Succeeding with Building Information Modeling: A Case Study of BIM Diffusion in a Healthcare Construction Project

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Abstract

Technological innovations such Building as Information Modeling (BIM) offer opportunities to improve collaborative work and integration in the architecture, engineering and construction industry. However, research to date has documented how many organizations struggle with how to work based on this new technology, and many implementations fail. In this paper we present a case study of a major healthcare construction project in which the use of BIM was paramount, and where designers claim to have succeeded in integrated design. The designers organized their digital collaboration by establishing 1) change agents; 2) a cloud computing infrastructure; 3) new roles and responsibilities; 4) BIM contracts; 5) an IS learning environment; and 6) by involving software developers. These factors have been identified as influential for the successful diffusion of BIM in this project, and may serve as an example for implementation of BIM in other projects for supporting integrated design.

1. Introduction

Today's major construction projects could not be completed at the necessary speed without the use of advanced Information Systems (IS). Especially, Building Information Modeling (BIM) solutions have proven their value for construction design. BIM is both a new technology and a new way of working providing a common environment for all information defining a building, facility or asset, together with its common parts and activities [29]. Leading architectural and engineering firms use BIM to collaboratively develop virtual 'prototypes' of buildings before they are built [14,19]. When used properly, BIM can aid the architecture, engineering and construction (AEC) industry to become a more innovative sector of the economy [5,6].

Construction designers wanting to use BIM in their project need to develop new processes for their collaborative work [15], and many of today's construction firms hesitate to undertake the necessary organizational changes [24]. Even when firms seek to establish a collaborative environment in their projects, a variety of individual, environmental and technological challenges prove to be difficult to overcome [9,14,30]. Consequently, many firms continue to work in 'siloed' environments instead of encouraging a more collaborative culture. Thus, many of the crucial advantages of collaborative BIM design remain unexplored in wider practice [15].

Recognizing that only a few leading firms collaborate effectively based on BIM technology, recent R&D outlook publications by institutions such as the Council for Research and Innovation in Building and Construction (CIB) argue for the need to further define collaborative processes between the actors in design [7]. This is echoed by literature reviews arguing for the need to strengthen the research on the inter-organizational work surrounding the modeling activity [20,32]. We contribute to this discussion by inquiring into the reasons for why some AEC firms succeed in their collaborative work while others fail. The research question guiding our work is:

How can individual, environmental, managerial and technological challenges be addressed to achieve improved design collaboration through the use of BIM?

The article presents a case study of advanced BIMbased collaboration in a major healthcare construction project in Norway. The desired outcome of the collaborative BIM work was to create "[the] biggest, most complete and best digital model in the world." (BIM manager client)

We present the findings of a series of interviews conducted with the key players in the design team in order to understand how they approached their work. Diffusion of Innovations (DOI) theory [31] serves as a starting point for our analysis of the factors leading to collaboration. The case study approach applied in this study allowed for operationalizing diffusion factors presented in prior work in the empirical setting of a construction project [26], and for building practical and conceptual knowledge about BIM's diffusion as a collaborative system useful for other projects [8].

2. Theoretical lens

The DOI literature serves as a foundation to understand why and how a set of actors succeeds in ICT adoption and use. An innovation is defined as an "idea[s], practice[s] or object[s] that is [are] perceived as new by an individual or unit of adoption" [31, p. 35]. Researchers interested in how and why an innovation becomes diffused in a social system study "what determines the rate, pattern and extent of diffusion of an innovation across a population of potential adopters?" [31, p. 2]. It has been suggested that the diffusion of an innovation depends on the type and characteristics of the innovation [37], and that traditional DOI theory is best fitted for the study of innovations having an "intra-organizational locus of impact" [18, p. 20]. Nonetheless, DOI has been used to study the diffusion of a wide range of complex, networked technological innovations, including Enterprise Resource Planning systems, corporate web sites, online games, and several more.

BIM and 3D visualization tools in the construction industry can be seen as inter-organizational persuasive digital technologies [27], in that they bring together user experiences by connecting previously unconnected organizations. BIM affords combinatorial innovation by connecting a set of previously unconnected design software modules in a common design space [6, 37].

Traditional DOI theory views innovation diffusion as a linear process and the DOI contagion model assumes that "innovations are being spread but are not changing" [37, p. 1403]. However, combinatorial innovations such as BIM mutate and evolve while they are spread [37]. To understand the dynamics of such innovations researchers need to go beyond what has been suggested in traditional DOI literature and inquire into the "local, complex, networked, and learning intensive features of technology, [and] the critical role of market making and institutional structures in shaping the diffusion arena" [18, p. 14]. Moreover, to provide a 'faithful' account on the diffusion of BIM it is important to acknowledge its evolutionary component and "trade simplicity and generalizability against accuracy" [18, p. 14].

How readily an innovation is diffused in a social system depends, among others, on the 'voluntariness' of the innovation decision. Literature suggests that three different types of innovation decisions exist [31]:

- Optional a decision made by an individual who is in some way distinguished from others in a social system.
- Authority a decision made for the entire social system by few individuals in positions of influence or power.

