Temporary interorganisational collaboration practices in construction design - the use of 3D-IT

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Abstract

Literature has studied how new information technology can influence routines and practices. However, few studies discuss how practices are impacted in a temporary interorganizational cooperation project. In this paper, the main question is how 3D modeling IT influences temporary intergoranizational cooperation practices in the Architecture Engineering and Construction (AEC) industry. The study has focused on four projects in the AEC industry that work in the design phase and in which multiple firms and disciplines are involved for a short period of time to deliver a design. The study is a comparative case study analysis based on interview material (25 interviews) and observations (22 hours). The study contributes to literature in three ways: (1) the study gives an insight in practices concerning how 3D-modelling IT is a boundary object primarily during meetings, but not outside the project meetings or over multiple project boundaries (2) Boundary objects are used in combination with other artifacts. (3) Within the meetings (face-to-face and online meetings) the 3D-modelling IT supports crossing multiple spaces.

1 Introduction

The architecture, engineering and construction industry (AEC) industry often works in temporary structures, i.e., project-based organization forms, in which several organizations cooperate on a particular project for a limited period of time. Literature in this field discusses the difficulties of learning over project boundaries and the sharing of capabilities and knowledge between the different project partners (Bosch-Sijtsema & Postma, 2009). The knowledge needed in order to perform these projects is often dispersed across firms and sometimes even geographical locations. Therefore, firms build up temporary project networks of engineering specialists from multiple firms and locations, i.e., project networks (Boland et al., 2007; Alin et al., 2013) and project members work partly distributed and meet face-to-face or online in project meetings. The specialist knowledge within these project networks is often practice based, situational, sticky and locally embedded which makes it more difficult to collaborate across structural, cultural and spatial boundaries. Boundaries are defined as sociocultural differences that give rise to discontinuities in interaction and action (Akkerman & Bakker, 2011). Even though many state that projects are temporary and partners in the projects change, literature has also stated that especially the construction project-based industry is strongly subjected to institutionalism and there is little variation in the organization between different projects (Kadefors, 1995).

Recently, new developments in information technology (IT), i.e., Building Information Modeling (BIM), in the industry have opened up for discussions to re-think and re-organize the interorganisational collaboration projects (Froese, 2010; Hartmann & Fischer, 2007), and develop new practices for collaboration and information sharing between firms in construction projects. This study focuses primarily on construction design, which comprises a multifaceted process in which a variety of stakeholders cooperate and there is a constant exchange of information and knowledge (Chiu, 2002; Gray and Hughes, 2001). These stakeholders often come from multiple organizations supplying specialist knowledge for the design project. Within the AEC industry multiple studies report on the difficulties of sharing knowledge, information, communicate and creating a shared understanding in these inter-organizational projects (e.g., Dainty et al., 2006) and crossing these boundaries between multiple disciplines, roles and organizations becomes an important element for design work. Organizations can develop competences in spanning boundaries of different professional fields or between organizations and these competences might be embedded in practices of the organizational members (Levina & Vaast, 2005; Orlikowski, 2002). Boundary spanning is supported by particular roles, i.e., the project manager in these design projects (Bosch-Sijtsema & Henriksson, 2014) or also enabled by artifacts and technology through boundary objects (Boland et al., 2007; Henderson, 1991). However, few studies focus on practices of spanning boundaries in temporary interorganisational cooperation and how IT, in this case 3D-IT, influences the cooperation. In this study the focus is on *how IT (i.e., BIM) influences temporary interorganizational cooperation practices in the AEC industry*.

The remaining structure of the paper as is follows. The following section discusses the theoretical background of the research. Section three presents the methodology and data collection and analysis of four case studies in construction design. In section four the findings are discussed and the paper is concluded with a discussion section in which the findings are related to the literature.

