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UNORCHESTRATED SYMPHONY: THE CASE OF INTER-ORGANIZATIONAL COLLABORATION IN DIGITAL CONSTRUCTION DESIGN

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SUMMARY: *This paper presents the findings from a study of collaborative work among design professionals in virtual modeling for building construction. The research is based on interviews conducted with members from various design professions. We analyzed a building project comprising a network of organizations interrelated by their information systems, to gain a better understanding of collaborative design based on Building Information Modeling (BIM). The findings suggest that the actors did not fully exploit the capability of BIM to transform and improve project communication, as they did not adjust the inter-organizational processes according to the BIM technology. Instead of effective collaboration, we found a system of "automation islands." To achieve full business-process integration, the actors would need to establish a shared organizing vision for BIM. This organizing vision needs to align inter-organizational processes and the functionality of BIM. Our findings illustrate weaknesses in existing practice and highlight possible improvements.*

KEYWORDS: *building information modeling, construction project, digital design, inter-organizational systems, collaboration, configuration analysis, case study*

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1. INTRODUCTION

It is widely accepted that Information and Communication Technology (ICT) promotes efficiency in communication and has the potential to change the way in which organizations in the Architecture, Engineering and Construction (AEC) industry interact. In this respect, organizations in the AEC industry gradually substitute their traditional, paper-based, two-dimensional (2D) Computer Aided Design (CAD) tools for three-dimensional (3D) technologies. These technologies, commonly referred to as Building Information Modeling (BIM), are digital representations of all physical and functional characteristics of a facility (NIBS, 2007). Moreover, BIM is intended to serve as a design space where multiple actors engage in collaborative dialogue. Ideally, the result of such dialogue is a common virtual building model created through a joint effort and close collaboration, with all the actors providing designs for the construction project. In this respect, there is a need for actors to coordinate design activities and to synchronize their cooperative activities toward working within a shared information system.

Innovative, ICT-supported practices, including BIM, can serve as a catalyst for firm performance and innovation (Baxter and Berente, 2010). In this respect, numerous scholars have discussed the opportunities of BIM to advance transparency, visualization, and clarity in construction design information sharing (Khanzode et al, 2008). However, to attain the anticipated IT-enabled benefits, actors need to substitute their old design technology with the new technology, and transform structures, and processes within, and across the participating organizations.

BIM's potential to transform or even revolutionize collaborative work in construction design is, however, frequently left untapped (Ahmad and Sein, 2008; Ahmad et al, 2010). Scholars argue that collaborative design using a shared information system such as BIM is virtually impossible without changing the actors' traditional working processes and routines (Owen et al, 2010). They see multiple hurdles for the free flow of information and intelligence across organizational boundaries. Especially the root characteristics of the AEC industry such as a high division of labor, cost consciousness, little institutional leadership, and a lack of standards in technology and business models seem to impair effective collaboration (Peansupap and Walker, 2006; Rankin et al, 2006). In addition, the document-based nature of traditional information exchange, actors' traditional mindsets, their "silo" mentalities and cultures, tensions arising from conflicting organizational interests, and their distinct organizational backgrounds impair effective collaboration in construction design (Gal et al, 2008; Rankin et al, 2006). Moreover, the use of a shared information system is governed by power resource dependencies, individual actor's ICT capabilities, and the significance attributed to the technology by the actors (Lyytinen and Damsgaard, 2011). Thus, finding a common modus operandi for BIM requires that actors deal with a variety of challenges stemming from historically developed structures and processes.

The study presented in this paper is motivated by a recent literature review calling for research into ICT collaboration methodologies for the construction industry and the need for fresh approaches to study digital design practices in construction projects (Shen et al., 2010; Whyte, 2011). We seek to contribute to the understanding of the alignment of strategies and structural arrangements toward BIM, and how these influence design, and information sharing in multi-actor collaboration. Thus, our research is guided by the following question:

How can we analyze the use of BIM for integration in multi-actor digital construction design, to identify challenges and improvements in related practices?

To address this question, we present the results of a case study conducted in a Norwegian construction project, analyzing how the multiple actors organized and used BIM in their project. The theoretical lens guiding the data collection and analysis is the configuration analysis framework (Lyytinen and Damsgaard, 2011). Configuration analysis is an approach employed to gain an understanding of ICT-enabled integration and communication at the inter-organizational level. The intended contribution of this paper is twofold: first, we argue that research taking a configuration analysis perspective can broaden the theoretical understanding of the structural arrangements and strategies governing organizational actors' interaction in digital construction design. Second, the practical contribution of this paper is to showcase how a configuration analysis approach can be of use in identifying the required changes needed to adopt and make use of BIM to achieve improved collaboration in design and construction projects.

The organization of the paper is as follows. Section two presents the theoretical perspective supporting the analysis, section three presents the research methodology, section four presents the data analysis, and is followed by a discussion of the results. Section six presents conclusions and implications.

2. THEORETICAL LENS

In contemporary literature on BIM adoption and use, we find multiple studies theoretically ingrained in ICT diffusion theory, focusing largely on the behavior of single adopters of BIM (Peansupap and Walker, 2006). In addition, we find studies based on the Technology Acceptance Model (TAM), the Theory of Planned Behavior (TPB), and the Unified Theory of Acceptance and Use of Technology (UTAUT), which seek to explain the behavior of multiple single actors (Adriaanse et al, 2009). In more recent work, the focus has shifted toward studying networks of organizations, for example, based on Actor Network Theory (ANT) and Boundary Object Theory (Gal et al, 2008; Jacobsson and Linderoth, 2010; Linderoth, 2010; Whyte and Lobo, 2010). These studies report that a variety of contextual factors (e.g. the project's mode of organizing, contracts, fees for delays, etc.) govern BIM`s rate of utilization and functionality in construction design. Further, the "Design Process Communication Methodology" (DPCM) has been developed based on ideas stemming from Business Process Modeling (BPM), Human Computer Interaction (HCI), and organizational science (Senescu et al, 2011). This methodology seeks to lay the foundation for communication-facilitating software that is useful for the visualization of the communication processes involved in construction projects. Scholars have begun to study how the technical details of BIM are linked to a "larger and more general view of the sociological nature of communication, coordination and knowledge creation" (Baxter, 2008, pp. 81–82). In this respect, a recent paper in ITcon argues that the actors' organizational attitudes, behaviors, and cultures shape the way in which organizations interact (Brewer and Gajendram, 2011). In addition, a further ITcon paper highlights how BIM might impact organizational structures in AEC firms (Oluwole, 2010). Our work can be positioned within the multi-actor-level studies and our paper intends to document how the theoretical lens of configuration analysis contributes to a more in-depth understanding of the collaboration process in BIM design.

