-to-face and eight Skype interviews were conducted. Five of the Vietnamese interviewees are working as BIM managers in their companies. While all bSN interviewees have worked with BIM since they started their careers in construction, eight interviewed members of BVC had less than five years of BIM experience. Two BVC interviewees have used BIM at work for nearly seven years. Besides the recorded interviews, the data includes documents from these two communities. The interview guide for the semi-structured interviews contained open questions on activities related to BIM, participation in the community, and professional background. Based on the Institutional Intervention Model, the open questions revealed different forms of innovation actions in bSN and BVC. The data were coded based on the Institutional Intervention Model to allow for a comparative analysis of the activities supporting BIM innovation in these two communities. Table 1 provides an overview of the characteristics of the cases and the interviewees.

Table 1. Characteristics of the case studies

	Case A: Building SMART Norway (bSN)	Case B: BIM Vietnam Community (BVC)
Established	2010	2015
Members	133 organizations	3200 individuals
Types of members	Universities, private companies, government agencies, research institutions, standardization bodies, professional associations	Universities, private companies, government agencies
Annual fee	Yes	No
Management	4 fulltime employees, voluntary steering board consisting of 12 members	Voluntary steering board consisting of 20 active members
Focus	Open standards, technology development, modelling workflows, research	Knowledge exchange of BIM experiences, practical BIM tool training
Activities	Interdisciplinary user seminars; Thematic seminars (technology; infrastructure; products; buildings); Disciplinary expert groups (education, HVAC, structural, architecture, software, competency, clients, trade); Projects (cloud data; judicial group;	Seminars; BIM tool training workshops

	work group); Regional groups (Alta, Bergen, Trondheim, Aalesund); student projects; openLab Hackathons	
Communication	Website, newsletter, meetings, events, online forum	Online forum, offline events
Profession, role, and experience for the 21 interviewees	bSN1 - Construction association, director, 20+ yrs. bSN2 - Building SMART Norway, director, 20+ yrs. bSN3 - Software vendor, director, founder, 20+ yrs. bSN4 - Software vendor, director, founder, 15-20 yrs. bSN5 - Software vendor, director, founder, 20+ yrs. bSN6 - Software vendor, director, 20+yrs. bSN7 - Consultant, manager, 15-20 yrs. bSN8 - Standardization, director, 20+ yrs. bSN9 - Standardization, manager, 20+ yrs. bSN10 - University, lecturer, 10-15 yrs. bSN11 - University, professor, PhD, 15-20 yrs.	BVC1 - Contractor, manager, 10-15 yrs. BVC2 - Consultant, manager, 10-15 yrs. BVC3 - Material supplier, director, 10-15 yrs. BVC4 - Consultant, manager, 10-15 yrs. BVC5 - University, manager, 20+ yrs. BVC6 - Consultant, manager, 20+yrs. BVC7 - Consultant, manager, 5-10 yrs. BVC8 - Consultant, manager, 5-10 yrs. BVC9 - Material supplier, manager, 5-10 yrs. BVC10 - Consultant, manager, 0-5 yrs.

4. ANALYSIS

The analysis of the work undertaken by the open innovation communities is based on the Institutional Intervention Model. Since the BIM innovation activities in the communities constitute the unit of analysis in our study, their development contexts are presented first. The first stage of the analysis elaborates how open innovation happens and in which direction the innovation is focused in these communities. After this, we present our findings related to the key activities defined in the Institutional Intervention Model: knowledge building; knowledge deployment; subsidy; mobilization; standard-setting; and innovation directive.

4.1 CONTEXT OF THE OPEN INNOVATION COMMUNITIES

BuildingSMART NORWAY (bSN)

As a chapter of buildingSMART international, bSN inherits from its parent organization the management structures such as steering board, discussion groups, innovation strategy, and membership fee. These structures create resources for bSN in BIM innovation development. For example, bSN has an annual budget allowing for hiring four full-time employees dedicated to facilitating and managing the activities. These full-time employees make bSN a professional organization for serving the community demands and supporting innovation development. bSN offers membership to organizations such as government agencies, universities, and construction companies. Interested employees of the member organizations have access to bSN resources and activities. In return, the member organizations pay an annual fee.

bSN is a membership-based community having organizational members whose activities have been open to anyone to participate. BuildingSMART international focuses on vendor-neutral data exchange formats (buildingSMART, 2019c). These formats, so-called open BIM standards, support BIM users to be more independent of BIM tool providers. Representing 25% of the Norwegian construction industry (Silva *et al.*, 2016), the members of bSN are drivers of open BIM standards in the Norwegian market. As mentioned, Statsbygg - the Norwegian government agency for public facility management and development - requested use of the IFC format from 2010 (Smith, 2014, Hjelseth, 2017). Norwegian-based private companies such as Catenda and coBuilder offer BIM-related business services based on open standards. For example, Catenda provides a platform for importing and visualizing IFC models (Hjelseth and Mêda, 2017).