2 Theoretical background

The AEC industry often works in project teams in which the knowledge needed to develop a design for a structure is often distributed over multiple disciplines and organizations. When looking at knowledge work based on distributed knowledge, several articles lift up the relevance of space (i.e., Bosch-Sijtsema et al., 2009; 2011; Fruchter, 2005; Hautala & Jauhiainen, 2014; Peschl & Fundneider; Vartiainen & Hyrkkänen, 2010). Especially in the context of knowledge creation, knowledge is not only created through interaction, interpretation as well as related to the context or spaces of creation (Hautala & Jauhiainen, 2014). There has been a strong focus in literature on the physical space or the workspace which looks at how a workspace could be developed, how workspace supports productivity, work, as well as cooperation (cf. Cairns, 2002). However, for interfirm projects, distributed over different organizations and disciplines and who only meet for short periods of time, the physical workspace is not the only space of importance for knowledge creation. Recently, more and more attention has been paid to different types of spaces and from this literature four types of space are often categorized (Bosch-Sijtsema et al., 2009; 2011; Fruchter, 2005; Hautala & Jauhiainen, 2014; Peschl & Fundneider; Vartiainen & Hyrkkänen, 2010): (1) a physical or object space consisting of the material environment as well as a physical space for geographical proximity. (2) A social or communicative space focuses on formal and informal interaction either one or two-directional of project members, or between individuals and an artifact. (3) A mental or cognitive space comprises mental models of individuals or shared mental models of a team. Finally, (4) a virtual or technology space for interaction and connection via technology means, i.e., via email, video conferencing. These spaces can overlap but have been argued to be of importance for distributed knowledge in project work (Bosch-Sijtsema et al., 2009; 2011; Vartiainen & Hyrkkänen, 2010).

The development of a 3D modeling tool (BIM) as a new IT-platform has been argued to support sharing of information, visualization, as well as interaction between project partners. Literature has lifted up a number of benefits of this IT in terms of supporting innovation, development of new work practices, effectiveness and efficiency (Froese 2010), as well as supporting collaboration in the design phase (Moum, 2010) and enabling a closer integration and communication between different stakeholders in a project (Hartmann and Fischer 2007; Jaradat et al. 2013). Furthermore, BIM supports visualization through 3D models, which has been shown to support interaction and knowledge transfer in project-based work and construction (Bosch-Sijtsema and Henrikson, 2014; Henderson, 1991). The technology of BIM might be perceived as a boundary object that can support knowledge sharing over the different spaces.

Boundary objects are a concept in understanding how IT based artifacts can support the development of boundary spanning competence (Levina & Vaast, 2005). Furthermore, the creation and management of boundary objects is discussed to be a key process in maintaining and developing coherence across multiple disciplines and even organisations (Star & Griesemer, 1989). BIM can be perceived as an artifact, or boundary object, enabling interaction and sharing information across organizational boundaries (Carlile, 2002; Star & Griesmer, 1989). The visualization part of BIM has been perceived as an artifact of knowing, which is a symbolic representation through which ideas are articulated, developed and exchanged and which facilitates the generation of multiple interpretations (Ewenstein & Whyte, 2007). The use of visual communication through 3D IT can support sharing of embedded knowledge and sharing and developing of work practices (Boland et al., 2007; Ewenstein and Whyte, 2007; Henderson, 1991; Nicolini, 2007).

Perceived as an artifact, BIM can be defined as a boundary object. A boundary object can interface providing a flexible environment containing multiple understandings, while remaining sufficiently robust to offer a common point of reference (Star & Griesmer, 1989). Literature concerning IT as boundary objects has focused on the object itself, and their role as translation devices that enable collaboration and knowledge sharing across diverse organizations (Henderson, 1991; Carlile, 2002), or facilitating cross-boundary negotiation and coordination (Alin et al., 2013; DiMarco et al., 2012). Other literature discusses interaction the boundary enables and the relation to organizational identity (Gal et al., 2008; Levina & Vaast, 2005). However, research has also found that IT may provide challenges in the transitions to and between IT systems (Gal et al., 2008). Especially, in transition periods the designated boundary object, which is named as valuable in boundary spanning in terms of design and properties, is not always the boundary object in use and incorporated into practice (Levina & Vaast, 2005).

However, studies focusing on virtual or geographically dispersed teams show that IT related boundary objects are ineffective and are in need of face-to-face interaction or a visual component in order to span boundaries (e.g., Alin et al., 2013; Sapsed & Salter, 2004; Whyte & Lobo, 2010). The visualization element of BIM, which is supporting multiple interpretations, is seen as an important part of an effective boundary object, but only in combination with real time communication (Alin et al., 2013). While many studies primarily focus on a single boundary object, Whyte and Lobo (2010) discuss a digital infrastructure in large AEC projects comprising multiple categories of objects like objects, models, maps, standardized forms and repositories. The different categories are related to earlier work of Carlile (2002) who discusses different categories of objects.

3 Method

The study applies a social constructivist practice based approach (Leonardi & Barley, 2012; Orlikowski, 2000), and compares four contractor led construction design projects. In order to study interorganisational collaboration practices and the use of IT, not only interviews were held (25 interviews), but also structured observations (22 hours of observations) based on a clear observation guideline were performed. The structured observation guideline was based on Fruchter & Bosch-Sijtsema, 2010. The observations can give unique insights into the day-to-day working practices (McDonald, 2005), and data was collected through extensive notes, photographs and the structured guideline. Next to observations, semi-structured interviews (25 in total) were held with members from the case study projects, management roles, and organizational IT managers.

