Managing projects with distributed and embedded knowledge through interactions

Citation for the original published paper (version of record):
Bosch-Sijtsema, P., Henriksson, L. (2014). Managing projects with distributed and embedded knowledge through interactions. International Journal of Project Management, 32(8): 1432-1444.
http://dx.doi.org/10.1016/j.ijproman.2014.02.005

MANAGING PROJECTS WITH DISTRIBUTED AND EMBEDDED KNOWLEDGE THROUGH INTERACTIONS

Petra M. Bosch-Sijtsema[*a], Lars-Henrik Henriksson[b]
[*]Corresponding author
[a]Chalmers University of Technology
Department of Civil and Environmental Engineering
Construction Management
SE – 412 96 Gothenburg, Sweden
+46-31-7721945
Petra.Bosch@chalmers.se

[b]Borealis AB
SE – 444 86 Stenungsund, Sweden
Lars-Henrik.Henriksson@borealisgroup.com

Abstract
In project-based industries studies show difficulties in extracting, distributing and applying embedded and practice knowledge across structural and organisational boundaries. We focus on interorganisational projects consisting of distributed and embedded knowledge. Interaction becomes important in order to cooperate and share interorganizational and distributed knowledge. The aim of the research is to explore how sharing and generating practice based and distributed knowledge occurs through interaction in interorganisational projects and how this is managed. The study focuses on the design phase and relates traditional design practices to concurrent design practices. In the study we observed six cases of design meetings in the construction and oil and gas industry and performed 31 interviews. The paper contributes with the following: (1) understanding and visualisation of interaction patterns, (2) insight in use of various forms of interaction, and (3) ways of managing distributed and embedded knowledge through interaction.

Key words: Managing Projects, Knowledge management, Engineering and Construction

1 Introduction

Changes in terms of globalisation, development of new information and communication technology (ICT) as well as economical crises have had an impact on ways of working in many industries. The focus has shifted towards knowledge work (KW) and how to improve knowledge work performance and thereby productivity. KW is the creation, distribution, or application of knowledge by highly skilled and autonomous workers using tools and theoretical concepts to produce complex, intangible and tangible results (Pyöriä, 2005;

Schultze, 2000). Although, there are different perspectives on knowledge, in this research we regard knowledge as situated and representing a social and collective phenomenon (Currie and White, 2012). From this perspective, knowledge is embedded in actions and practice and is an on going social accomplishment in everyday practice (Orlikoswki, 2002). Knowledge work is increasingly performed in cooperation with others in teams for complex tasks (Pyöriä, 2005), in multiple and changing contexts. Especially, in the case of project-based firms, in which complex projects are performed, often involving multiple organisations and disciplines, either collocated, or geographically distributed, it becomes difficult to share embedded knowledge. Team members working in these settings can simultaneously work in multiple projects with different members. The teams are closely embedded in a social system having fluid borders, working in changing and often temporary contexts with multiple actors. The knowledge in such projects often crosses over organisational, disciplinarial and sometimes geographical boundaries and is therefore perceived as distributed knowledge (Tsoukas, 1996). In this article we focus on the construction industry, which is an example of a project-based industry (Gann and Salter 2000). The industry works in projects, consisting of situated and distributed knowledge based on embedded practices, know-how, and organisational culture from multiple firms. From earlier literature we know that project-based industries have difficulties of extracting, distributing and applying knowledge across both cultural and structural boundaries (Bosch-Sijtsema and Postma, 2009; Prencipe and Tell 2001). The knowledge is sticky, situational and often locally embedded (Szulanski, 1996; Von Hippel, 2005), which makes it more difficult to collaborate in such settings.

The focus of our study is primarily on interaction in an interorganisational project consisting of distributed and situated knowledge. Interaction in this respect is perceived as human-to-human communication as well as human-to-artefact communication with help of various means (i.e., sketches, ICT, 3D models). Communication and interaction are perceived as indicators for project success in terms of knowledge work (Ramirez and Nembhard, 2004) and interaction is perceived as the process through which negotiations of meaning and co-creation of knowledge occur (Gunawardena, Lowe, and Anderson, 1997). Furthermore, the use of new communication means as well as information and communication technologies (ICT) can support part of the knowledge work.