Collective – a decision made collectively by all individuals of a social system.

Researchers have found that construction projects make a challenging 'diffusion arena' for networked technology such as BIM [26]. Several reasons are mentioned for this: first, construction firms exist along a spectrum ranging from highly computer literate 'diffusion ready' organizations to those hardly using computers in their work [25,34]; second, AEC organizations struggle to develop new forms of organizing and to change their established ways of working [12]; third, AEC firms frequently fail to establish common infrastructures for BIM technology use within and between organizations [2]; and last, many construction executives remain skeptical about the business value offered by BIM technology for their projects [35].

The practical side of BIM diffusion and use is at the focus of several studies. Some scholars apply a DOI approach to explain intra-organizational BIM diffusion [26,27,28,36], or the industry wide diffusion of BIM [25]. Much of this prior DOI-based research relied on surveys to identify generalizable factors important for BIM diffusion [26,27,36]. Researchers studying behavior of various organizations in BIM adoption have used theoretical lenses such as Actor Network Theory [16] or Boundary Object Theory [23] to develop their findings. This work established for instance that the creation of networks between a set of AEC organizations frequently fails.

We argue that prior work can be extended by providing a more in depth account on the necessary conditions for BIM use at the inter-organizational level [18]. In our study we use a set of diffusion factors identified by Peansupap and Walker [27] as a starting point to structure our analysis:

- > Individual factors, refer to the personal characteristics of an individual working with the technology, such as IT skills, capability to learn, and previous experience of IT.
- Environmental factors, describe the workplace environment in which the individual works, such as the availability of an open discussion environment and the possibility to share knowledge about ICT.
- Management factors, focus on the managerial approaches taken to organize the digital work, and the availability of ICT support considered important for ICT diffusion.
- Technological factors, technology characteristics, e.g. functionality, speed and accessibility, which may influence the diffusion of an innovation in construction projects.

Based on these factors we present how the design team in our case study established a collaborative BIM work space for their project.

3. Method

We conducted a case study of a major hospital construction project in Moss, Norway, initiated by the Southern and Eastern Norway Regional Health Authority (Helse Sør-Øst). A case study approach is appropriate to understand 'sticky' practice based problems where experiences and the context of the action are important [4]. The project was suggested to us by the educational coordinator of the Norwegian branch of the industry-led organization Building-SMART©, as an example of advanced BIM-based design practice. The project comprises the construction of several facilities including buildings for emergency, surgery and intensive care, patient rooms, psychiatric care, and for services such as a laundry and central sterilization. Altogether, the buildings comprise a gross floor area (GFA) of 85.082 square meters, and the project costs are estimated at € 670 million. In hospital design architects, health-care experts and users need to work in a "dynamic alliance" in order to build a hospital satisfying future users [1]. The Health Authority decided to use BIM technology to facilitate communication and teamwork among the parties involved in design. The outcome of the collaborative design process was a highly detailed virtual model signifying each of the buildings' components ranging from sprinkler heads to lighting fixtures. Thus, this project in which BIM and collaborative design was prioritized makes a compelling context for our study.

The drawings were prepared by 100 architectural consultants working for three different firms, and roughly 100 engineering consultants covering different areas of expertise. These consultants had different levels of BIM maturity. Only a few consultants had experience from jointly creating semantically rich BIM based models (5-10%), some had experience from creating disciplinary models (15-30%), while most of the consultants had never used modeling technology except for creating simple 3D visualizations (60-80%). Percentages above stem from an "educated guess" by two interviewees (client#1 and architect#1).

Our data was collected through eight semistructured interviews with design professionals, aiming to gain an understanding of the phenomenon by asking those experiencing it. The target was to interview BIM knowledgeable key actors in the design team. All interviewees were disciplinary or project level leaders responsible for BIM-based design and management. The interviews were conducted in April 2013, at a point in time when the design had been ongoing for three years and the team worked on finalizing the detailed design. Table 1 provides an overview of the interviews conducted. Six interviews took place at the designers' construction site offices in Moss, one was conducted via Skype and one took place at a firm's branch office in a different part of Norway. All interviews were voice recorded, transcribed, and coded by using the qualitative data analysis software NVivo9 [22]. Categories were derived from the data by assigning nodes to notions which could be related to the topics as presented by Peansupap and Walker [27].

Affiliation	Project level	BIM services provided	Interview Duration	Interview technique	
Client #1	Project	BIM manager (strategy)	60 min	Face-to face	
Client #2	Project	BIM manager (technical)	60 min	Face-to face	
Architect #1	Discipline	BIM coordinator (architectural)	45 min	Face-to face	
Architect #2	Discipline	Façade designer	20 min	Face-to face	
Electrical Engineer #1	Discipline	BIM coordinator (electrical engineering)	60 min	Face-to face	
Electrical Engineer #2	Multi- Discipline	BIM coordinator (all engineers)	75 min	Face-to face	
HVAC Engineer	Discipline	BIM coordinator (HVAC engineering)	35 min	Face-to face	
Structural Engineer	Multi- Discipline	BIM coordinator (all engineers)	190 min	Skype	

Table 1. Interviews conducted

4. Analysis

The analysis part of this paper is structured as follows: first the type of innovation decision is presented, followed by a systematic presentation of the diffusion factors as suggested by Peansupap and Walker [27]: 1) individual; 2) environmental; 3) managerial; and 4) technical. The factors discussed have been identified based on interview statements that could be related to the diffusion of BIM.