Table 1: Overview of project cases.

Projects	Description	Size	Observations	Interviews
BoStu - 6 firms	Concurrent engineering, detailed design apartments	11 (6 contractor, 5 external)	2 meetings (of 5 h each)	6 interviews
BoPre - 3 firms	Concurrent engineering, conceptual design apartments	8 (6 contractor, 2 external)	1 meeting (5h)	4 interviews
BoDes - 9 firms	Concurrent engineering, detailed design apartments	14 (6 contractor, 8 external)	1 meeting (6 h)	6 interviews
ScanInf - 1 firm, 4 locations	Geographically distributed project, detailed design road	13 (total)	1 meeting (2h)	9 interviews
			23h - 5 meetings	25 interviews

All four case studies are based on construction design projects, which were managed by a contractor firm (contractor-led) with duration of 4-9 months. In these type of projects the management is structured in such a way that the owner or client works directly with a contractor who coordinates subcontractors. The AEC industry is known to work in interorganisational projects for designing and building a structure. The projects studied in this study are all relatively smaller projects and primarily focus on the detailed design stage. In this phase earlier schematic design decisions are worked out in greater detail and a clear description of all elements of the design including architectural, structural, mechanical, plumbing and electrical is developed in combination with cost, energy efficiency and constructability. The first three cases are focusing on the design of a building while the fourth case is an infrastructure project. In the first three cases (BoStu, BoPre, BoDes) the contractor worked with a more integrated or concurrent design approach, which is also sometimes called extreme collaboration (Garcia, et al., 2004). In such a way of working, project members meet once a week for a full workday in a shared workspace. All stakeholders of the project are present and participate in collaborative planning, decision-making and problem solving. The stakeholders often present at these full workdays are owner/client, site manager for construction, project leader, BIM coordinator and various subcontractors like the architect, structural engineer, heating, ventilation and air conditioning (HVAC) representatives and electricity representatives. In the physical space in which these teams meet, there are visual methods for sharing planning, information sharing and 3D representations of the design. In all three cases the design teams consisted of project members from the contractor firm as well as external consultants with specific expertise, or an external client. The different project partners only meet face-to-face once a week for the full day working meeting, during the rest of the week they either work on other projects or work at their own company with their specific project tasks.

Case ScanInfra is not working with a concurrent design procedure because they are working with a large geographically distributed team in both Sweden and Norway and have online video conference meetings of 1-2 hours for sharing information and decision making. Problem solving and design work are not performed during these meetings, but performed at the different locations outside of the online meetings. Case ScanInf was a geographically distributed team across 4 locations in Sweden and Norway; they held shorter meetings supported by video conferencing, BIM and other IT. Case ScanInf was an internal organization team, however, the subsidiaries they worked with had different nationalities and organizational identities.

The study is part of a larger research project and the analysis of the data comprised of multiple methods. The observational data analysis both focused on interaction between members, and between members and the 3D modeling tool. Furthermore, the observations contained sketches and photographs of the physical location, discussions, decisions that were made, and activities performed. The interviews support the observations in terms of increasing understanding of the observed meetings as well as gain an insight in the work performed outside of the meetings. The interviews and part of the observational material were coded thematically.

4 Findings

All four cases worked throughout the design with 3D IT. The use of 3D-modelling IT was performed in their own disciplinary designs in their own firm - some disciplines use particular software to be able to design and draw particular elements, i.e., architects and HVAC disciplines. Furthermore, all teams used the 3D models during their project meetings for (1) clash detection sessions - in which all models of all disciplines are combined and the project members can see if there are any clashes between the different designed elements, (2) to support parts of the discussion during design with help of visualization. The findings are related to the four different spaces mentioned earlier in the literature section and how 3D modeling IT can support to cross the boundaries and spaces of a multi-firm cooperative project.