The configuration analysis perspective is rooted in organizational theory, where organizations and markets are defined as interconnected structures (Williamson, 1979). The key idea of the configuration analysis is to study a "family" of organizations that are interrelated by their information systems. The authors introduce a set of key parameters, which are briefly presented in the following: Firstly, the parameter *organizing vision* addresses the aims and functionality of an Inter-Organizational Information System (IOIS), which should be agreed upon through the creation of a shared organizational vision. Secondly, *key functionality* defines the scope and content of the data exchanged. Thirdly, the *structure* parameter seeks to describe the roles that organizational actors take in facilitating the inter-organizational information exchange. Fourthly, *mode of interaction* is a measure seeking to describe whether equal relationships between the actors exist, or if obligatory or hierarchical relationships are evident. Lastly, the parameter mode of *appropriation* addresses actors' varying appropriations of technology (Lyytinen and Damsgaard, 2011). The aim of our analysis is to bring about an altered understanding of how interaction in construction projects happens or why it happens as it happens. Table 1, by Lyytinen and Damsgaard (2011), provides an overview of the key elements that constitute an adopter configuration.

TABLE 1: Key elements of an adopter configuration (Lyytinen and Damsgaard, 2011)

Adopter configuration element	Definition
Organizing vision	Conveys a persuasive cognitive model of how the IOIS helps to organize better inter-organizational structures and processes
Key functionality	Defines, in turn, the scope and content of data exchanges and related business functionality in terms of the content of messages, their choreography, and coverage
Structure	Defines the volume of structural relationships between the participating organizations, as defined by the IOIS
Mode of interaction	Nature of relationships between the participating organizations, as defined by the IOIS
Mode of appropriation	The scope and intensity of potential effects of adopting the IOIS for the participating organization

3. METHOD

The setting for our case study is a wood frame, multi-story, low-energy housing development in Norway. The project includes the construction of three apartment buildings altogether consisting of one hundred individual apartment units. The project has been chosen based on several selection criteria. The first criterion was that the projects' participants should resemble a rather typical project constellation in the industry (e.g. client, architect, contractor, HVAC designer, structural engineer, electrical designer). The second criterion was that digital modeling technology had to be in use in the project's design stage. The last criterion was to choose a project that had neared the completion of the design phase. The chosen project fulfilled all of the aforementioned criteria. The data collection was undertaken during the final design stage of the project. Most of the organizations subject to our case study were located in Norway, with five in the same city, and one in a different region of Norway, while the structural timber engineering firm was located in Switzerland. Bi-weekly design meetings were held in one of the Norwegian cities where most of the firms were located. The design meetings required firms to send their representatives. No videoconferencing systems or similar support technologies were deployed to facilitate the meetings. This practice precluded some actors, such as the Swiss firm, from regular participation in the project meetings.

Ten semi-structured interviews were conducted with actors involved in the project's design in the period from September 2011 to March 2012. The case project's design was produced by six firms: the architectural office, the timber frame builder, an engineering office producing structural, mechanical, and electrical design components, a geotechnical engineering office, a fire-protection designer, and a specialized structural engineer for timber structures. We decided to interview at least one designer in each firm who actively participated in the project's design. We collected data from interviews with project managers, designers who were working hands on with the technology, and firms' CEOs. A detailed overview of the modalities of the interviews—that is, the persons interviewed, the interviewing technique applied, and the design services provided by the actors—can be found in Table 2. Four of the interviews were conducted face-to-face at the firms' branch offices and six were conducted through Skype. Each interview lasted approximately one hour. The chosen interviewing strategy allowed us to capture the on-going design interaction in the case project in its full breadth. After the interviews, we provided the participants with a transcript of our article, and called the interviewees thereafter to briefly discuss, and clarify our findings. The respondents agreed overall with our interpretations, and we considered critical comments, and improved our work by filling "holes" through close collaboration with the practitioners. We argue that this procedure of member validation added to the plausibility and validity of the findings presented in this article (Bygstad and Munkvold, 2011).

TABLE 2: Interviews conducted

Person interviewed	Services provided	Interview technique
Timber frame builder, design manager	Design, production, and installation of all wooden components	Face-to-face
Timber frame builder, CEO		
Timber frame builder, drafter		
Timber frame builder, production manager		
Geotechnical engineer	Geotechnical design	Skype
Architect	Architectural design	
Engineering design coordinator (structural, HVAC, and electro)	Structural, electrical, and HVAC design	
Fire-protection engineer	Fire-protection design	
Client, CEO	Client	
Structural engineer (timber frame)	Specialist structural design of wooden components	

The researcher's civil engineering background, comprising both work experience and university level education, helped to minimize the social dissonance between the interviewer and respondents. In addition, the interviewer's background allowed for the mutual use and understanding of construction-specific jargon/language**.** All interviewees were informed beforehand about the modalities of the interviews and gave their informed consent for the process. The interviews were recorded, transcribed, and coded according to the parameters relevant in configuration analysis. The software used to support the coding of the interviews was NVivo 9. The coding was performed by uploading transcripts as documents into NVivo9, assigning nodes to notions that could be related to the key parameters, and creating reports that related the occurrences across interviews.

4. ANALYSIS

The analysis in this paper is based on the configuration analysis approach. We define an adopter configuration as a group or cluster of organizations that are interrelated by their information systems. The elements that constitute the configuration in our case are design systems that allow information to be sent across organizational boundaries. In what follows, we report on which set of organizations assembles the adopter configuration in our case project and we map the information systems linking these organizations. After having established the adopter configuration as a unit of analysis, we present our aggregated data based on the key parameters in configuration analysis; that is, organizing vision, key functionality, structure, mode of interaction, and mode of appropriation.

4.1. The adopter configuration

The adopter configuration forms the unit of analysis for our case study. Our criterion for including organizations in the adopter configuration was their use of design systems. The firms using systems that allowed them to create, transmit, and retrieve virtual models via the Industry Foundation Classes (IFC) file format were considered as part of the adopter configuration. Ergo, the adopter configuration is made up of a set of organizations that had the technical capability to be able to participate in BIM. The adopter configuration of our case project included the following firms: architect, electrical engineer, structural engineer, HVAC engineer, main contractor (timber frame), and the structural engineer (timber frame). The "outliers" of the adopter configuration in the case project were the client, the geotechnical engineer, and the fire-protection designer. These firms did not deploy systems that were useful for active participation in BIM design. The black squares in Figure 1 depict organizational actors being part of the adopter configuration, while those remaining white portray firms that were not technically able to participate in a shared BIM. On the left-hand side in Figure 1, we identified a group of actors—the engineering design coordinator, the electrical, and structural, and HVAC engineers—who were part of a single organization and who had established an internal role as a design coordinator. The lines in Figure 1 represent the project's main communication path throughout the design phase, acknowledging the architect's role as a communication hub.