However, literature also suggests that communication is one of the primary concerns in the construction project environment, as both structural and cultural barriers exist. These barriers hinder the transfer of information across and between professional and project boundaries (Dainty et al., 2006).

Our study focuses on the design phase in the construction industry. Construction design is a multifaceted process continuing to extend complexity due to the increase of specialist knowledge needed in the design phase (Gray and Hughes, 2001). As the design process in construction projects involves a variety of stakeholders, i.e., clients, architects, contractor, structural engineering, and heating, ventilation and air condition (HVAC), there is a constant exchange of information and knowledge needed (Chiu, 2002; Gray and Hughes, 2001). However, especially communication and transfer of information have been found to be problematic during the design process (Dainty et al., 2006). Research discusses in this respect; difficulties to create a shared understanding amongst all different players, a fragmented use of information and data (Anumba et al., 2002), lack of sufficient incentives for collaboration and communication, as well as ineffective cooperation due to unclear information dependencies (Senescu et al., 2013), and difficulties to share distributed and embedded knowledge throughout the project.

Many mention the development of new working methods like concurrent design (Anumba et al., 2002; Kamara et al., 2002), extreme collaboration in which different stakeholders come together in a particular room or space to collaborate (Garcia et al., 2004), and the use of new ICT and visualisation means as options to improve interaction between the different stakeholders. Several of these working methods focus on parallel processes, working in multi-disciplinary teams, and providing a working environment facilitated through the integration of various information and communication tools (ICT) that support these methodologies. Especially the focus on the use of space supporting social interaction is discussed as one school in knowledge management, i.e., spatial knowledge management (Earl, 2001). The use of space supports intertion, discussion and tacit knowledge transfer.

Studies have argued for knowledge sharing in project-based industries, but has focused to a large extent on the difficulties and complexity of sharing knowledge (Bosch-Sijtsema & Postma, 2009; Prencipe and Tell 2001). From knowledge management literature we know that sharing embedded and practice-based knowledge can be supported by face-to-face communication (Hislop, 2005) and the use of communication means like ICT. However, few studies discuss how distributed and embedded knowledge is shared over disciplinary and organizational boundaries in temporary cooperative projects. In this study we focus primarily on interaction. The aim of the research is to explore how sharing and generating practice based and distributed knowledge occurs through interaction in interorganisational projects and how this is managed. This research studies how a combination of concurrent and extreme collaboration work processes aided by a variety of visual communication means influence the interaction and information sharing of distributed knowledge in the project. We are especially interested in the interaction between the different project partners and relationships and how such distributed and embedded knowledge transfer and creation is managed and maintained.

The paper contributes with (1) understanding and visualisation of interaction patterns during design; (2) insight in use of various forms of interaction, and (3) ways of managing a distributed knowledge through interaction.

The article is structured as follows. In section 2, the literature concerning interaction in design teams is discussed as well as research on boundary spanning. Section 3 discusses the methodology applied for this study, which is based on a comparative case study analysis with observations and interviews. In section 4, the results are discussed and related to literature. Finally a conclusion with main contributions and future research is taken up.

2 Design Project Interaction

An important element for successful cooperation during the design process is the interaction within the distributed knowledge network consisting of different project participants and stakeholders. This interaction can be affected by both internal and external factors. Internal factors can be related to the interpretation and context of the message or medium through which is interacted. External factors impacting interaction can be the availability of tools and different types of interference or noise that can lead to misinterpretations, misconceptions, and confusion (Dainty et al., 2006). From earlier literature we know that many different aspects influence how information and knowledge can be shared within a project. However, for sharing embedded and distributed knowledge in a project consisting of multiple firms and stakeholders, the techniques, means and tools to support different types of interaction, e.g., visual communication, as well as ways of working and working culture are argued to be important.