4.1 Crossing communication space - new communication practices

In the AEC industry there are particular practices who communicates to whom and when in a design project. Through the implementation and use of 3D-modelling technology, the communication lines and practices between the different disciplines, roles as well as involved firms have changed. The use of the 3D model requires new input and different type of data from the different firms involved, which opens up for new lines of communication. One example is mentioned below:

> *But then this changes too this with cost estimation, we must take out estimates of material. This is based on the architect's model, so this implies that the cost estimater and the architect have some contact with each other because the architect can suddenly understand how you take out the amount of material from the model. The cost estimater takes out the quantities based on the order in which the project will be built. - So here is a contact that has never ever happened before. The*

*two (*architect and cost estimater*) have not spoken to each other at all. It is actually a deeper understanding in which the architect is involved from the early stages and presents different proposals to the stage that he talks with the cost engineer in which order one should build this and design the project thereafter.* (Contractor BoStu)

Others discuss that the use of BIM supports communication and coordination between the different firms and project members.

I think there are a number of built-in drivers in BIM for you to work and communicate in a different way. You do not land in the various documents, but it is a continuous process. The client is more involved, you share files often and it is more accessible to each other. You become more a group than seperate individual efforts since all members coordinate everything, starting from the same model, so there are many incentives for you to work more closely together and communicate better. (Consultant BoDes).

In ScanInf they mention clearly that participants who work in the 3D models are often not the same persons with specific knowledge (including embedded knowledge) and also not always the person who is making design decisions in the different firms. This is also perceived in some of the other projects, i.e., BoStu where junior architects draw in the 3D model and a senior architect makes the design decision during the face-to-face meeting. In both these projects new communication line are developed between the project members, the senior consultant and the person responsible to draw the design elements in the 3D model.

Another problem is that the person who is drawing in the model is not the same person as the one who is calculating which in turn is not the same person who is deciding. So the person who is changing in the model has to be in contact with the person who is deciding. Phone contact wouldn't do it because mostly it is not possible to give permission without seeing the problem more closely. (ScanInf).

Therefore, in the interview they state that by using this IT in practice, and making changes in the 3D designs, project members of the different firms need to be in contact with each other to understand the impact of changes in the model for other disciplines as well as for the final decision makers. This finding is similar to statements of BoDes and BoStu who see the importance of closer communication concerning design.

4.2 Crossing cognitive space - different expectations on BIM use

From all the data it became clear the BIM was mentioned as being used in all design projects, but during the observations joint practices concerning the use of BIM were not always clear. From the interviews and observations it became clear that project partners and firms had different expectations on managing information and responsibilities. These differences in expectations might come forth out of the institutionalized way of working within construction projects without BIM, or through the practices present at the parent organization. Especially in case BoStu it became clear that project partners had different expectations on BIM information in terms of what information is needed, or how the quality of the information should be, or who is responsible for decisions concerning information and data in the BIM model during the design process. Applying BIM in the projects lifted up that roles, responsibilities as well as accountability were changing in relation to 2D drawing practices. Within the project, the project partners mentioned these differences during the interviews. The BIM coordinator in the project lifted up some of these issues from a contractors perspective. During a clash detection session in which the team went jointly through the model, questions arose concerning basic practices, measurements and who is changing what element in the model.

In ScanInf (internal project, but geographically distributed), these discussions were already further ahead and they were developing and applying new practices concerning responsibilities and accountability of particular parts of the 3D models. In ScanInf the partners all work in the same type of software and build up the practice to share information, what to do when one makes changes in the model, and note down in the model who is responsible for a particular change in the 3D model. These practices were newly initiated and developed within the group and members shared a model on how to work with 3D modeling technology.

4.3 Crossing multiple spaces

BIM-use in conjunction with other artifacts

Interviewees discussed that the use of 3D models and visualization of the models helps to share the models and information about the design in a better way and increases understanding between the different disciplines involved in the project. In the physical space in which projects BoPre, BoStu and BoDes were working, members mentioned that they gained a better awareness of the other disciplines through working with the 3D modeling technology. Members showed their own disciplinary specific 3D model in the project as well as the joint 3D model in which all disciplines were combined.

> *You can see how other disciplines are working in the project and how they design their parts of the structure.* (Architect BoPre).

Furthermore, in all observations the 3D-model was used in conjunction with other visual tools like 2D-drawings and sketches in order to discuss the design. For example in project BoPre, it became clear that through the use of multiple visualization means (both the 2D drawings and 3D models) the different parties involved could explain particular aspects of the design; design problems were found through visualization; alternative solutions were lifted up by several parties and drawn on the white board through the 3D-model projection; and finally a decision could be made with an alternative drawing on the whiteboard concerning how to deal with a particular design problem. It was especially the combination of various artifacts that supported the joint problem solving. However, it was through the 3D visualization of the design, that project members could discuss different perspectives and interpretations and could clarify these through the use of various other artifacts. Below is an example of an observation of BoPre.