4.1 Innovation decision

The decision to prioritize collaborative BIM use for the hospital's design was made by the client's organization, on behalf of the project team. Like in most construction projects, the client held a position of influence and power in this project. Thus, following Roger's typology for innovation decisions, the decision to use BIM in this project can be seen as an "authority innovation decision", with the client as central actor in the diffusion system [31]. A drawback of authority driven innovation decisions is that new practices might be resisted by other members of the social system (e.g. architects, engineers). To minimize the risk for this, the client formulated contracts in which the collaborative use of BIM was explicitly demanded from all parties wishing to partake in the design of the buildings. BIM technology was considered important:

Well, as a building owner it is an important part of the strategy to have building models which can be used [...] and the intention is to save money in the operation phase. (Client, BIM manager 1)

The complexity inherent in large healthcare construction projects provides an "opportunity to harness the strengths of BIM" [19, p. 446]. The client anticipated that a semantically rich and highly detailed BIM model would be a useful resource for decision making, facilities management, and for active inclusion of the users in the facilities design (doctors, nurses).

To insure that the outcome of the model-based design would be of sufficient detail for facilities management, the client made clear that the model was to be an: "acceptable [virtual] prototype of the building". However, only few leading AEC organizations possess a sufficient level of expertise to collaboratively create models of such high quality. In awareness of this lack of expertise, the client promoted BIM competency development as a project goal:

The client has the objective to implement model-based design in this project and shall contribute to increase the competence about BIM in general and insure the knowledge gained can be transferred to other projects. (Client, BIM manager 1)

Introducing new technology is a costly undertaking and additional funding was needed to insure the design team could learn model-based collaboration while designing the project. Additional funding was made available by the client in conjunction with the Norwegian government. To guide the project's design team towards the anticipated goal of creating a sophisticated building model, the client appointed 'opinion leaders' or 'change agents' enforcing the collaborative use of modeling technology at project level. Two BIM specialists having the power to promote BIM use in the project were appointed by the client. One of these BIM professionals had the responsibility to manage the strategic aspects of the BIM collaboration whereas the other had the task to manage technical aspects of the BIM-based collaboration. However, the client decided to procure the project based on a design-bid-build method. This traditional procurement method involves three sequential phases: design, tendering, and construction. A drawback of procuring the project this way is that contractors creating the workshop design joined the project relatively late and thus were largely excluded from collaborative BIM-based design.

4.2 Individual diffusion factors

The use of BIM to facilitate the collaborative design work in this project was not a matter of choice for the design team. The client simply imposed a new way of working and collaborating upon the design team. This decision was not without risk, as collaborative BIM-based design is significantly different from the traditional way of working in this industry. The designers might have responded with hesitation or even resistance to the technology and the new way of working. The client marketed the project as a "BIM learning project", allowing companies to develop skills and processes while working on the project. This created a positive attitude towards the new technology and the new collaborative way of working. As noted by one designer, who initially had only rudimentary BIM skills, the team enjoyed having had the opportunity to learn how to work based on BIM:

What I have learned [about BIM]? Everything. When I came here my BIM skills had never been good, I kind of self-trained me. [...] Now, I have learned everything about BIM [and] I advise everybody to do this kind of project. (Electrical engineer, BIM coordinator 1)

Other, more experienced designers saw this project as a good opportunity to advance their firm's BIM development. The electrical engineer stated:

Those projects provide a good opportunity to take the next step [in BIM] because you have a big project and professional builders and owners. [...] I am sure that we will use many of the things we learned here in all our projects in the years to come. (Electrical engineer, BIM coordinator 2)

Ergo, some firms used this project to develop templates for new processes, advance their knowledge about available technology, and to develop BIM solutions. These designers built transferrable knowledge which could be 'rolled out' in other projects.

The design team had an overall positive attitude towards collaborative BIM design and the structural engineer stated that BIM helped to get rid of some "tiresome, time consuming and dull work" included in traditional design. In addition, there seems to be wide agreement that BIM has positive implications for design quality and the overall quality of the building. However, having to purchase systems useful to work faster and more efficient can lead to a contradicting situation for some of the designers:

We get paid by the hour so if we buy software to save time it is the client that benefits from it. Because we have to use our money to buy the software and we get less money from the client. But the client will benefit from us using less time. (Structural engineer, BIM coordinator)

4.3 Environmental diffusion factors

Establishing a collaborative work environment requires creating structures, rules and practices that promote cooperation. The establishment of a work environment depends to some extent on prior experiences: "in every project we [the designers] stand on the shoulders of the previous projects" (structural engineer, BIM coordinator). The design team in this case project arranged their collaborative environment for BIM-based work by establishing: 1) guidelines and rules for model based work; 2) roles and responsibilities; 3) a project BIM-room; and 4) crossdisciplinary exchange and control processes.