2.1 Forms of interaction

Interaction is concerned with a dialectic process of acting, reacting, and interacting either based on human-to-human communication, or with support of a representation of methods and technology. Human-to-human interaction is discussed often in communication literature (e.g., Dainty et al., 2006), but also in human computer interaction literature (e.g., Gunawardena et al., 1997) which focuses more on means to support interaction. For sharing practice based and embedded knowledge, research discusses the importance of extensive social interaction processes (Hislop, 2005). Hislop (2005) discusses that this type of social interaction typically requires some kind of face-to-face interaction. In this article we primarily focus on synchronous interaction in which project members are able respond immediately either via chat, video conference, telephone, or in face-to-face meetings. One of the means to support interaction is through the use of visual communication means. Especially in sharing embedded knowledge and practices, the use of visual communication has been argued to engender innovations in technology, sharing and development of work practices, and supporting sharing of knowledge (Boland et al., 2007; Ewenstein and Whyte, 2007; Henderson, 1991; Nicolini, 2007). In construction design, the use of information systems, like 3D representations and visualisation software (i.e., Building Information Modeling, or BIM) is found to enable collaboration (Moum, 2010) and a closer integration and communication between different stakeholders in projects (Hartmann and Fischer 2007; Jaradat et al., 2013; Wikforss and Löfgren, 2007). These types of visual communication are components of the social organisation and the locus for practice situated and practice generated knowledge (Henderson, 1991). Some perceive the visual communication types as an artefact of knowing (Ewenstein and Whyte, 2007), while others discuss them as boundary objects (Gal et al., 2008) enabling interaction and sharing information across organizational boundaries (Carlile, 2002; Star and Griesmer, 1989).

2.2 Ways of work and working culture

Several authors discuss the importance of participative coordination structures between the involved members of the project network in construction (Eriksson, 2013) to enhance innovation and knowledge sharing (Bosch-Sijtsema & Postma, 2009). Recently, more attention has been paid to cross-functional teams to support joint problem solving and knowledge transfer among design and construction actors (Eriksson, 2013). This focus is supported by integrated work approaches like concurrent engineering or design (Anumba et al., 2007; Kamara et al., 2002) and extreme collaboration supported by ICT, and,adapted workspaces for cross-functional teamwork (Garcia et al., 2004; Hartman and Fisher, 2007). These type of work processes can support the rich social interaction processes important for sharing, creation, and applying practice-based knowledge between different project partners.

Next to the ways of working processes, also the working culture and institutions of both the network participants as well as the collaboration project plays a role. From earlier studies concerning interaction in construction design groups we know that the roles of individuals in construction projects influence how effectively they can communicate in a construction project (Dainty et al., 2006; Foley and Macmillan, 2005; Moore and Dainty, 1999). These studies reveal that the communication culture only enable a few particular roles to engage in the decision-making process, while the remaining are rarely involved. The interaction culture within the construction industry makes it difficult for design teams to work and collaborate effectively.

2.3 Crossing boundaries for embedded and distributed knowledge

Within organisations a myriad of networks intertwine (Akkerman & Bakker, 2011). These networks connect individuals within as well as outside the organisation. In our study we perceive these networks of relationships consisting of distributed and embedded knowledge in practice (Currie and White, 2012). Project leaders and members in design projects must be able to communicate with the different organizational partners involved in the project, i.e., the design team, the behind-lying organisations, production, and supply chain to overcome organisational boundaries (Dainty et al., 2006).