Table 2: Observational data from project BoPre

Activity		Artifact
PM walks towards projected 3D-model.	PM goes to projector and shows where they are in the 3D-model Discussion on particular item (staircase) - '*is this correct, and even possible?*' Client states this is a problem and is not according to regulations. PM and client start a discussion towards architect and structural engineer if this is legally correct or not.	3D model on projector Requirement specifications
Architect (external) walks towards whiteboard and projected 3D model	Architect shows how and what concerning this problem (points to projected model) and tries to explain in more detail: '*Now we take it very easy*' he says. Client and PM state once more that they are almost sure that this is not allowed - not a safe structure. Architect states: '*then we have a problem - that needs to be changed'*. The architect starts to make notes concerning this. All move towards the PM (location) (client, structural engineer, and architect) and go through the 2D-model on paper (not the projected 3D model). Trying to see how this was designed on the 2D model and how they can solve this issue. Together they follow the 2D drawing and discuss this.	3D model on projector Whiteboard 2D drawings Requirement specifications
Structural Engineer walks towards projected model Architect walks towards drawing	Structural engineer starts developing (drawing) a solution on the whiteboard behind the projected 3D model. Architect discusses this solution together with the structural engineer. Both point and draw on the whiteboard behind the model as well as next to the model to clarify a new solution.	3D model on projector Whiteboard 2D model Notes

and projected model	The whole group agrees on the new solution and the PM makes the final decision that they will continue with the new solution in the design.	

In the example above the project members use the physical space for being able to work and design a construction together during a longer period of time. They use the social space to interact both with the project members as well with the multiple communication and technology means (technology space) in order to create a common understanding of the particular design issue (cognitive space).

Boundary spanning in practice

Many discuss the importance of the BIM model coordinator (as seen in all case studies) for managing information and communication in the project. The BIM coordinator is the role that combines the 3D-models of all the different disciplines into one model, makes clash detections and analysis, and navigates through the model during the project meetings. The implementation of BIM can support new roles, but also changes the content as well as the responsibility of existing roles. From the observations (especially case BoDes and ScanInf) it became clear that the change in roles also brought a change in power in the team. During the BIM meetings in ScanInf, the BIM coordinator is organizing and leading the meeting and is in control of navigating through the 3D model. Furthermore, the BIM coordinator specified important points that need to be discussed and decided upon with help of the clashes detected in the model. Clashes found in the 3D model steer the discussion. From the observations it became clear that members who are knowledgeable and experienced in working with BIM became boundary spanners in practice during the meetings. This happened in BoDes and ScanInf in which the BIM coordinator became a boundary spanner and in BoPre and to some extent in BoStu in which the structural engineer, knowledgeable with 3D modeling, took the active role of facilitation and spanning boundaries in terms of asking questions, interpreting and requiring information and visualizing this with the model, and supporting joint decision-making with help of the 3D-model.

However, on the other hand in BoStu, the BIM coordinator failed to become a boundary spanner and this was reflected in confusion, lack of understanding, and discussion concerning the 3D design and how to work with the design. In the observations of BoStu when external firms in the disciplines of electricity and ventilation went through the BIM model with help of a BIM coordinator of the contractor firm, there were at least a number of times that the external firm representatives were not able to recognize were the BIM coordinator was in the model and had difficulty following the navigation through the model. The representatives of the external firms had to ask for 11 times for explanations of the particular viewpoint.

The boundary spanner in these cases could support to cross the multiple spaces concerning physical, communicative, and cognitive space with help of the 3D modeling technology as artifact.

4.4 Multiple projects and work outside of the project meetings

In the construction industry often many firms work simultaneously in multiple projects. The cases, except for ScanInf were all smaller projects and in the cases of BoStu, BoPre, and BoDes many of the different disciplinary consultants (i.e., structural engineering, architecture, HVAC, electricity) worked simultaneously in two or more design projects with different partners. These members mentioned clearly that they had difficulty participating full days in project design meetings (concurrent design meetings). Several members in BoStu and BoDes discussed that when they worked in multiple concurrent design meetings for full days, they felt they lost touch with their parent organization as well as discussions and sharing knowledge with peers in their own discipline and own firm.