1) Guidelines and rules. The design team developed a project 'BIM manual' based on a template for BIM use provided by Norway's largest construction client [28]. The architect suggests that BIM manuals and handbooks are of crucial importance and should be established before the design work commences:

The key learning is to be a little in front of planning to create some rules for how we work, how we draw and who is doing what, and that you have to make a BIM manual before you start. (Architect, BIM coordinator)

Furthermore, the designers customized the manual for the particular needs of a hospital building project. The manual specified the way in which modeling information was to be delivered by the parties in the project. The manual included for instance a naming convention for parametric objects allowing designers to tag every component used in design in a consistent way based on unique identifiers specifying the location and type of component. In addition, the manual specified the file exchange format, in this case Industry Foundation Classes (IFC), to provide a basis for reliable cross-disciplinary information exchange. Beyond the project level manual, each design discipline developed a BIM handbook which provided the individual designers working hands on with the modeling technology with some practical advice of how to create models that would comply with the project level agreements specified in the BIM manual.

2) Roles and responsibilities. The design team created the position of "disciplinary BIM manager". These managers had the responsibility to monitor the modeling activity within disciplinary design groups. The structural engineer described the tasks involved in being a BIM manager as to include quality control of disciplinary models and to insure their compliance with the project's BIM manual. Further tasks are the preparation and weekly submission of disciplinary IFC models for the cross-disciplinary model control. The coordinators engaged actively in disseminating knowledge about the BIM manual and its practical implications for the designers. Disciplinary BIM coordinators had to report to the client's project level BIM managers whose job included the following tasks: Well, [the job of a client's BIM manager] is to secure that the BIM model is working as it should and that it is suited for the operation phase after the building is finished. Working with that is quite important. So we put together the different sections of the building [into one model of] the whole building. (Client, BIM manager 2)

The client's BIM managers assembled the models produced within the disciplines on a weekly basis into a joint model of the entire building. This work included to combine 42 different IFC based models created within the disciplines. The complete model was then used for clash detection in order to find and eliminate inconsistencies between the designs created within the different disciplines.

3) Project BIM room. The design team agreed that it would be necessary to establish a project BIM room as a central location for the weekly (Monday) crossdisciplinary meetings in which the designers discussed the overall building model assembled by the client's BIM manager. The room was equipped with two screens and a computer to which the updated and combined model of all disciplines was uploaded. Not only was the room intended as a collaborative space for the designers, but also for the contractors so that they would be able to look at the models while constructing the building. Figure 1 shows the project's BIM room.



Figure 1. BIM room at hospital construction site

4) Cross disciplinary exchange and control process. The design team developed a process for crossdisciplinary model control. The weekly routine established for design exchange and model control included the following activities:

Thursday - All designers make their models ready for exchange and deliver these to their disciplinary BIM coordinators. The coordinators control the model for correctness and create exchangeable IFC files that are uploaded via a web-server (Byggeweb©).

Friday - During the night from Thursday to Friday the delivered IFC files are synchronized with the local construction site server. Friday morning the client's BIM manager has access to all disciplinary IFC files via the local server. Next, he controls all models for compliance with the BIM manual and for logical errors. In case of obvious errors he requests new IFC models. Last, he assembles all disciplinary sub models into a joint model of the entire building by using the model checker software Solibri©.

Monday - The client's BIM manager uploads the model of the entire building to the computer in the BIM room. Then, in a cross-disciplinary model control meeting with the entire design team the models are controlled for geometrical clashes based on a set of

pre-defined clash-detection rules for Solibri©. Further, the designers conduct virtual walk-throughs in order to detect other necessary improvements. All design tasks are protocolled, tagged and extracted from the digital Solibri© model. Last, the disciplines receive lists with design tasks requiring immediate attention.

Tuesday-Thursday - The client's BIM manager controls the design changes undertaken based on the agreed task lists and in case of compliance approves the respective part of the model as ready to be built. After approval, the model is used to extract data to plan areas, rooms, functions and the time schedule based on database applications (e.g. dRofus©; Navisworks©).