Due to specialization in organisations, these boundaries can become more explicit. In order to avoid fragmentation in communication and information, involved parties can bridge communication and organisational boundaries (Akkerman and Bakker, 2011). Team members who facilitate the exchange of information and knowledge exchange by bridging boundaries are referred to as ‘boundary spanners’ (Hoe, 2006; Peng and Sutanto, 2012), ‘linking pins’ (Organ, 1971), ‘coordinators’ (Katz and Tushman, 1979), and as ‘knowledge brokers’ (Currie and White, 2012). Boundary spanners assist the sharing of information and knowledge and thereby provide a competitive advantage through the facilitation of knowledge exchange (Peng and Sutanto, 2012). A boundary spanner can improve organisational efficacy by supplying information from internal and external sources, represent the ideas across boundaries to ensure stakeholder involvement, and the creation of value by establishing knowledge exchange between parties (Shantz et al., 2011). In practice, boundary spanning enables a quicker and more direct form of communication and thereby collaboration that increases the organisation or team efficiency (Di Marco et al., 2010). A project manager can be such a boundary spanner in particular contexts, such as obtain political support, protect the team, coordinate with external stakeholders, and search and supply information and ideas (Brion et al., 2012).

3 Methodology

The study applies a comparative case study analysis approach (Eisenhardt, 1989), in which we compare five different cases of detailed design meetings in the construction industry. The detailed design stage follows an initial design scheme (schematic design) where the schematic design decisions are worked out in greater detail. In this phase, a clear and coordinated description of all aspects of the design including architectural, structural, mechanical, plumbing, and electrical is worked out, as well as cost savings, energy efficienty, and constructability are determined. The detailed design provides drawings and specifications concerning the detailed requirements for the construction of a building. In addition, a case (6A and 6B) from the oil and gas industry is added as a reference case, as the industry has a long-term experience of parallel work processes and cross-disciplinary team work. In all cases the projects were contractor-led design projects, in which the management is structured in such a way that the owner or client works directly with a contractor who coordinates subcontractors.

In our study we primarily focused on the face-to-face/video meetings of the design projects. There was additional interaction via email, phone and intranet in between the meetings for sharing information, which we were unable to observe or follow. However, most problem solving and decision-making is performed during the meetings we observed. In order to explore the interactions within these six case studies (see table 1 for case study data collection methods) we applied a structured observation approach (see Fruchter & Bosch-Sijtsema, 2010). The data collection technique of structured observations can give unique insights into the day-to-day working practices and interactions (McDonald, 2005) and is an attempt to identify patterns (Farenga, et al., 2003). During the observations (30 hours of observations) we collected data through the structured guideline, extensive notes, and photographs. Next to the observations we held a number of semi-structured interviews per case study (in total 31 interviews). We held two types of interviews (a) project interviews (12 in total) were held in conjunction with the observations with project members present at the meetings, (b) firm interviews (16 in total) were held with members of the contractor firms who were leading the design phase in the projects, e.g., managers who implemented concurrent engineering principles in the firm, and managers who implemented new ICT (i.e., BIM) in the firm. In the interviews we asked about the role of the project leader, communication, commitment, coordination, different types of meetings, work processes and the ICT applied during design collaboration. The interviews were held between 30 minutes to 1.5 hours. Most interviews were taped and transcribed, but some project interviews were more ad hoc and careful notes were taken of these interviews. We selected the companies based on the fact that they clearly presented themselves in the media and/or on their company website as working with concurrent engineering or more extreme collaboration methods. Observations were divided over the two authors and NDA contracts with the three firms were signed. The authors are not related to any of the firms and entered the firms as academics.