When asking members for their motivations for joining the bSN network, they pointed to getting to know people in the industry, learning about the latest developments of technology, and sharing knowledge. The statements listed below illustrate this:

> "We are there [the bSN community] for contributing in a good matter that creates trust… When they [other members] hear about our products, immediately they might think it must be good products because there are good people behind it." (bSN4)
>
> "I strongly believe in this [involvement in the Norwegian construction community] for 30 years, so people come to me because they know what they can get from me." (bSN6)

In addition, some members participate in bSN activities because they want to share their knowledge. In that way, they not only develop their own knowledge but also help the community adopt new technology.

> "Why we have supported the [openBIM] dictionary development is because I have seen the future value for the community and for us." (bSN5)

> "We see a lot of Norwegian companies that have their solutions and services based on buildingSMART standards. For example, Catenda, Rendra, Areo. Our members in buildingSMART are contributing to the development [of open standards] and they are building their business based on that." (bSN2)

BIM Vietnam Community (BVC)

BVC was established in 2015 to share experience related to BIM implementation among Vietnamese construction practitioners. The BVC members are individuals working in the Vietnamese construction industry. BVC is a non-profit organization and has no restriction to join its activities. At the end of 2018, BVC had nearly 3200 registered individual members on Facebook, which has been the main communication channel since the establishment. The BVC members come from different types of construction organizations which are applying BIM or plan to implement this. The activities of BVC are to organize seminars and BIM tool training workshops.

The Vietnamese private sector and research institutes have been active in BIM implementation. For example, Tran *et al.* (2014) reported that Harmony Soft provided add-on packages for mainstream BIM software to match Vietnam's building regulations. In academia, the University of Construction and the Institute of Construction Economics have conducted BIM studies (ibid.). Besides research, these two institutions have organized various BIM seminars to increase BIM awareness in Vietnam. These seminars have supported government agencies, research institutes, universities, and construction practitioners in Vietnam in updating themselves on on-going BIM-related trends and good practices (ibid.).

Furthermore, scholars have reported BIM practices in Vietnam in a broad range of themes. Case studies in consultant and contractor firms showed that Vietnamese construction practitioners were willing to adopt BIM gradually while waiting for more demand from the market (Le *et al.*, 2018). Another case study of a BIM pilot project pointed out barriers of BIM implementation from the local construction regulations (Bui, 2019). Other topics of BIM in Vietnam include project quality management (Nguyen *et al.*, 2018), adoption (Dao and Chen, 2020, Le *et al.*, 2020), risk management (Nguyen and Nguyen, 2020), national strategies (Matthews and Ta, 2020) and supply chain management (Chen and Nguyen, 2019). These scholarly works present an increasing trend of BIM use in Vietnam.

When asking BVC members about their motivations for participating in the network, they pointed to building trust and relationships as being important for them:

> "I might meet other [BVC] members again in some bidding projects…They know about my competences so that they trust me better." (BVC4)
>
> "I met one client in a seminar. After presentation of a BIM topic, this client approached me and offered a work package in their project." (BVC10)

Just like their Norwegian counterparts, the BVC members also viewed sharing of expertise as an important aspect of their participation:

> "After being offered some free BIM tool courses to the members, I feel that I know more about those tools because I have to systemize and update the knowledge…I suppose the more I share the more I know." (BVC 2)
>
> "Although you are an expert, you are familiar with one or some domains only. Participating in the community helps me to know more [about BIM in other disciplines] … Sharing will help the community to have better understanding of BIM" (BVC4)