According to the designers the cross-disciplinary model control procedure had both advantages and disadvantages. The advantages include that more design errors could be identified before the construction commenced. In addition, the increased design clarity allowed designers to develop a better understanding of each other's work, creating a better, more respectful relationship between the designers:

Suddenly, the structural engineer understands why the architect is doing what he is doing. [...] You get a totally different understanding for each other's challenges. (Structural engineer, BIM coordinator)

On the downside, increasing clarity in design increased the accountability for the designers. This accountability may be unwanted in cases where the design is still under development. To provide an example:

One corner of the hospital may be very well developed and almost finished and another part of the project can be on a preliminary stage. So, then when the client gets the model of the whole hospital he finds things that clash in the unfinished areas because that is really not coordinated yet. (Structural engineer, BIM coordinator)

4.4 Managerial diffusion factors

The seemingly most prominent managerial challenge related to BIM work in this project was that most designers did not have any prior experience in BIM design and collaboration. In a typical construction project this issue would have been more challenging to resolve. In our case study additional funds granted by the Norwegian government were available to develop BIM knowledge. This makes the study a showcase of what can be achieved once enough funding is available:

For 60-80% of the people that have been working in this project, working and drawing in a BIM project model was totally new [...]. They [the client] have got some incentive from the Norwegian state [...] so we have extra hours to train our people. (Architect, BIM coordinator)

The design team decided to use various approaches to IS training, and they decided that most of the training should take place on the construction site to keep the disruption of the daily design work at a minimum. The training was delivered based on four basic approaches: 1) super users (internal and external); 2) crossdisciplinary BIM training; 3) disciplinary BIM training; and 4) learning aids.

1) Super users - highly capable and BIM experienced designers were identified and formally appointed as 'BIM super users' for their disciplinary design group. These super users were seen as a 'BIM task force' to start up the project and provide training and help for less experienced designers. These persons had a double role of troubleshooting practical BIM problems and training their peers in BIM use, in addition to working in their usual roles as project engineers or architects. Due to the lack of availability some firms had to appoint external super users to train their designers, e.g. the electrical engineers hired an expert from a software vendor to train their people in BIM design until they felt confident to work without this help.

2) Cross-disciplinary BIM training - three hour courses were developed to introduce all designers to the basic functionality of the cross-disciplinary systems used at project level including Solibri© for clash detection and Navisworks© for time scheduling. These courses were designed to provide a strategic overview rather than to teach the actual hands-on work with those systems. The courses were held on the construction site.

3) Disciplinary BIM training - these training programs were designed to teach users the hands on skills required to design based on a particular disciplinary BIM design system (such as Revit©MEP or Revit©Architecture). These courses were targeted foremost at those designers that needed to learn from 'scratch' how to design based on BIM. The training was organized by software vendors and usually went on for several weeks. Typically these courses were held at a vendor's training facilities.

4) Learning aids - were developed by people having extensive prior experience from working hands on with BIM technology within their disciplines. The learning material was customized for each discipline's unique learning needs. The material was bundled into a set of disciplinary BIM handbooks placed at every BIM workstation in the project. These manuals provided hands-on knowledge on BIM design and included step by step recipes which could be followed by the designers in order to create a digital model.

Adopting new systems and training the workforce to use them is a costly undertaking, and its success depends largely on the degree of top-level support in each of the firms participating in design.

You cannot do anything without top-level support. [...] We roll out [new technology] wherever we have a budget for it and where it is cleared by the [top] management. (Structural engineer, BIM coordinator)



Figure 2. Network for collaborative BIM design

4.5 Technological diffusion factors

Collaborative BIM design requires a set of BIM workstations to be linked by a supportive server infrastructure. At project initiation the design team decided that all designers should work physically colocated at the construction site in Moss. Co-locating the design team was regarded as useful to build team relationships and to improve communication in design. Thus, all BIM workstations were initially set up on-site and linked towards a local server. The server functioned as a team work space in which the central BIM model was placed and the designers worked 'live' on the same model. This co-located setting and infrastructure was used throughout the conceptual design phase. When the design advanced to the detailed design phase the infrastructure was altered:

In the beginning we were all sitting here working towards a local server. When the project advanced further in detailing we needed more people and all these people could not travel to this place because they were all located in different offices. (Electrical engineer, BIM coordinator 2)

There was a need to include additional design team members distributed geographically (Oslo, Trondheim etc.). The designers agreed that the cost of supporting a fully co-located team and the expenses of travel involved would outweigh its benefits and justify a more distributed setup. In this second phase the design team set up a 'mirror' web-server (Byggeweb©) featuring the same content as the local server. This web-server allowed for distributed work where all designs could be accessed and altered via the internet.

In addition, the engineering consultants decided to build a server infrastructure based on Revit © server technology. This allowed them to work in a real time 'live' modeling collaboration while operating in a distributed setting. They placed a Revit@CentralServer in Gjøvik and linked all their design offices through the use of Wide Area Network (WAN) technology to this server. Thus, their distributed BIM workplaces were linked and models were synchronized every night. In essence this meant that designers in Trondheim would be able to see the design changes a colleague in Oslo had produced. The setup of the collaborative infrastructure during the detailed design phase is depicted in Figure 2. Figure 2 shows that the design team has in essence built a 'cloud computing' infrastructure for their BIM project. Building such an infrastructure is however often only feasible for large projects:

You are able to do that in bigger projects because you get time to develop it [...] but often in small little office building projects, like here in Kristiansand, you have maybe half a year to finalize the design of the building. (Electrical engineer, BIM coordinator 1)

After having set up the collaborative infrastructure the design commenced. Since none of the designers had prior experience in creating a digital model for such a large facility, the design team was surprised by the sheer amount of data that was to be shared through this network. The models quickly became far too large to be handled by the designers' computing equipment:

That was a wakeup call for us in the beginning that we actually cannot use those crappy computers anymore, we need top of the line computers because it is so much data. (HVAC, BIM coordinator)

To establish a stable information flow between all design and database applications used in the project network these applications needed to be interoperable. The design team approached this challenge by firstly establishing that all design software used was to be IFC compatible. Second, all designers not yet working based on BIM software adopted software solutions similar to those already used in their design group. For example, two architectural firms adopted 'Revit© architecture' since a third firm already worked based on that software. Revit© software was used by most engineers and by the architects allowing them to collaborate 'live' based on the work sharing functionality embedded within Revit. Having most designers work based on software by the same vendor eliminated most interoperability challenges.