We compared a number of different types of design events. Cases 1, 2, and 3 worked according to a more integrated approach (e.g., concurrent design approach), in which project members met once a week in a shared workspace for a full workday. In these events, project stakeholders are present including the owner/client, the site manager for the construction site, project leader, and ICT-BIM coordinator as well as various subcontractors like the architect, structural engineer, heating, ventilation and air conditioning (HVAC) representatives, electricity representatives (see figure 1-3 for the different roles in the projects). Furthermore, all stakeholder participate in collaborative planning, decision-making, and problem solving and stakeholders used these events to work parallel. In this event the project team worked in an extreme collaboration setting (Garcia et al., 2004) and used a number of visual methods like a shared planning activity and a shared information request/delivery activity. Furthermore, members were provided with facilities to access their own organisation files as well as the project intranet. Projectors were used to visualize the agenda, time-schedule, decisions, actions, as well as 3D representations of the designs. In case 4 and 5 the teams held design meetings that are more commonly used in the construction industry, i.e., traditional meetings. These meetings are primarily held for sharing information and decision making and last 1-2 hours. In these meetings not all stakeholders are present, only those who are able to make larger decisions. Furthermore, problem solving and design work is not performed in this meeting, but at the home office or in a separate working meeting with only a limited number of partners. In cases 4 and 5 there was at least one member and in case 5, a large group geographically distributed (see Table 2 for the team configurations of the case studies). These groups communicated with a shared file system and video conferencing tools. Next to these meetings we observed also clash detection work (case 3B, 4B, and 5) in which the project team goes through a 3D design model to see if different elements and disciplines clash in the visual model. This is performed once all different 3D drawings from all disciplines are joined in one model by a BIM (Building Information Modelling) coordinator. Finally we observed two meetings in another industry, the oil and gas industry (case 6A and 6B). In this case one traditional and one concurrent engineering meeting were held in the same project group. Both meetings of case 6 were supported by ICT (3D model, project information system, projectors).

INSERT TABLE 1 AND 2 ABOUT HERE

Data analysis:

The data analysis was performed in two parts. One part focused primarily on the interaction patterns within the physical meetings, while the second part focused more on the events occurring during design collaboration. For the second part of the data analysis we included observation data concerning the process, the activities during the meetings, the ICT and tools that were used, and the role of the project manager. Data was collected in notes, photographs, documents, sketches of the seating and work place. The interviews are used to support and explain the findings of the observations in more detail. The analysis of the interactions pattern between all the actors present during collaboration design events is performed through counting all interactions which are divided into four different groups:

1. Alone: There is no interaction with people in the group - but happens when a person is working alone, is on the phone, or working behind their computer.
2. Group: These are statements, presentations, callouts and interactions not directed to a specific individual, but more to the whole group. This includes interactions from the project leader in brief summaries, or non-directed statements.
3. Incoming: are interactions directed to the person in question, such as a direct question or a request.
4. Initiated: are interactions that are initiated by the person in question. This includes all questions directed to other persons initiated by this particular person.

From the transcribed interactions we developed interaction graphs per case study with all the different types of interactions presented in Microsoft Excel. Furthermore, the transcribed interactions were imported to develop a social network matrix using Gephi 0.8.2 in order to visualize the interactions patterns. The social network comprises of nodes, as entities within the network matrix, like the project leader (PL), and edges. Edges are interactions between nodes or to itself, like interactions between the project leader and an engineer. The edges are weighted by the amount of interactions occurring during the meeting. The visual layout chosen for the social network is the Fruchterman Reingold (1991) layout because this presents a good visualisation of the interaction distribution.

4 Findings

In order to understand the interaction and transfer of information and knowledge between members of a distributed knowledge network with embedded knowledge in practice, we performed observations as well as interviews. During the observations we looked at interaction distribution, as well as the ICT applied and other visual means for communication, e.g., drawings, sketches, other aspects provided in the working environment. Below we discuss empirically found forms of managing a distributed knowledge network through interaction in design teams. These forms are: integrating information through interaction (4.1); bridging towards all stakeholders (4.2); setting up and ensuring a supporting and stable work environment (4.3); bridging interaction through multiple communication means (4.4) and facilitation of the knowledge network.

4.1 Integrating Information through interaction

In all cases (except case 5), the project leader (PL) played an important role in integrating information within the project team as well as outside of the project team. In figure 1 and 2 it is clear that the PL initiates interaction to particular project members, and receives information back. Furthermore, in all the cases, the PL clearly searched and collected information from outside the project team, and this information were shared with the project team during the meetings and workdays. One of the firm interviewees of case 6 trained PLs to work in a more concurrent way and stated:

> *Some of the project managers compare it to being teachers where they need to pull on all lines to get input from everybody … in order to get the best of everyone to design a good product* (Firm interview case 6).