4.2 KNOWLEDGE BUILDING

Jointly creating the knowledge base for supporting the innovation is referred to as knowledge building. Both communities engaged in a range of knowledge building activities for supporting BIM. bSN creates knowledge in a range of topic areas related to BIM, including file exchange, technology development, workflows, and collaboration processes. bSN's knowledge-building activities are guided by a so-called ´digital roadmap´ which explicates the areas in which knowledge is to be advanced. The roadmap sets the agenda for user seminars, expert groups, and projects. The bSN community, together with local universities and vocational schools, provides topics and data for student thesis work which results in new knowledge and practical solutions. These student projects are guided, too, by the digital roadmap. Another avenue for knowledge building is the openLab hackathon initiative in which students advance innovative technological solutions. These hackathons belong to an innovative program of the management board:

> "We are now creating a program for innovating and developing digitalized ways of working together in the whole industry… The lowest level in this program is the Hackathons… For example, the problem owners such as Statens Vegvesen [Norwegian Public Roads Administration] come to us and ask how digital twins can reduce the travel time from Bergen to Stavanger…We invite problem owners, and everyone interested to come up with ideas for action. In that way, we engage a lot of creativity and come up with a solution." (bSN 2)

One recent example of bSN knowledge-building activities is the development of the latest Statsbygg BIM manual (Mohus and Onarheim, 2019). This manual provides a practical guideline for BIM-based design in public projects in Norway. In the latest iteration, the expertise of a range of different organizations is used for developing a manual incorporating the expertise of architects, structural-, mechanical- and electrical-engineers (e.g. BIM consult, Sweco BIMlab, Cowi, Multiconsult, and DigiBIM (ibid.). The bSN network forms the backbone of this development since it established the links between the BIM knowledgeable experts in the country.

In contrast to bSN, BVC creates new BIM knowledge in mere informal ways. The BVC steering board often organizes small groups to develop add-ins for BIM tools. These add-ins, such as quantity take-off and auto naming, support the automation of local construction processes. One example of BVC building knowledge as a community is a combined effort by the construction consultancy BIM Factory, the University of Technology, and the Institute of Construction Economics in activating the BVC network to raise BIM awareness in Vietnam by presenting a range of case studies.

4.3 KNOWLEDGE DEPLOYMENT

Both bSN and BVC provide shared BIM standards, case studies, and training to members. BVC shares translated standards on the Facebook forum or through personal connections among members. Some BVC members offer free BIM tool training to the others:

> "I have taught [BVC members] programming with Revit and Tekla without any fee. The members who want to learn from a group of 5 to 7 people and choose a place like a coffee shop. Then, I agree about

the schedule with them and come to teach… One course might last for two months." (BVC 2)

bSN has developed a more formal approach for disseminating BIM-based knowledge (buildingSMART). Besides providing standards and case studies through the website and newsletters, bSN offers training curricula, certificates, and BIM courses. bSN certificates ensure minimum competence for participation in projects with openBIM (ibid.). bSN has appointed an educational coordinator working with lecturing and creating teaching materials for the BIM certification classes. The diverse activities in BIM education play an important role in diffusing openBIM knowledge into the community.

4.4 MOBILIZATION

The concept of mobilization entails promotion and awareness campaigns to spread a common opinion about the innovation. Seeking to encourage other construction practitioners to use BIM at work, bSN and BVC have organized various seminars and offered guest lectures and BIM courses. While BVC focuses on BIM in general, bSN held discussions on both overviews of openBIM and particular topics. Moreover, bSN has a dissemination strategy seeking to establish the buildingSMART process in the entire industry by increasing understanding through active dissemination throughout the network (buildingSMART Norway). Moreover, case studies shall illustrate how the process can be applied to solving specific problems, the goal being that BIM users have a shared understanding of the content of the information models. Last, their strategy states that bSN shall actively contribute in projects seeking to further digitalization in the Norwegian AEC industry (ibid.). Moreover, bSN conducts deliberate outreach campaigns seeking to attract further organizational members who in turn would raise BIM awareness within the industry. bSN also has a strong presence in the AEC trade press, mostly presenting case studies of BIM technology deployment. Finally, the annual bSN assembly has become a well-established convention attracting construction experts from many parts of the country.

4.5 SUBSIDY

bSN has invested in four full-time employees to manage the activities. During the preparation phase for the establishment of bSN, the steering board decided that the organization needs dedicated people to perform effectively. bSN also organizes student awards to encourage research related to BIM.

> "From 2005 to 2013, the main achievements were actually to make it [bSN] a stronger and more professional organization. We do need fulltime people working with it [bSN] to get good results." (bSN1)

Different from bSN, BVC members pay no fee to participate in the community. BVC members contribute on a voluntary basis in small groups to community activities such as organizing seminars, developing add-ins, and translating foreign standards. The members participating in these small groups receive no payment. As a result, other BVC members have available add-ins and guidelines to apply BIM more efficiently to the local context. This saves time and budget for research and development in the members' organizations.