In addition, all the software for the door, window and room databases and the servers needed to be aligned and linked to allow for synchronization of the digital works. To arrange for this an external ICT consultancy was appointed to set up and service the infrastructure. The designers faced challenges where the software in itself was not sufficient for its purpose. For instance, the application used to design the sprinkler system proved to be unfit for large structures, or the system used in clash detection proved to be insufficient for clash detections of large models. The structural engineer stated that these challenges were addressed by appointing a software consultancy:

We do have [a software company] that on our request developed a software to be used in Revit so the fire engineers and the acoustic engineers can take a copy of the architect's file and put the fire ratings on the doors and walls. (Structural engineer, BIM coordinator)

Appointing the developers helped to address some of the problems experienced, for instance, the fire protection engineers could partake in BIM design. As a result of the efforts undertaken to establish a functional BIM collaboration, the design team collected large amounts of documentation data on the individual components used in the facilities design and placed this in databases. However, so far the client has not been able to identify any commercially available system useful to structure the data in a meaningful way for facilities management.

5. Discussion

The case project is an example of advanced practice where a collaborative BIM work environment has been

established. The established design space linked architects, engineers and clients. However, the link between the design team and the construction firms was less well developed and contractors were largely excluded from the collaborative work. This resonates with earlier research arguing that those working in 'the periphery of digital innovation networks' are frequently excluded from innovative practices [38]. Further, even though the design team claimed to have succeeded in BIM design it remains to be seen whether the project as such will be regarded a success after completion.

Keeping these limitations in mind, we argue that our study provides a useful starting point for practitioners seeking to set up a collaborative BIM workspace in their projects. The key diffusion factors aiding the case project's designers to establish their collaborative work environment are summarized in Table 2. These factors, however, need to be seen as a product of their context, and practitioners would need to evaluate their fit to other project situations [18]. For instance, the case project has been unique in that BIMbased work was supported by a grant provided by the Norwegian government. Even though the diffusion factors would need to be customized to a specific construction context some of the approaches have proven effective to eliminate some widely experienced problems in construction projects:

First, establishing a BIM learning environment helped to equip all designers with the capabilities and maturities required for collaborative BIM work. Extant research has identified the uneven distribution of capabilities and maturities in project teams as a major barrier for collaborative design [34].

Second, involving system developers during the design to assist designers in overcoming technical challenges proved effective to connect previously unconnected designers (e.g. fire protection engineers).

Third, establishing a cloud based infrastructure allowed the designers to choose either to work colocated or distributed. The opportunities of cloud computing and virtual teams for BIM-based design are discussed in the literature, and it is debated whether colocated or virtual design teams perform better in BIMbased design [11,13]. We argue that the value of virtual teams and cloud computing technology for construction is an area in need for further research.

Fourth, there is a wide debate in current BIM research about the challenges of technical interoperability among different BIM design solutions [10]. The case design team addressed this challenge by deciding to work, where possible, based on software provided by the same vendor. In addition, they agreed to only use applications supporting the IFC open file exchange standard. However, just adopting new

Table 2. BIM diffusion in the case project

DOI Element Cose regiont's law diffusion for the				
DOI Element	Case project s key diffusion factors			
Decision	- Authority innovation decision by			
	DIM integral next in contractual			
	- Bivi integral part in contractual			
	arrangements			
	- Government funding to increase			
	industry's BIM competency			
Individual	- BIM use promoted as project goal			
	- Change agents appointed at			
	project level to enforce BIM use			
	- Project framed as a BIM learning			
	project			
	- Possibility for designers to develop			
	BIM competence in the project			
Environment	- Formulation of guidelines and			
	rules for collaborative BIM work			
	 New roles and responsibilities 			
	developed			
	 Project BIM room 			
	- Cross-disciplinary model exchange			
	and control process			
Management	- Organized approach to IS learning			
	(super-users, cross-disciplinary and			
	disciplinary BIM training, and			
	learning aids)			
	- Top management support			
Technology	- 'Cloud computing' network for			
(hardware)	distributed and co-located design			
× ,	- Top of the line equipment			
Technology	- Interoperability achieved by using			
(software)	software from a single provider			
()	- All software used IFC compatible			
	- Close collaboration with software			
	developers to improve the			
	functional affordance of BIM			
	technology			
	teennology			

systems may not be a feasible solution for projects where limited funds for BIM-based work are available.