Another element found in the data was that many external firms (not the contractor) worked with their own IT system and BIM software in their parent firm. Even though in the projects BoStu, BoPre and BoDes the firms could work with their own software, this was not the case in other parallel projects these firms were working in. In some projects, the contractor or client choose the type of software the collaborating firms could work in. One architect mentioned:

> *As an architect we are sometimes forced by the contractor or client to change 3D software programs and to know several different 3D programs. I am now working in multiple programs and this is very complex. All these programs are different, complexity is high, and they are very difficult and time consuming to learn (BoDes).*

Furthermore, it was also found that the 3D modeling IT supported interaction and design work during the meetings - either co-located or distributed meetings - through applying BIM with other work methods, drawings, planning methods, and tools. It was important that the models and methods that were applied were visual to all members for both face-to-face (BoStu, BoPre and BoDes) as well as online meetings (ScanInf). However, outside of the project meetings when project members worked in their home office or with other projects, BIM was not used for collaboration and was not a boundary object for crossing knowledge and spatial boundaries. Although members worked with other tools, e.g., phone, project network and email, the main knowledge transfer between the different project partners was done during the meetings.

5 Discussion and conclusion

The study has primarily looked into the question of how 3D modeling IT influences temporary intergoranizational cooperation practices in the AEC industry. The study has focused on the design phase in which multiple firms and disciplines are involved for a shorter period of time. The study contributes to literature in three ways: (1) the study gives an insight in practices concerning how 3D-modelling IT is a boundary object primarily during meetings, but not outside the project meetings or over multiple project boundaries (2) Boundary objects are used in combination with other artifacts. (3) Within the meetings (face-to-face and online meetings) the 3D-modelling IT supports crossing multiple spaces.

5.1 Boundary object in multi-firm projects

The AEC industry is known for its project-based way of working in which multiple firms collaborate temporarily and research discusses the complexity and difficulties of interorganisational collaboration in this context. The implementation and use of the IT platform BIM is argued both in literature as well as the industry, to support information sharing, communication and collaboration between firms in such projects (Froese, 201; Hartmann & Fischer, 2007; Jaradat et al., 2013; Moum, 2010). Studies have shown that IT based artifacts can be seen as boundary objects supporting boundary crossing (Gal et al., 2008; Levina & Vaast, 2005; Whyte & Lobo, 2010). However, other studies discuss that these objects are less effective for geographically distributed project teams and they require face-to-face interaction or a visual component (Alin et al., 2013; Sapsed & Salter, 2004; Whyte & Lobo, 2010). From the findings discussed above it became clear that the 3D-modeling technology was a boundary object during the meetings - either virtual or face-to-face, primarily because the technology provided a visual element which supported the discussion between different disciplines and partners. However, outside of the meetings, the technology did not support boundary crossing because many partners worked with their own software important for their particular discipline. Furthermore, the joint model was not used outside of the meetings as communication means. This finding is in line with the earlier mentioned literature that in particularly the visual element as well as the collaborative moment of a planned meeting are important for spanning boundaries. The cases BoStu, BoPre and BoDes tried to solve this by having weekly full day meetings in which all project members worked in a physical co-located space. During this particular time, the 3D modeling technology supported having multiple interpretations as well as jointly coming towards a shared understanding of the work practices and the final design, which is in line with literature (e.g., Boland et al., 2007; Ewenstein & Whyte, 2007; Henderson, 1991; Nicolini, 2007).

Another aspect that is often not taken into account in interorganisational collaboration practices for the AEC industry is the fact that engineering projects in Sweden are often small projects, and many firms are collaborating in multiple projects with different partners. In our cases these members felt challenges between priorities and time for their work in multiple projects, as well as a lack of identity towards their own peers in their own discipline or parent organization. This topic is somewhat discussed in multi-team work within organizations, but often neglected in interorganisational collaboration. The use of IT as boundary spanning object does not support multiple project collaboration but primarily focuses on single collaboration projects. The use of particular practices concerning BIM in one project or parent firm could even make it more difficult to build up practices in another project, which was reflected in the differences in expectations concerning BIM in use.

5.2 Combination of various boundary objects

IT can be perceived from the literature as a designated boundary object, however, from the cases the designated boundary object is not always the boundary object in use (Levina and Vaast, 2005). Especially in construction design multiple firms and multiple disciplines are cooperating in order to develop a conceptual and detailed design. BIM was shown to only support part of the boundary crossing process, but as shown from the data it was always used in conjunction with other means, e.g., sketches or 2D drawings. The combination of multiple visual means supported lively discussions, sharing of experiences and embedded knowledge (Bosch & Henriksson, 2014; Ewenstein & Whyte 2007). The boundary object as confirmed in literature changed per context as well as per problem that needed to be solved, however, multiple boundary objects were applied simultaneously in order to cross organizational, disciplinary as well as multiple spatial boundaries in the design projects. In especially temporary interorganisational projects it became clear that a combination of boundary objects used conjunctly were a ‘means of translation’ (Star & Griesemer, 1989) between multiple perspectives. These findings are in line with other literature in the AEC industry that discuss combinations of various boundary objects apply for crossing boundaries in multi-organizational engineering projects (Bosch-Sijtsema & Henriksson, 2014; Gal et al., 2008; Whyte & Lobo, 2010).