When we compare the interaction patterns of a more traditional design meeting (case 4A, 4B, 5, and 6A), with a more integrated or concurrent design type of interaction, there are a number of differences. From figure 1 and 2 it becomes clear that for the more integrated projects the distribution of interaction is more equally divided over all team members (see case 1, 2, and 3A). All team members are actively involved during the process as can be seen from the incoming and initiating interaction patters (figure 1 and 3).

INSERT FIGURE 1, 2 AND 3 ABOUT HERE

In the traditional meetings (see figure 2 and 3), the project leader has a major role in initiating interaction, decision-making and asking questions to participants in order to ensure all concerns being voiced (case 4A, 4B, and 5). In the more traditional design approach, interviewees mention that they have planning meetings, technical/engineering meetings, and 3D-clash detection meetings in which clash controls between different 3D models are performed.

In a more integrated design type of meeting all these different meetings are performed during one working day, while some team members can sit down with a part of the team for a more technical, planning, or clash detection discussion. From the observed interactions in figure 1 and 2, in these working days, most of the team members have a possibility to interact and share information with either part of the team or the whole team (see case 1, 2, and 3A and 3B). One member mentions the following:

> "*In a traditional design meeting, there will be only a short reconciliation of about half an hour maybe and then the team has to solve the rest in between meetings. But here* (in the integrated design work day) *all players stay and are available for questions and if there is an issue or question, you can receive the answer during the day. When they go from here*

in the afternoon they have received all information they needed and they do not need to chase the other so much during the coming week." (Contractor - case 1).

In the integrated design meetings most members were involved in the discussions, were committed to share their experiences and information, which was less the case in the traditional meeting type. Furthermore, the members were involved during the work and had a possibility to influence the discussions (see figure 1).

4.2 Bridging towards all stakeholders

In all cases the PL coordinated information, concerns, questions and requests with different stakeholders. In the more integrated projects, some of the external stakeholders were part of the project team, like the client and a representative of the production site (cases 1, 2, 3, and 6B). In these cases the representatives of the client organisation and production organisation communicated information and decisions made towards their own organisation. In figure 4 and 5 the interaction patterns of the different cases are shown in a Fruchterman Reingold layout. The role of the project leader is presented with a dotted circle. As can be seen from the figures 4 and 5 these external stakeholders in case 1, 2, 3, and 6B played an important role in the interaction distribution networks and exchanged situated practice knowledge with the project team.

INSERT FIGURE 4 & 5 ABOUT HERE

For the different stakeholders involved in the projects, it becomes important to connect to their home office and their external knowledge network. These connections are crucial for sharing knowledge, gaining information, solving problems, as well as recognition of a professional identity. In especially the more integrated workdays, the external stakeholders are represented more clearly and are able to collect input and distribute input, both within the project team, as well as towards the external network during the workday.

Although, the more integrated meetings show different interaction patterns and attention to stakeholder representation, it was also found that this representation could be taxing on some of the stakeholders. For example, the smaller players of external firms, often HVAC firms, mentioned that they worked in several design project teams parallel and sometimes they sat every day in another project, without having the possibility to report back to their home office, or share knowledge from projects with their peers (this was mentioned by four people). Some members mentioned that especially the connection to their home office and their external knowledge and professional community was crucial for their own professional identity and for sharing and learning new knowledge amongst their peers.

4.3 Setting up and ensuring a supporting and stable work environment

In all cases the project leader tried to set up a supporting environment for the project team. In the integrated work cases this was by providing a physical space, as well as guiding the team to use particular methods and means to support collaboration and interaction. Another important aspect for the integrated workdays was that it was important for a PL to be able to deal with conflicts, misunderstandings and confusion between the different project team members.