Last, the design team created a holistic approach to manage their collaborative design by establishing formal arrangements (contracts), a coherent way to produce models (BIM manual), a model exchange process, and defining roles and responsibilities for their collaboration. Former research has suggested that establishing an overall 'organizing vision' is essential for the functionality of inter-organizational systems [17,21], and this case shows how that could be achieved in construction projects.

It would be an interesting avenue for further research to inquire how such shared organizing visions for working together in BIM could be established in other project situations. Our case study showed that some issues for collaborative design remain unsolved, such as the lack of commercially available applications to reuse BIM data for facilities management. This finding does not come as a surprise, as researchers are just beginning to explore BIM's application areas for facilities management [3].

Our study has documented that if designers are given sufficient financial resources it is possible to

achieve integrated design in construction projects, and has provided insights for practitioners seeking to diffuse BIM technology in their projects. In addition, the usefulness of DOI as a theoretical lens to study BIM-based collaboration in a construction project has been shown. However, we developed our view on BIM diffusion based on a single case study, and further studies should be conducted in other types of projects to validate our findings.

6. Conclusion

This paper has presented a case study of a construction project in which the design team succeeded in integrated design based on digital modeling technology. By doing so the team managed to reduce some of the tiresome and time consuming work in construction design, and, according to the client, to produce an acceptable virtual prototype of the buildings.

By conducting a study based on DOI we were able to identify inter-organizational factors driving the diffusion of BIM technology at the project level. We identified how individual, managerial, environmental, and technological challenges typically experienced by construction firms in BIM diffusion can be addressed to set up a collaborative BIM workspace.

The identified diffusion factors include the establishment of BIM 'change agents', putting in place a cloud computing infrastructure, appointing software developers, establishing solid BIM contracts, a systematic approach to IS learning, and the establishment of new roles and responsibilities.

However, even though we claim to have provided a faithful account of the factors that aided designers in this case study to facilitate their collaborative work, these factors need to be seen as a product of their context. Practitioners seeking to find a diffusion approach for their projects need to evaluate whether these factors fit their given project situation.

We argue that BIM technology and its use in the AEC industry is an interesting field in need for further IS research, including questions such as: what is the value of virtual teams and cloud computing technology for construction projects? How is the diffusion of BIM influenced by a construction project's context? And how can the content produced in BIM design be managed in order to be useful for facilities management?

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8. References

- Adams, A., "Medicine by design: the architect and the modern hospital, 1893-1943". University of Minnesota Press, 2008.
- [2] Ahuja, V., J. Yang, and R. Shankar, "Study of ICT adoption for building project management in the Indian construction industry", Automation in Construction, 18(4), 2009, pp. 415-423.
- [3] Becerik-Gerber, B., et al., "Application Areas and Data Requirements for BIM-Enabled Facilities Management", Journal of Construction Engineering and Management, 138(3), 2012, pp. 431-442.
- [4] Benbasat, I., Goldstein, D. K., and Mead, M., "The Case Research Strategy in Studies of Information Systems." MIS Quarterly, 11(3), 1987, pp. 369-386.
- [5] Berente, N., R. Baxter, and K. Lyytinen, "Dynamics of interorganizational knowledge creation and information technology use across object worlds: The case of an innovative construction project", Construction Management and Economics, 28(6), 2010, pp. 569-588.
- [6] Boland, R., K. Lyytinen, and Y. Yoo, "Wakes of innovation in project networks: the case of digital 3-D representations in architecture, engineering, and construction", Organization Science, 18(4), 2007, pp. 631-647.
- [7] CIB, "White Paper on IDDS Integrated Design & Delivery Solutions", International Council Research and Innovation in Building and Construction, 2010.
- [8] Eisenhardt, K., "Building theories from case study research." Academy of management review, 14(4), 1989, pp. 532-550.
- [9] Espadanal, M. and T. Oliveira, "Cloud Computing Adoption by firms" eights Mediterranean Conference on Information Systems, 2012, paper #30.
- [10] Grilo, A. and R. Jardim-Goncalves, "Value proposition on interoperability of BIM and collaborative working environments", Automation in Construction, 19(5), 2010, pp. 522-530.
- [11] Hosseini, M.R. and N. Chileshe, "Global virtual engineering teams (GVETs): A fertile ground for research in Australian construction projects context. International Journal of Project Management, 2013, in press.
- [12] Howard, R. and B.C. Björk, "Building information modelling Experts' views on standardisation and industry deployment" Advanced Engineering Informatics, 22(2), 2008, pp. 271-280.
- [13] Jardim-Goncalves, R. and A. Grilo, "SOA4BIM: Putting the building and construction industry in the Single European Information Space", Automation in Construction, 19(4), 2010, pp. 388-397.
- [14] Khanzode, A., M. Fischer, and D. Reed, "Benefits and lessons learned of implementing Building Virtual Design and Construction (VDC) technologies for coordination of Mechanical, Electrical, and Plumbing (MEP) systems on a large Healthcare project", ITcon, 13 (22), 2008, pp. 324-342.
 [15] Leeuwis B., Prins M., Pastoors A., "BIM at small architectural
- [15] Leeuwis B., Prins M., Pastoors A., "BIM at small architectural firms", nineteenth CIB World Building Congress, Brisbane, Australia, 2013.
- [16] Linderoth, H., "Understanding adoption and use of BIM as the creation of actor networks", Automation in Construction, 19(1), 2010, pp. 66-72.
- [17] Lyytinen, K. and J. Damsgaard, "Inter-organizational information systems adoption - a configuration analysis approach" Eur J Inf Syst, 20(5), 2011, pp. 496-509.
- [18] Lyytinen, K. and J. Damsgaard, "What's wrong with the diffusion of innovation theory, the case of a complex and networked technology", Diffusing Software Products and Process Innovations, Kluwer Academic Press, Boston, MA, 2001, pp. 173-190.
- [19] Manning R, Messner J., "Case studies in BIM implementation for programming of healthcare facilities", ITcon, 13 (18), 2008, pp. 246-257.