The organizations in the case project deploy a variety of information systems to facilitate the creation and transmission of design information. These systems allow partners in a network to collaborate by exchanging structured design information across organizational boundaries; they are therefore IOIS (Kumar and van Dissel, 1996). In virtual construction design, each party prepares a specialist model covering their area of expertise. This is reflected by the information systems used in the case project, which are essentially design programs adapted for the special needs of subject-matter experts.

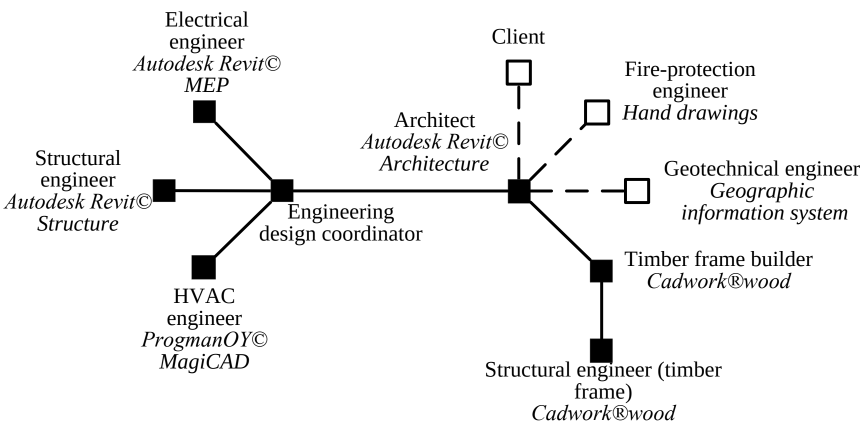


FIG 1. Project configuration

In the case project, the architect designed the project using architectural design software (Autodesk Revit© Architecture). The electrical engineer used software suited for mechanical, electrical, and plumbing engineers (Autodesk Revit©MEP), the structural engineer used software suited for structural design (Autodesk Revit©Structure), and the HVAC designer used software developed for building services (ProgmanOY©MagiCAD). The electrical, structural, and HVAC designers worked for the same firm and they received their modeling information via an internal server. The firms involved in the design of the timber structure used customized software for timber construction (Cadwork®wood). All of the aforementioned programs have in common that they allow for the creation of virtual models that could be joined to a common building model. The geotechnical engineer created a virtual terrain model by using a Geographic Information System (GIS) and, in parallel, they used a 2D drawing system to create their drawings (AutoCad). The CAD system was, however, not designed for the creation of parametric objects. The fire-safety engineers created hand sketches to provide their services. A detailed map of the information systems deployed within the case project can be found in Figure 1.

4.2. Organizing vision

For the functionality of an IOIS such as BIM, it is of critical importance that the actors involved agree on the aims and functions of the IOIS through the development of a shared organizing vision (Lyytinen and Damsgaard, 2011). A shared organizing vision is a cognitive model of how to organize the inter-organizational structures and processes (ibid.).

Specially designed building contracts are regarded by many researchers as an essential means to create a shared organizing vision of BIM. Such contracts could specify, for instance, the role of each participant in the shared system, the role of the model manager, design detail limitations, and could resolve issues related to the intellectual property held in BIM. However, the parties in the case project worked based on traditional design-bid-build contracts. Their contracts did not address the routines of working together in a shared IOIS in any way. The agreed design deliverables were tender documents consisting of 2D drawing packages and the accompanying documentation. The actors had binding dates for the delivery of the tendering documents. The architect stated that in not establishing a strict arrangement surrounding the BIM model, the design collaboration had been convenient for the actors, as they were not forced into rigid working routines:

> "… for this project at this time it is easier to use what is easy to use for the consultants than to force everybody into a specific way of working, which would maybe be strange to them, or where they would not have experience from before." (Architect)

Beyond contractual arrangements, there are other, less formal, means for creating a shared organizing vision towards working in BIM. The instruments used in the case project for aligning the design activity were bi-weekly, design team meetings. These meetings aimed at resolving design issues along the way and actors voiced what design information they would need from which party at what time. According to the architect, these meetings created a dynamic and open communication among the parties involved. Further, the architect stated that these meetings did not create a strict and rigid routine for drawing and collision checking in BIM, but rather allowed for discussing solutions together. However, due to the geographical dispersion, not all the relevant actors were able to attend all of the design meetings. Alternative possibilities for participating in the design meetings such as videoconferences were not available. The architect was quite satisfied by the way in which the project communication was organized, as the manner of communication was left open and was dynamic:

> "I am kind of satisfied because, as I explained, for us and for many, this project was kind of for the first time, so to leave the way to communicate open and dynamic … and in a way we tried that out on the way as we went along … now I am happy not to have been forced into a very strict routine of drawing and collision checking in Revit from the very beginning, and a full BIM kind of design process, and so on." (Architect)

Neither the contractual arrangements, nor the design meetings were deliberately designed to create a shared organizing vision toward working together with BIM. Moreover, our interview data did not provide evidence for the existence of a shared organizing vision of BIM. This finding is supported by actors stating that they did not have any idea about the design tools that other actors had used to create design contributions. Moreover, actors stated that the modalities of design communication had not been up for discussion:

> "I knew what the architects use and I know what we use but what the timber frame contractor uses, I haven't got a clue." (Engineering design coordinator)

> "In my experience, I have only had a talk with one of them [other actors] a few times as to how the communication should be. So, usually, we do not talk about this." (Drafter timber frame builder)

Not all project actors shared the architect's positive opinion about the way in which the project's communication channels were organized. The absence of a shared organizing vision for BIM was perceived by some actors as a hurdle for effective communication. The timber frame builders, for instance, argued that the ill-defined BIM communication resulted in misunderstandings among the actors:

> "I know when we started off with that program we had a lot of intentions but maybe because we are a small company […] but still we are talking of a well-known architectural company … but I find that communication is not defined enough … there have been misunderstandings already, so again it's sort of mailing things back and forth; it's really the same old thing." (CEO, Timber frame builder)