5.3 Boundary object crossing multiple spaces

Within the meetings (face-to-face and online meetings) the 3D modeling IT supports crossing boundaries between multiple firms, disciplines as well as spaces. The concept of different types of spaces has been used especially in literature concerning knowledge work as well as geographically distributed work to gain an understanding of how distributed knowledge in temporary projects is developed and shared (Bosch-Sijtsema et al., 2009; 2011; Fruchter, 2005; Hautala & Jauhiainen, 2014; Vartiainen & Hyrkkänen, 2010). The new technology of 3D-modeling IT supports the crossing between the earlier mentioned spaces in terms of communication space, cognitive space, physical as well as technology/virtual space. The new technology supported the development of new practices concerning communication space in terms of new lines of communication was formed. Furthermore, the technology opened up discussions concerning different interpretations and expectations on ways to work with the technology and in such a ways helped to cross the cognitive space towards a more shared idea of 3D modeling work practices. During the meetings, both face-to-face as well as the online meetings, the technology supported interaction, discussions, and information sharing between different disciplines. Primarily the visual element of the 3D modeling IT made it possible that members were able to discuss different insights and interpretations based on their own discipline, discuss these differences and make decisions on how to continue with the common design. Within the meetings observed in the four case studies, the 3D modeling technology can be a boundary object crossing multiple spaces in terms of physical, communication, cognitive as well as virtual/technology space. Furthermore, perceiving the 3D modeling IT as a boundary object can support the development of new work practices as well as reflecting on existing practices.

The findings also showed that the role of the boundary spanner becomes important to be able to support knowledge transfer between the spatial boundaries. Especially, the boundary spanner in use who was familiar with the technology became important in the case studies.

Future work could look into extending these presented findings and look into how interorganisational practices develop in smaller temporary multi-firm projects, how firms cooperate not only during the meetings but also outside of the project meetings. Furthermore, important would be to study the impact of firms working in multiple smaller projects and if there are particular interorganisational practices developed between the projects. Finally, the concept of space is often discussed in virtual team literature as well in architectural literature, but less focused upon in project management literature or interorganizational practices. It would be worthwhile to study how AEC projects could span multiple spaces during their knowledge work.

6 References

Akkerman, S.F. & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of educational research, 81*: 132-169.

Alin, P., J. Iorio & J.E. Taylor (2013). Digital boundary objects as negotiation facilitators: spanning boundaries in virtual engineering project networks. *Project Management Journal*, 44 (3): 48-63.

Boland, R.J., Lyytinen, K., Yoo, Y. (2007). Wakes of innovation in project networks: the case of digital 3-D representation in architecture, engineering, and construction. *Organization Science*, *18*(4), 631-47.

Bosch-Sijtsema, P.M., & L-H. Henriksson (online 2014). Managing projects with distributed and embedded knowledge through interactions, forthcoming International Journal of Project Management. DOI: 10.1016/j.ijproman.2014.02.005

Bosch-Sijtsema, Petra M., Renate Fruchter, Matti Vartiainen & Virpi Ruohomäki (2011). A framework to analyze knowledge work in distributed teams. *Group & Organization Management Journal*, 36(3), 275 - 307.

Bosch-Sijtsema, P.M., V. Ruohomäki & M. Vartiainen (2009) "Knowledge Work Productivity in Distributed Teams," *Journal of Knowledge Management,* 13 (6): 533-546.

Bosch-Sijtsema, P.M. & Postma, T.J.B.M. (2009). Cooperative innovation projects: Capabilities and Governance Mechanisms", *Journal of Product Innovation Management*, *26*(1), 58-70.

Brion, S., Chauvet, V. Chollet, B., Mothe, C. 2012. Project leaders as boundary spanners: relational antecedents and performance outcomes. International Journal of Project Management, 30, 708-722.

Cairns, G. (2002). Aesthetics, morality and power: design as espoused freedom and implicit control. *Human Relations*, 55: 799-820.

Carlile, Paul R. (2002): 'A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New product Development.' Organization Science, 13, pp. 442–455.

Chiu, M-L. 2002. An organizational view of design communication in design collaboration. Design Studies, 23, 187–210.