4.6 STANDARD SETTING

bSN members have engaged in BIM standardization through various organizations such as Standard Norway, International Organization for Standardization (ISO), and the European Committee for Standardization (CEN). Since the bSN members wanted to find ways for improving the information exchange with BIM, the development of new standards was required:

> "We need standards, protocols, and some joint libraries to make things [collaboration and information exchange] work… The real value of BIM is the information. We are at ISO, CEN and buildingSMART International working on that" (bSN 1)

The bSN management board noticed that some organizational members had built their business competencies based on open BIM standards. One of these companies has contributed to preparing standards for more than 15 years.

> "We are a company which is working on the information part…We started 17 years ago when we understood that there was a need for a common definition… That means you have to standardize the information… So, we are leading the work in CEN and ISO to standardize how to create properties." (bSN 5)

In contrast, BVC has so far not participated in any standardization organization. Some of the BVC members participate in the consultant team of the government BIM steering committee where Vietnam BIM guides have been prepared. While BVC had no direct contribution to the Vietnam BIM guides, the community is active in translating standards and supporting members seeking to apply foreign BIM standards such as PAS 1192-2:2103 and BS1192:2007 in their projects.

4.7 INNOVATION DIRECTIVE

The focus of bSN has been to develop a universal approach for BIM-based construction design using open standards and workflows for the digital work (buildingSMART Norway). The direction of the community is to enable a smarter sharing of information for achieving a more sustainable built environment (ibid.). The three steps for achieving better information sharing are (1) creating a neutral arena for innovation and digitalization of the AEC industry; (2) enabling a free flow of information throughout the lifecycle of a building, and allowing for effective collaboration between all actors; and (3) ensuring that all ICT solutions are based on open standards allowing for user-driven development and free competition. When asked about the direction of their community, the interviewees stressed the importance of open standards:

> "We believe that open standards and BIM have a big future." (bSN1)
>
> "All of us have a sort of grounding belief that open standards are the only way to have innovation flourish." (bSN 4)

Prominent advocates for openBIM in bSN were the large public construction clients participating in bSN:

> "There was not a lot of requirements for openBIM until Statsbygg went out and said, from 2010, all our projects require openBIM" (bSN 7)
>
> "Statens Vegvesen came to us and said "we want to use open standards for model-based project planning and execution… We want to explore it". So, we [bSN] started a project and hackathon is an activity in that. We also have other members who come to us, and they want to support [bSN] directly or use buildingSMART as an arena for innovation." (bSN 2)

Moreover, a part of the direction is to make participation in bSN a good experience for everyone with the building of mutual trust among the members being a priority:

> "We didn't want to be in the buildingSMART community pushing our product… We are trying to contribute in a good manner that creates trust." (bSN 4)

At the time of data collection, BVC was preparing an innovation direction. Most of the activities in this community are related to introducing new software, sharing BIM experience, and promoting new technologies on an ad-hoc basis.

> "Our events are mainly about supporting to implement or promoting new technologies. There is no long-term plan. The steering board is looking for a direction for the community." (BVC 4)

Trust is also important in BVC for experience sharing. However, the marketing-oriented activities of BVC seem not enough to build trust among members.

> "BIM seminars often include software sale or company promotion. I think most of the seminars allocate 30% of the time for sharing knowledge and experience. I have to listen to unnecessary information in the remaining time" (BVC 10)
>
> "If you ask someone about the experience in BIM, he only shares the details if he knows you well… Most participants in the seminars feel uncomfortable when I ask them about the experience. They mention only the results, not the insights or detail of their BIM experience." (BVC 10)

Although some BVC members hold management positions in government agencies and construction companies, the data reveal no evidence of them seeking to influence the BIM directives in Vietnam.

5. DISCUSSION

BIM innovation in the studied communities is performed on a voluntary basis. Both bSN and BVC members contribute to the community work on a voluntary basis and provide open access to their work. Although bSN and BVC members have different experience and contexts, they share some common motivations and activities. Table 2 summarizes the interventions by the two communities according to the Institutional Intervention Model. The motivation of members and the management of innovation activities seem to be the main drivers for BIM innovation development in the studied communities. In the community activities, trust is an essential factor in relationship building. Besides, the innovative approaches of the two communities provide insights for BIM innovation in the construction industry.