The fire-protection engineer voiced the opinion that inter-organizational arrangements should not be overly complex and demanding. Nevertheless, he stated that the communication in the case project might have benefited from a clearer understanding of how to interact:

> "I have been on projects with much more control, and with much less control, and I have to say that it should not be too demanding and there should not be too many rules. But in … [this project] … we would have benefited maybe from a slightly clearer understanding of how to interact." (Fire-protection engineer)

The engineering design coordinator stated that it would have only taken a little more effort and precision by the actors to align the communication and to make the project a full-blown BIM project. However, they decided not to pursue the alignment of communication routines because they were not sure who was going to pay for the additional work required to run a fully functional BIM system:

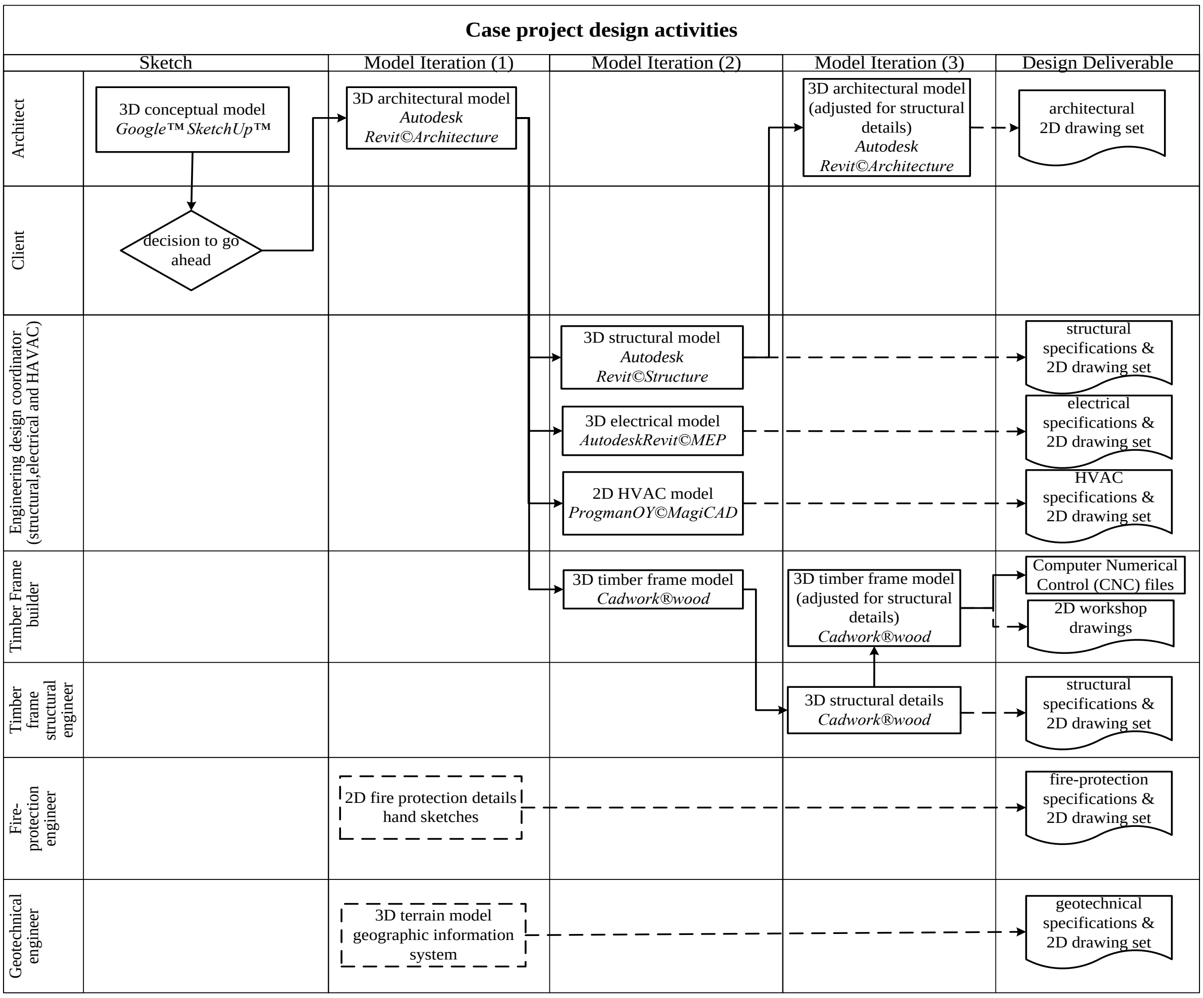
> "It's not that difficult [to run a full BIM], you have to be a little more precise, you need a little more effort. […] The clients have to be willing to pay for the extra work that we do." (Engineering design coordinator)

The parties in the case project did not establish a shared organizing vision for their BIM system. Moreover, no evidence could be found about any efforts that had been undertaken to create such a shared vision. We found that the actors had different opinions about the significance of a shared organizing vision for BIM. Some actors regarded the creation of an organizing vision as counterproductive for free and dynamic project communication (architect). Others regarded the absence of an organizing vision as counterproductive for effective BIM collaboration (timber frame contractor). Some regarded "overly" strict arrangements of inter-organizational processes as counterproductive for information exchange, while acknowledging that some regulations are needed to allow for effective communication (fire-protection engineer). Some actors were concerned about the additional costs for intensified design collaboration (engineering design coordinator).

4.3. Key functionality

The key functionality of an IOIS describes the scope and content of data exchanges and their related business functionality (Lyytinen and Damsgaard, 2011). Therefore, the key functionality of a BIM system, at the inter-organizational level, can be identified by assessing the extent of its usage in facilitating inter-organizational data exchange. Rooted in the interviews taken, we analyzed our case project with the objective in mind of understanding just how much the project communication was shaped by BIM technology. We present our findings by a narration of communication events arranged according to their occurrence throughout the design phases. The chart in Figure 2 presents an overview of the design activities undertaken by the project actors and the software used, encompassing all phases from conceptual design-to-design deliveries onward. The full lines in Figure 2 depict the de facto exchange of modeling data, whereas the dotted lines illustrate occasions of 2D CAD data exchange.

FIG 2. Project design activities



In the early design stages, the architect deployed 3D sketching software to develop and visualize the building's envelope and form (Google™ SketchUp™). These early sketches were used to create a mutual understanding between the client and the architect of what the building would "be like" once completed. The sketches were presented at meetings and formed the basis for discussion. Once the early stage concepts and sketches matured to the stage where they were mutually agreed upon, they served as a foundation for the architectural design. The architect imported the sketching files into the architectural design software that was used from that point on.