Di Marco, M., Taylor, J., Alin, P. 2010. Emergence and Role of Cultural Boundary Spanners in Global Engineering Project Networks. Journal of Management in Engineering, 26(3),

Engwall, M. (2003). No project is an island. Linking projects to history and context. *Research Policy, 32,* 789-808.

Ewenstein, B., Whyte, J.K. 2007. Visual representations as artifacts of knowing. Building Research Information*,* 35, 1, 81-89

Froese, T.M. (2010). The impact of emerging information technology on project management for construction. *Automation in Construction, 19*, 531-538.

Fruchter, R. (2005). Degrees of engagement in interactive workspaces. *International journal of AI and Society*, 19: 8-21.

Fruchter, R., Bosch-Sijtsema, P.M. 2011. The WALL: participatory design workplace supporting creativity, collaboration and socialization, AI & Society, 26, 3, 221-232.

Gal, U., Lyytinen, K., & Yoo, Y. (2008). The dynamics of IT boundary objects. Information infrastructures, and organizational indentities: the introduction of 3D modeling technologies into the architecture, engineering, and construction industry. European *Journal of Information Systems, 17*(3): 290-304.

Garcia, A.C.B., Kunz, J., Ekstrom, M., Kiviniema, A. 2004. Building a project ontology with extreme collaboration and virtual design and construction. Advanced Engineering Informatics, 18, 71-83.

Gray, C., Hughes, W. 2001. Building Design Management. Butterworth-Heinemann, Oxford.

Hartmann, T., & Fischer, M. (2007). Supporting the constructability review with 3D/4D models. *Building Research and Information, 35*(1), 70-80.

Hautala, J. & J.S. Jauhiainen (2014). Spatio-temporal processes of knowledge creation. *Research policy*, 43: 655-668

Henderson, K. (1991). Flexible sketches and inflexible data bases: visual communication, conscription devices, and boundary objects in design engineering. *Science Technology Human Values, 16 (*4): 448-473.

Jaradat, S., Whyte, J. & Luck, R. (2013). Professionalism in digitally mediated project work. *Building Research and Information*, *41*(1), 51-59.

Kadefors, A. (1995). Institutions in building projects: Implications for flexibility and change. *Scandinavian journal of management*, *11*(4), 395 -408

Karrbom Gustavsson, T., Samuelson, O., and Wikforss, Ö. (2012). Organizing IT in construction: present state and future challenges in Sweden. *IT in construction*, *17*, 520-534.

Leonardi, P. M. & Barley, S. R. (2012). What's under construction here? Social Action, materiality, and power in constructivist studies of technology and organizing. *The Academy of Management Annals*, *4*(1), 1-51.

Levina, N. & E. Vaast (2005): 'The Emergence of Boundary Spanning Competence in Practice: Implications for Implementation and Use of Information Systems.' MIS Quarterly, 29 (2), pp. 335–363.

Moum, A. 2010. Design team stories. Exploring interdisciplinary use of 3D object models in practice. Automation in Construction, 19, 554-569

Nicolini, D. 2007. Studying visual practices in construction. Building Research Information, 35, 5, 567-580.

Orlikowski, W.J. (2000). Using technology and constituting structures: A practice lens for studying technology in organizations. *Organization Science, 11*(4), 404-428.

Peschl, M.F., & T. Fundneider (2014 online). Designing and enabling spaces for collaborative knowledge creation and innovation: from managing to enabling innovation as socio-epistemological technology. *Computers in Human Behavior*, online article in press.

Sapsed, J. & A. Salter. 2004. Postcards from the edge: Local communities, global programs and boundary objects. *Organization Studies*, 25(9): 1515-1534.

Star, S.L. & Griesemer, J.R. (1989). Institutional ecology, 'Translations' and Boundary Objects: amateurs and professionals in Berkeley's museum of Vertebrate Zoology, 1907-39. *Social Studies of Science, 19*(3): 387-420.

Vartianen, M. & Hyrkkänen, U. (2010). Changing requirements and mental work-load factors in mobile multi-locational work. *New technology, work and employment*, 25: 117-135.

Volkoff, O., Strong, D., Elmes, M., Michael, B. (2007). Technological Embeddedness and Organizational Change. *Organization Science*, *18*(5), 832-883.

Whyte, J., Ewenstein, B., Hales, M., & Tidd, J. (2008). "Visualizing knowledge in project-based work." *Long Range Planning*, 41, 74–92.

Whyte, J. & S. Lobo. 2010. Coordination and control in project-based work: digital objects and infrastructures for delivery. *Construction Management and Economics*, 28(6): 557-567.