- [20] Merschbrock, C. and B.E. Munkvold, "A Research Review on Building Information Modelling in Construction - An Area Ripe for IS Research" Communications of the Association for Information Systems, 31(1), 2012, pp. 207-228.
- [21] Merschbrock, C., "Unorchestrated symphony: The case of interorganizational collaboration in digital construction design", Journal of Information Technology in Construction (ITcon), 17 (22), 2012, pp. 320-337.
- [22] Miles, M. B., and Huberman, A. M., "Qualitative data analysis" ,1994, 2nd ed. SAGE publications, Inc.
- [23] Neff, G., B. Fiore-Silfvast, and C.S. Dossick, "A case study of the failure of digital communication to cross knowledge boundaries in virtual construction" Information, Communication & Society, 13(4), 2010, pp. 556-573.
 [24] Oakley, J., "Getting a BIM Rap: Why Implementations Fail, and
- [24] Oakley, J., "Getting a BIM Rap: Why Implementations Fail, and What You Can Do About It" Retrieved March 7, 2013 from the World Wide Web http://www.aecbytes.com/viewpoint/2012/issue 65.html

[25] Panuwatwanich, K. and R.A. Stewart, "Evaluating innovation diffusion readiness among architectural and engineering design firms: Empirical evidence from Australia", Automation in Construction, 27 (7), 2012, pp. 50-59.

- [26] Peansupap, V. and D. Walker, "Factors affecting ICT diffusion: A case study of three large Australian construction contractors", Engineering, Construction and Architectural Management, 12(1), 2005, pp. 21-37.
- [27] Peansupap, V. and D. Walker, "Factors enabling information and communication technology diffusion and actual implementation in construction organisations" ITcon, 10(14), 2005, pp. 193-218
- [28] Peansupap, V. and D. Walker, "Innovation diffusion at the implementation stage of a construction project: A case study of information communication technology" Construction Management and Economics, 24(3), 2006, pp. 321-332.
- [29] Pittard, S., "What is BIM?" London, UK: Royal Institution of Chartered Surveyors (RICS), 2013.
- [30] Prescott, M.B. and S.A. Conger, "Information technology innovations: a classification by IT locus of impact and research approach" SIGMIS Database, 26(2-3), 1995, pp. 20-41.
- [31] Rogers, E.M., Diffusion of innovations, Free Press New York, 2003.
- [32] Shen, W., et al., "Systems integration and collaboration in architecture, engineering, construction, and facilities management: A review" Advanced Engineering Informatics, 24(2), 2010, pp. 196-207.
- [33] Statsbygg, "Statsbygg Building Information Modelling Manual Version 1.2", Statsbygg, Oslo, Norway, 2011.
- [34] Succar, B., W. Sher, and A. Williams, "Measuring BIM performance: Five metrics" Architectural Engineering and Design Management, 8(2), 2012, pp. 120-142.
 [35] Suermann, P.C. and R.R.A. Issa, "Evaluating industry
- [35] Suermann, P.C. and R.R.A. Issa, "Evaluating industry perceptions of building information modeling (BIM) impact on construction", ITcon, 2009, 14(37), pp. 574-594.
- [36] Whyte, J., D. Bouchlaghem, and T. Thorpe, "IT implementa-tion in the construction organization", Engineering Construction and Architectural Management, 9(5-6), 2002, pp. 371-377.
- [37] Yoo, Y., Boland, R., Lyytinen, K., and A. Majchrzak, "Organizing for Innovation in the Digitized World", Organization Science, 23(5), 2012, pp. 1398-1408.
- Science, 23(5), 2012, pp. 1398-1408.
 [38] Yoo, Y., Lyytinen, K., Boland, R., Berente, N.,Gaskin, J., Schutz, D., & Srinivasan, N., "The next wave of digital innovation: Opportunities and challenges. A Report on the Research Workshop 'Digital Challenges in Innovation Research" Fox School of Business, Temple University, PA, USA, 2010.