The architect deployed architectural design software to create a virtual model of the buildings' shape and outer appearance (Revit® Architecture). Once the buildings' shape and envelope had been completed, the architect plotted the model into IFC files, and transmitted them to the structural engineer, the electrical engineer, the HAVAC designer, and the timber frame builder. The architect produced 2D drawing sets and transmitted them to the fire safety and geotechnical designers, who did not deploy BIM-ready software. The communication between the architect and the other parties concerning the developed model was facilitated by snapshots of the model and hand sketches presented at the design meetings:

> "I used SketchUp to take snapshots of my model and I used, of course, hand drawings and sketches … just in a way to get along, and try to show what we are thinking, and so on. So, it's kind of dynamic, the way we like to do it. It is the fastest way to do it by hand and a quick sketch in a way—for more complex things I would maybe use a SketchUp model as a background for the sketch I make by hand, and so on." (Architect)

The structural engineers used the received architectural model as an envelope for their design work. They imported the received IFC file into their structural design software and used it as an under-layer while creating their own models. The structural designers were experienced BIM users and they did not face any interoperability problems when importing and using the architectural model. Throughout the design process, the structural designers transmitted their models to the architect. The architect incorporated the changes suggested by the structural designers into the architectural model.

However, the majority of the design information between the structural engineer and the other parties was exchanged at the regular design meetings, or via other channels such as mailing back and forth snapshots of their model. Once the structural design had been completed, a 2D drawing package and the accompanying structural calculations were delivered in print and pdf format to both the client and the architect. Like the structural designers, the electrical engineers used the architectural model as a template for their work. The following statement by the engineering design coordinator illustrates that the architectural model was used as an under-layer through which to position the electrical installations:

> "Now we need BIM just as an under-layer as an xref in dwg, etc. We use it to place our components. Find out where we are going to put cables, etc., etc. And, this is then printed out when needed." (Engineering design coordinator)

They had no issues incorporating the architectural model into the electrical design software. However, unlike the structural designers, they did not deliver a completed electrical model back to the architect. The electrical designers used the regular design meetings and mailed back and forth snapshots of their model to align their design work with others. Upon completion of their design, they delivered a 2D drawing package and a list of components to both the client and the architect. The argument for not delivering a model to the other actors was that the lack of complexity in terms of the buildings' electrical design did not require such an exchange:

> "… we haven't been doing that in this project for the technical installations, it's a quite simple project, it is not necessary to do a lot of collision controls because we don't have what you call a large cable routing." (Engineering design coordinator)

The HAVAC designers decided to use architectural 2D drawings instead of the architectural model as the reference frame for their work. The decision to use 2D drawings over 3D models was taken based on the firm's prior experience that working in 2D would require less resources and would be faster than working in 3D. Like the other designers, the HAVAC engineers relied on the design meetings and e-mails to share their design and to receive information concerning integration. When their design was finalized, they submitted a set of drawings, accompanied by building systems' specifications in 2D to both the client and the architect. The argument given for not creating 3D models was that the designers were confident that 2D models would be sufficient for the project:

> "If we just have an ordinary project that is not really complex, and we have a good feeling, then we use MagiCAD because it's much faster to draw with." (Engineering design coordinator)

The timber frame builder was appointed early on in the project due to the owner's preference for using prefabricated wood elements as the main building material. In this respect, the design of the building's shape had to be optimized for the use of prefabricated elements. Therefore, the timber frame builder had a considerably large share of the design activity. Moreover, the decision to execute the project as four-story timber buildings made it necessary to appoint a structural engineer who specialized in timber structures. The timber frame builder's drafter received the architectural design as an IFC file and decided to use just the geometrical information provided in the architectural model. Therefore, they stripped the model of its information by transforming the received IFC file into a Standard ACIS Text (SAT) file, which left nothing but geometrical data behind. The reasons for this practice can be attributed to the actors' differing levels of precision, detail, and foci in terms of the modeling process:

> "I do not know if it's because they [the architect] are not trained enough or if they do not have the right focus, but it seems like always the model is sort of too much [detail] ... there is a lot of rubbish you are not able to use. So, in the end, you sort of only take over the geometry." (CEO, Timber frame builder)

Just as did the other designers, the timber frame builders relied heavily on the information provided in the design meetings. However, their designer was not able to attend to all of the design meetings. The contractors developed a model with the purpose of precisely drafting all of the buildings' wooden components so that they could be machined. They used their model to create Computer Numerical Control (CNC) files, which could be read by their machinery. The timber frame contractors delivered neither their model, nor a set of workshop drawings to any external party other than the structural engineer appointed to handle the timber structure. The structural engineer appointed for assessing the stability of the timber structure, communicated exclusively with the timber frame contractor. After having received the model of the timber components created by the contractor, they returned models of structural details, and a report accompanied by structural calculations to the timber frame contractor. The structural engineer (timber frame) did not participate in any of the project's design meetings, as their firm was located in Switzerland, and the meetings took place in Norway.

The main information exchange was facilitated by traditional means such as meetings, 2D drawing sets, and mailing back and forth snapshots of the models. In support for this, we quote the timber frame construction firm's CEO, who stated that the overall BIM information exchange had been much of the "same old thing," and that it had not worked sufficiently well:

> "Now it feels like it always has been, that somebody might have different models and might have been working on the façade of the building, and they are doing that in SketchUp because that is easier for this, or they write something in a pdf and send that over, and then he is doing his changes to the model, and comes back, and it's not working." (CEO, Timber frame builder)

Several actors opined that the functionality of the project's BIM system might have benefited from a shared BIM server infrastructure, which was not established for the project. However, even though several actors were aware of the importance of such an infrastructure for the BIM system's functionality, no party took the initiative in setting up a BIM server. The following statements show that several actors would have liked to have worked with such a platform, but no party felt responsible enough to actually establish a server:

> "It is normal to use a web hotel to share drawings on the Internet and we have not had it. So, that was some kind of drawback. Often we see that it is the client that in a way demands it or supplies it, that web-hotel solution thing, a server, a system. (Architect)

> "Maybe they [the other participants in the project] should have just made a Revit site in the web where everyone could link in their models. And, everyone could update his information day by day, for instance. And, when someone does a change, one gets notified." (Engineering design coordinator)

> "… as long as people keep on sending things back and forth with e-mails you never get this … because the basic idea is, of course, that you are going to work on the same model, as long as you do not have the same IT platform, you would never do that." (CEO, Timber frame builder)

The overall key functionality of the BIM system in this project can be described as a system of "automation islands." By the term "automation island," we refer to the fact that the actors use their systems only rarely to communicate with each other. Designers used BIM technology as a mere enhancement tool for their individual design processes and exchanged full-fledged models only on rare occasions. The main information exchange between these "islands" was facilitated by traditional communication tools such as snapshots of the models and presentations at regular design meetings. According to the actors interviewed, the key functionality of the BIM system could have been significantly enhanced by the establishment of a shared BIM server or platform to facilitate the information exchange.