Table 2. BIM innovation development activities of bSN and BVC

Interventions	bSN	BVC
Knowledge building	Prepare the Digital Roadmap, organize openLab Hackathon, collaborate between academia and industry	Develop add-ins for BIM tools
Knowledge deployment	Offer training curriculum, organize online repository, issue newsletters	Share studied cases, translate standards, provide free training
Subsidy	Employ four fulltime employees for the management board, sponsor research projects	Voluntarily organize seminars, develop add-ins, translating standards
Mobilization	Promote openBIM through different communication channels, give guest lectures	Organize BIM seminars, give guest lectures
Standard-setting	Participate in ISO, CEN, buildingSMART international, Standard Norway	Not performed yet
Innovation directive	Request BIM use in the members' projects	Not performed yet

In the cases studied, the motivations to participate in the community work are derived from corporate social responsibility (CSR) and business relationships. The interviewees in both bSN and BVC explained that they contributed to BIM innovation because the new technology has value for the construction community and society. This indicates that CSR is a reason for contributing to BIM innovation in the community. This finding is in line with a survey in China where Zhou *et al.* (2019) found construction companies with higher scores on CSR tend to invest more in research and development than others. Besides, CSR might benefit companies not only in innovation but also in business opportunities.

Upstill-Goddard *et al.* (2016) argue that the requirements from clients or large organizations lay pressures on small and medium-sized construction companies (SMEs) to consider CSR. Their case study of construction companies in the United Kingdom reveals that SMEs implement CSR standards to avoid business loss and gain access to projects which have CSR requirements. The situation is similar in Australia and New Zealand where large-sized firms are leading in CSR initiatives (Loosemore and Lim, 2018). However, SMEs seem to have a low level of awareness of CSR even though they have incorporated ethical and economic aspects into the business activities (Bevan and Yung, 2015). Further understanding of how CSR influences BIM uptake would give better insight into adoption motivations of BIM users.

Regarding the business benefits, bSN and BVC members consider the communities to be useful for business networking. The interviewed BVC members seemed to focus on experience sharing, BIM training, updates on BIM innovation and BIM tools. Some bSN members have developed their business based on open standards created by the community. In this way, those bSN members utilize knowledge gained from the community to build their business competencies. Also, bSN members use their experience and resources to develop buildingSMART deliverables (IFC, BIM collaboration format, Model view definition, and the data dictionary).

To promote buildingSMART deliverables, individual bSN members have participated in BIM standardization at the international level. Some bSN members work for the ISO committee TC59. By focusing on the directions from standardization, bSN members can reduce development cost and software training. BVC members have translated standards and held seminars about buildingSMART. These community deliverables might be necessary for successful BIM implementation (Chan *et al.*, 2019). In the cases of bSN and BVC, the knowledge use and development represents the inside-out, and outside-in flows under the open innovation approach (Chesbrough, 2017). Since technology development needs an innovation process to influence practice (Dossick *et al.*, 2019), applying open innovation might strengthen the way BIM is being used in construction. Open innovation in construction communities represents an interesting area to explore further.

Modifying BIM to meet the local conditions is necessary for the technology adoption (Akintola *et al.*, 2020). Both bSN and BVC have connected construction practitioners for innovative solutions that meet the local requirements. While bSN links problem owners and solution creators through hackathons and research projects, BVC focuses on facilitating experience sharing among members. In both communities, individual knowledge is leveraged in the networks to create new values. The major forms of actions for creating new values were knowledge building and knowledge deployment. De Silva *et al.* (2018) notice that shared experience and resources are essential for the development of communities. However, the activity management members should restrict their individual interests on the development and support transferring knowledge among community members. De Silva *et al.* (2018) argue that communities need to harmonize the interests of individuals and communities for maintaining motivations in innovation development. To support innovation development, scholars might pursue further investigations on strategies which balance interests in open innovation communities.

Trust is essential for knowledge building in open communities since members have to believe in others' will to fulfil contribution commitments (Chesbrough *et al.*, 2018). Although bSN interviewees reported that their positive contributions to the community could build relationships and trust with other members, the link between trust and knowledge building seems unclear in the studied cases. Porto Gomez *et al.* (2016) suggested that open innovation communities should have trust builders who facilitate interaction among stakeholders for innovation. In the light of innovation development, the role of trust builders in communities is an interesting topic for further studies.