4.4. Structure

We define the structure of a shared information system, such as BIM, as "the scope and volume of structural relationships among participating organizations" (Lyytinen and Damsgaard, 2011, p. 498). The structure may vary from simple didactic relationships to complex industry wide hubs. We argue that the structure of the BIM system in the case project can be best described as a hub and spoke configuration. A criterion for labeling an IOIS as a hub and spoke configuration is that the system spans a single industry and involves at least three adopters (ibid.). The case project's configuration consists of six BIM adopters and all of them work in the architectural, engineering, and construction industry.

A second criterion for labeling the structure of an IOIS as a hub and spoke constellation is the presence of a central "hub" or "middleman" coordinating the activity and information flow within the IOIS. In the case project, the organizational roles regarding the BIM were not clearly assigned. However, we argue that the architectural firm acted, at least to some degree, as a central “hub” in the BIM system, since they communicated with all the other actors via the BIM system (except for those who had not adopted the technology). Ergo, “one-to-many” BIM communication with the architect as a central actor took place in the case project. Moreover, the architect’s firm received all of the firm’s designs in paper form, virtual models, or drawing sets. A visualization of the “hub” and “spoke” constellation within the case construction project can be found in Figure 1.

When interviewing the structural engineer (timber structure), we found that their entire information flow was facilitated by the timber frame builder. The structural engineer (timber structure) stated that their role in this project was somewhat special, as they were used to taking a more central role in project communication. They argued that their decision of mainly relying on the timber frame contractor to manage the project communication was firmly rooted in language difficulty issues. They were used to communicating in German, whereas the other parties were communicating in Norwegian. The timber frame builder, however, had positioned a bilingual designer, speaking both Norwegian and German, at project level. However, a second reason for entrusting the timber frame contractor with their project communication was put forward by the structural engineer. They argued that a participation in bi-weekly project meetings in Norway would have been too costly due to their firms’ geographical location in Switzerland. No digital means such as video conferences were deployed to facilitate the project meetings.

Three organizational actors—namely, the client, the fire-protection engineer, and the geotechnical engineer (depicted by the white square in Figure 1)—did not actively participate in the case project IOIS, as they did not have BIM modeling systems in place. The geotechnical engineer stated that they did not deploy systems that were able to integrate GIS data into BIM models. The fire-protection engineer stated that s/he designed the fire-protection details by hand; however, they had acquired a BIM software license to explore the system’s usefulness for fire-simulations in future projects. The client stated that they did not deploy BIM systems in their work.

4.5. Mode of interaction

The mode of interaction defines the nature of the business relationships among the organizations, as defined by the IOIS. In the previous section, we argued that the case project’s BIM system resembles a “hub and spoke” configuration. In addition, we stated that the architect acted as a “middleman,” facilitating the BIM information exchange in the case project. This is our point of departure for discussing the relationships among the actors in the case project.

Typically, the role of a central “middleman” in an IOIS is enforced by both technological capabilities and formal power. Within the case project, however, the architectural firm had the technological capabilities to take ownership and establish routines and guidelines for integrating the business processes surrounding BIM, but no formal power to do so. The lack of formal power can be explained by the absence of contractual agreements specifying the power dependencies among the actors participating in the BIM system.

Moreover, organizing a shared information system is time consuming and costly, and the architectural firm had no financial incentives to commit resources to organizing the shared BIM system, again, due to the absence of a binding contract. This holds equally true for the other parties in the project; none of these had any financial motivation for engaging in a collaborative, BIM-enabled design. This finding may explain the observation that neither the architect, nor any other party attempted to align their systems by creating a shared organizing vision, or by motivating other actors to work in a certain way.

Even though the case project’s BIM system was far from being fully functional, it is evident that it was used for design, and that it facilitated some of the project communication. After having ruled out financial incentives and contractual obligations as motives for the use of BIM as a shared system, a possible explanation for its actual use is that the parties used the system voluntarily. A reason might be, for instance, that the actors regarded BIM technology as important in effectively executing their individual design tasks.

When studying the prior historical relationship among the actors, we found that most had a long history of working together. In this respect, many actors knew each other personally from previous projects, which created a working atmosphere best described as a “partnership amongst equals.” When asked, most of the actors were satisfied with the project communication levels. Moreover, some stated that the informal nature of interaction and the absence of strict formal arrangements and hierarchies in using BIM benefited the overall collaboration in the project.

Actors can be forced into IOIS interaction through powerful companies trying to reap benefits from using a shared system. In a BIM project, a powerful actor such as a large client's organization could, for instance, require a virtual model for its purposes. A forced mode of interaction is defined by Lyytinen and Damsgaard (2011) as a "conflict" mode. The client's organization in the case project, however, was more or less indifferent toward which design technologies would be deployed by the designers to create the buildings' design. Moreover, when asked if it was of any importance in terms of which digital design tools designers deployed to create the buildings' design, the client's CEO responded that only the buildings' appearance and their physical qualities were of importance, and the way in which this was achieved was of less importance:

> "No, but it [the building] has to look new and modern and so on." (CEO, Client)

Thus, we argue that the interaction in the case project's BIM system happened informally and voluntarily, and no obligatory and hierarchical relationships between the actors could be identified. Lyytinen and Damsgaard (2011) refer to a voluntary mode of interaction as a "matching" mode. A matching mode can be best described as an "electronic partnership for virtual business integration" (ibid., p. 501), with no single actor seeking a dominant position in the system. Thus, we argue that the mode of interaction in the case project's BIM system can best be described as the matching mode.

4.6. Mode of appropriation

Organizational actors attribute different significances to BIM technology. These attributed significances or appropriations of technology shape the actors' participation in a shared system. A way to identify organizational appropriations of BIM technology is to identify what kind of attention is paid to IT, in general, or BIM, in particular, in their organizational strategies. Several of the actors interviewed stated that their firms were actively involved in screening the market for technological innovations that would be useful in terms of improving their work. The following statement by the architect highlights the actors' interest in using modern technology:

> "… of course, so we are looking out for new technologies and applications to help us do what we are doing every day." (Architect)

To understand the actors' attitude toward innovative technology, including BIM, we asked them how they would evaluate the innovativeness of their firms when compared to others in the industry. Most actors considered their firms to be innovative and to be among the leading-edge firms within their respective disciplines in the Norwegian marketplace (i.e. structural, electrical and HAVAC engineers, timber frame builders, and geotechnical engineer):

> "There are many good people in good firms out there and I believe that we are up there in the top, for instance, this is the first project we are running on MagiCAD and MEP for electrical systems, and I don't believe that there are many companies in Norway that use this software at the moment." (Engineering design coordinator)

> "I do not think that you will find today another [timber frame] company in Norway that is able to build a project like this." (Drafter, Timber frame builder)

> "The company is very competent in our discipline, where a lot of experience and personal skills make us among the best. This statement is also based on feedback from clients based upon questioning them as to how satisfied they are with our work. This company was, if not the first, one of the first consultant companies to implement BIM for building design." (Geotechnical engineer)

In addition, we asked the interviewees whether their organizations had formulated strategic goals toward using BIM technology in their operations. In addition, we found that, for instance, some of the firms had established practical guidelines for working in BIM and had set the goal of participating in as many BIM projects as possible:

> "Yes, absolutely, we have a very clear strategy toward BIM projects. We want to get involved in as much of the BIM projects as possible. Big, big, BIM projects." (Engineering design coordinator)

"… this company is based on technology; it's based on the 3D model, that is the whole idea." (CEO, Timber frame builder)

However, to understand the significance attributed to BIM technology at the project level, we considered it valuable to ask the individual designers drawing hands on with BIM tools to what extent they considered BIM technology as important for doing and sharing their work. Most of the interviewees replied that they saw improvements when using this technology related to the clarity, accuracy, and visualization of the design information shared:

"We understand better when we see things in 3D." (Geotechnical engineer)

"It makes it much easier to understand where you are; you can see the heights and "ah, ok it's like this" instead of just having a 2D drawing. But, then again, it's more difficult to draw in a model. You have to be more precise, you can't do any cheating. No easy solution." (Engineering design coordinator)

"It is a big difference, of course, that we are kind of building a model with parametric objects—it's not only lines, it's a window model, and you are taking this information out of the model afterwards, and we get, in a way, schemata for windows and doors and so on, and all these things, so that is maybe the biggest difference. It's sort of simplifying the process of making the documents for the building." (Architect)

"I have lots of both good and bad experiences and frustrations, and I also see some hopes for the future." (Design manager, Timber frame builder)

Maybe the clearest indicator for the organizational appropriation of BIM systems is to observe their behavior at project level. For instance, most project actors created virtual models, even though they would have fulfilled their contractual obligations by delivering 2D drawing sets created in traditional 2D CAD software. According to the engineering design coordinator, it would just have taken a little more precision and a little more effort to run this project as a full-fledged BIM project. Moreover, most of the drafters had been trained by their employers in designing with BIM software and were experienced users. Thus, we argue that most actors in the case project attributed a high significance to BIM technology.

However, there were some exceptions as the fire-protection engineer, the geotechnical engineer, and the clients' organization did not deploy BIM technology at all. Moreover, the HAVAC designers decided deliberately to design in 2D, even though they had the competence and software in place to create 3D virtual models. The client's appropriation of BIM technology was low when compared to the other actors. When asked if they would be willing to pay extra for receiving a virtual model once the design was completed, the client's CEO stated that they did not need a model:

"Nope, we do not need it [a virtual model]." (CEO, Client)

5. DISCUSSION

Our findings make it possible to understand why the case project's BIM system functioned in the way in which it did. An overview of the key findings of our analysis can be found in Table 3. We found that many actors had substituted their old 2D CAD systems with the new BIM technology. In addition, the BIM software applications deployed at project level were technically interoperable and the actors attributed a high significance to the new technology. Thus, we argue that several preconditions for a fully functional BIM system have been met in the case project. However, the inter-organizational processes in our case project still resembled, in essence, traditional, 2D working routines. This finding is in line with earlier research arguing that many processes surrounding 2D CAD are institutionalized and taken for granted in construction projects (Baxter and Berente, 2010). Moreover, it is widely accepted that it is not easy for actors to separate their work practices from the underlying logic of 2D design (ibid.).

Our findings led us to conclude that replacing old technology with new, and concurrently leaving old processes intact leads to the emergence of "automation islands." By the term "automation island," we refer to the fact that actors use the new technology predominantly to automate old design processes rather than to substantially transform the way in which they communicate their designs. This reflects an untapped potential similar to that which was pointed out in early reengineering literature (Hammer, 1990). Our findings thus support the argument made in contemporary literature that BIM's "transformational capability" to change the way construction organizations do business is frequently left untapped (Ahmad and Sein, 2008; Ahmad et al, 2010).

TABLE 3: BIM adopter configuration in the case project

Adopter configuration element	Case project's adopter configuration
Organizing vision	• Neither formal nor informal arrangements toward BIM have been established • No attempts to create a shared organizing vision could be identified • Actors simply did not know with what software the others worked • Actors used standard design-bid-build contracts • No evidence for the existence of a shared organizing vision of BIM
Key functionality	• Full-fledged BIM models were only exchanged on rare occasions • Actors mail back and forth snapshots of their models • Main information exchange via meetings and other traditional means • The BIM applications in use are technically interoperable • Three actors did not deploy BIM-ready design tools • No shared BIM server or IT platform • Overall 'dysfunctional' BIM system • System of 'automation islands'
Structure	• One-to-many BIM communication evident • 'Hub and spoke' constellation with the architect as central hub • Three actors could not participate in the system
Mode of interaction	• Hub role enforced by architect's technical capability • Hub role not enforced by formal power • Hub had no financial incentives to coordinate design • Spokes had no financial incentives to work in a shared BIM system • Interaction can be described as a "partnership among equals" • Client as powerful actor was indifferent about BIM use • Actors' use of BIM voluntary to improve individual design processes • 'Matching' mode of interaction
Mode of appropriation	• Most actors attributed a high significance to BIM technology • Client did not attribute a high significance to BIM technology • Actors had personnel trained to design in BIM • Actors had up to date BIM applications in place • Actors' organizational strategies enforce the use of BIM systems • Most actors perceived themselves as leading-edge innovative firms in Norway

Literature reports that transforming design practices requires significant departures from established practices beyond simply substituting technology (Baxter and Berente, 2010). Moreover, it is well-established knowledge that a fully functional BIM system can only be achieved by changing a set of contractual and organizational arrangements toward working together in BIM (Whyte and Lobo, 2010). We add to this literature by suggesting that, based on our findings, a "shared organizing vision" toward BIM is an essential precondition to changing old design practices.