This paper provides a cross-case analysis of the bSN and BVC communities, revealing how these communities perform innovation in different contexts. bSN is more established with an innovation direction, annual membership fees, and various activities toward knowledge creation. The community has developed BIM guides for different types of construction and includes experienced BIM experts. In contrast, BVC organizes the activities on a voluntary basis. The focus lies on experience sharing and supporting tool development. Since BVC is still developing its direction, most activities of this community are currently marketing oriented. Moreover, the Vietnamese government is preparing the first BIM guide at the time of data collection.

The industrial contexts of bSN and BVC lead to three main differences. First, bSN has been established as a formal entity with four fulltime employees who are dedicated to organizing the community activities. The full-time employees help to make bSN activities more diversified and connect the members better. The BVC steering board, on the other hand, operates on a voluntary basis. Therefore, the board members have limited time to contribute to the community work. Second, bSN has a long-term vision. Moreover, the Norwegian community contributes to joint products at the industry level, such as the digital roadmap and standards. These products and the direction from buildingSMART international shape the long-term vision for bSN. In contrast, the activities in BVC are organized more on an ad-hoc basis. Finally, the neutrality principle helps bSN members to build better relationships among their members which might lead to future business collaborations. Different from bSN, BVC activities are influenced by marketing activities and seem inadequate to create good relationships among members. Weak relationships hinder knowledge sharing in the BVC community.

The main practical implication of our work is that we document how innovation through communities is a viable approach to BIM innovation. Moreover, innovation communities shape the national discourses on policy and guidelines related to BIM. Thus, by proactively participating in BIM innovation communities, companies become able to foresee and prepare for future developments related to the digitalization of the construction industry. Consequently, by being part of innovation communities, companies may have a competitive edge when it comes to the development and utilization of next-generation technologies. Further, by facilitating non-commercial activities, innovation communities are able to create a better environment for knowledge sharing.

The theoretical contributions of this work follow from applying the institutional intervention model to construction innovation communities. Our findings indicate that not all the interventions specified by the model were deployed to an equal extent by the communities. Knowledge building and subsidies are the main interventions focused by the communities. Activities such as preparing digital roadmaps, organizing openLabs, hackathons and establishing collaboration with academia are deployed as means for developing BIM knowledge. Moreover, the communities are focused on developing subsidies enabling them to actively engage in research projects as well as hiring staff. Both interventions were influential for the community's effectiveness in conducting BIM-related R&D work. However, the degree to which a community can develop knowledge and raise subsidies depends upon its stage of development. A well-established community would be able to outperform a new community on both subsidies and knowledge building. Our findings indicate that communities become only truly effective in their innovation work once they collaborate freely, develop an innovation directive, put aside adverse commercial interests, have dedicated management staff, and succeed in building trust.

The main limitation of this paper is related to the composition of the interviewees. About nineteen out of twenty-one interviewees are top and middle-level managers with more than ten years of experience. Their opinions can provide comprehensive insights into BIM use in the construction industry but might focus only on the managerial aspects. Therefore, including more voices of specialists working hands-on with BIM could have given other perspectives on the community work. In addition, the interviewees and the interviewer use English as a second language. To avoid misinterpretation in translation, the data were cross-checked with documents posted by the communities' members and among different interviewees. In the BVC case, the interviews were conducted in Vietnamese and were then translated into English. The language barrier might have affected the collected data. Notwithstanding these limitations, the paper provides an understanding of open BIM innovation in AEC.

6. CONCLUSIONS

The paper provides a cross-case analysis of bSN and BVC to describe how open innovation communities support innovation in construction. The research question asked at the outset was: "How do open innovation communities support BIM innovation?". The answer from our study is that innovation communities support BIM innovation by shaping national guidelines, legislation and policies related to the digitalization of the construction industry. Moreover, the inter-organizational communities subsequently operationalize these guidelines, legislation, and policies into organizational practice. The contribution of this paper is twofold. First, it applies the Institutional Intervention Model for understanding BIM innovation in construction communities. The results suggest that this model is useful for exploring innovation in communities. Second, the paper provides insights for construction communities seeking to further develop ICT innovation in AEC. Moreover, companies proactively participating in BIM innovation communities become able to foresee future developments related to the digitalization of the industry and thus providing them with a competitive edge. Although the contexts of the studied communities are construction, these insights might be transferred to other industries which have low uptake of ICT.

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