Despite having well-trained people, up to date software, and interoperable systems, the actors in our project made no attempt to create such a vision. Our findings allowed us to understand that actors need a clear understanding of what can be gained by operating a fully functional BIM system before they will engage in changing inter-organizational processes.

Practitioners in our case project had conflicting views about the business value of operating a fully functional BIM system and aligning their processes. First, the architect opposed strict working routines toward BIM, arguing that this would hinder free and dynamic design expression. Second, the engineering design coordinator opposed the alignment of processes. They argued that running a fully functional BIM system would require more design precision and additional work, which would be costly. Third, the client was indifferent toward the functionality of the BIM system. Fourth, the timber frame builder was in support of a fully functional BIM system. This actor's work required a high level of design precision and detail. Last, there were actors who expressed an interest in participating in the BIM system without having the technical capabilities of doing so (geotechnical engineer, fire-protection engineer). We claim that the presence of many different, and at times, conflicting organizational interests in BIM's functionality led to actors retaining their old processes at inter-organizational level.

Further, we found that project actors did not actively question their traditional communication routines and that they communicated little about the way in which BIM should be used to facilitate their inter-organizational communication. Thus, we argue that this absence of meta-communication about BIM could be an alternative explanation for the emergence of the automation islands. For the purpose of our paper, we define meta-communication as "all exchanged cues and propositions about (a) codification and (b) the relationship between the communicators" (Ruesch and Bateson, 1951, p. 209). Given the earlier mentioned conflicting organizational interests toward a fully functional BIM system, we find it surprising that inter-organizational routines were not up for discussion. We argue that a fully functional BIM system only comes within reach if actors actively discuss and agree on the modalities of BIM communication.

However, our work has limitations, rooted in the key characteristics of the project under study. First, we developed our view on configuration analysis based on a single case study and interviews with a selected sample of the project participants. Even though we argue that our findings have relevance beyond the case project studied, additional research studying multiple projects and contexts is needed to further validate this. Second, some of our findings may be attributed to the type of construction project studied; namely, a residential project. The client in our case project developed residential apartment units to sell them shortly after completion. We argue that the client had little interest in a fully functional BIM model, since they were not concerned with the operation of the completed building. Arguably, clients involved in projects in which they have to operate the building throughout its life cycle (e.g. commercial, industrial, or infrastructure projects) might have a stronger interest in a fully functional BIM system. However, this claim needs to be validated by further research. Second, some of our findings may be attributed to the degree of complexity of the construction project. The three buildings constructed were similar in design and size (e.g. design repetition). It made the design and construction less complex. Therefore, arguably, a fully functional BIM system might be less relevant in this context. However, the relationship between BIM and a building's complexity needs to be examined. This is an interesting future research avenue. Thus, further research should analyze multiple projects differing in type and complexity by using the configuration analysis lens to identify the major weaknesses in today's BIM practice and how they can be resolved. In addition, our analysis pointed to the need for further research on the business value of BIM beyond the study of first-order effects such as BIM's impact on scheduling or cost accuracy. Moreover, further research should seek to explain how multiple actors could overcome conflicting organizational interests to transform the process of construction design.

6. CONCLUSIONS

We have shown the usefulness of configuration analysis as a theoretical model to analyze, explain, and understand the BIM-enabled interaction in a construction project. Throughout our analysis, it became apparent that the structured analysis of the key elements constituting an adopter configuration could lead to a holistic understanding of actors' behavior in a shared IOIS. Our work has established that it is not a given that a set of well-trained, BIM-ready organizational actors makes use of BIM to jointly develop design solutions. Moreover, we found that the actors have diverse opinions about the benefits of a fully functional BIM system. Thus, our article complements and reinforces existing research on BIM adoption by providing an insight into the communication practices and the areas in need of managerial attention when BIM is used for integration in digital construction design projects.

Our findings illustrate several weaknesses in existing practice in terms of integrating BIM business processes. While most actors had substituted their old design technology with BIM, we found that they still created their virtual models largely in isolation, instead of collaborating effectively. The organizations thus substituted old technology for new BIM technology without transforming inter-organizational structures and processes. We therefore argue that leaving old, cross-organizational processes intact leads to the emergence of "automation islands."

In terms of practical contribution, we argue that our study complements the current development on BIM adoption. Scholarship on BIM adoption has, to date, been largely focused on the technical requirements of BIM, and on the definition of new standards for information exchange, but less on the inter-organizational practices surrounding the modeling activity (Dossick and Neff, 2011). By conducting a configuration analysis, we were able to point out both leadership decisions and communication practices that were required to enable a fully functional BIM system: the creation of an organizing vision, overcoming conflicting motivations, and the active discussion of BIM modalities. We identified several aspects where improvements might be possible. Improvement is possible by creating a shared organizing vision toward working together in BIM. In this respect, actors need to discuss desired communication outputs and the role of ICT in facilitating such communication. Furthermore, actors need to mitigate for discontinuities caused by different languages, firm location, and technical capabilities. They could, for instance, use shared information systems such as videoconferencing tools and online repositories to exchange drawings, models, documents, and information surrounding the BIM model. Moreover, a "critical mass" of actors needs to be convinced about BIM's business value at inter-organizational level to make it work. In our case project, with only one actor (the timber frame builder) expressing an organizational interest in a fully functional BIM system, this "critical mass" was not reached. In this respect, project actors need to identify and discuss what might be gained by operating a shared system. Especially those actors who are interested in a functional BIM system, should actively seek discussion, and build coalitions with others having similar interests. Naturally, the aforementioned improvements are only within reach for BIM adopters. However, we did identify that some designers in today's practice continued to struggle in terms of overcoming the technical hurdles to BIM adoption. Especially, issues related to the integration of BIM and GIS, and other advanced engineering systems remain unsolved.

We developed our view on configuration analyses by exploring a single construction project. While we argue that the chosen case is typical for projects in the AEC industry with regard to the actors involved and the actors' digital modeling practices, our findings need to be validated beyond the project studied. Thus, we recommend further research analyzing multiple project types and complexities using the configuration analysis lens. Further, we recommend research exploring how conflicting organizational interests in a fully functional BIM system can be overcome.

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