> "*The interpersonal work environment is more constricted in projects which have adopted a concurrent design process compared to normal projects. Therefore, conflicts within the project team have to be handled more quickly as it may derail the whole project team. A good project manager knows to adapt the conflict resolution style appropriately to mitigate damage*" (Contractor - PL case 4).

From the interviews it became clear that members viewed that in more traditional meetings several disciplines received unequal amounts of attention. This perception caused a lack of commitment of certain disciplines and players during meetings (4 people mentioned this). Furthermore, others mention that project members work in their own discipline, as a silo. Working in a silo had implications for not integrating their embedded knowledge and practice, and complicates coordination within the meeting as well as between meetings (9 interviewees mention this).

When discussing the integrated design working days, interviewees mentioned that their communication improved (stated by 5 people), their cooperation improved between team players (mentioned by 5 interviewees in case 1, 2 and 3), and that all players were more committed to the design work (3 interviewees from case 1 and 3 discussed this). Case 6 (see figure 3) from the oil and gas industry had long experience with using concurrent design approaches. One of their senior managers stated the following:

> *"It is even easier to see who has done their work and who hasn't and if there is anyone who has not understood the task or whether the person is overburdened and you can easier steer the project and provide everyone with the necessary help"* (senior PL, case 6).

Although, we primarily focused on the observed interaction patterns and not on the final outcome of the design, the interaction distribution is more balanced in the integrated workdays in relation to the traditional work meetings. The integrated work approach in which members have a work environment that supports visual communication, time for interaction, and face-to-face communication can facilitate the sharing of embedded knowledge based on practice. In a distributed knowledge network, consisting of embedded knowledge, the use of visual communication means and a supporting environment can cross the boundaries of such a knowledge network.

From the interviews we also found that the use of a more integrated design type of meeting could create a more unbalanced workload at times. In some meetings several disciplines were very busy, while others could work more on their own with their own computer and phone (this was mentioned by two people). Furthermore, especially in case 1, it was clear that such a type of meeting can set demands on actors in particular phases of the design process. In case 1 the architect was very occupied and initiated, as well as received a large amount of comments and requests, but had very little time to sit down and work through all these requests. Three interviewees mentioned that such a type of work process sets demands on particular players in the design team. Interviewees from case 1, 2, and 3 also discussed that sometimes project members needed to have quiet time to work on their designs and models or needed expertise from their back-office (mentioned by three people).

4.4 Bridging interaction through using multiple communication means

During all design meetings it is clear that visual communication means are important to support the interaction, discussions, and decision-making. However, in the more traditional meetings there is less time and possibility to utilize multiple visual means of communication and most information is placed on the internal project intranet. These more traditional meetings have a shorter duration and have members who are geographically dispersed (case 4, 5, and 6A), which makes it more difficult to use visual means. During the longer integrated work sessions, there are more opportunities to use various types of visual means of communication. In case 1, projection screens are shared with notes, the planning schedule, and the 3D model. While in cases 2 and 3 the planning schedule is placed on one of the walls, and most information is shared through the internal project tool online. During all integrated design workdays team members work with documents, 2-D drawings on paper, and computer models as well as rulers, calculators, laptops, and their mobile phones to call for additional information. Case 4, 5 and 6A work with a distributed team and share files, documentation, specifications, and the 3D model over an online link, next to a videoconference tool.

Even though, the team members use a number of different types of visual representation means, the use of 3D representations was mainly used during clash detection meetings and was only used limitedly during the work discussions. The 3D visual representation of the design and models was projected and navigated through on a projection screen. Many interviewees mentioned the potential and benefits of using 3D visual models:

> *Since we use a 3D-model, everybody can see where we are going with this project and you get a good interface between the disciplines … and we get a better progress of the work* (PL case 6).

From the cases we found that especially in the more integrated cases the project teams employed various means for visual communication in order to understand each other; explain particular aspects in more detail; and finally make decisions concerning the design. Especially, the combination of various visual means was important to share embedded knowledge of the different project network partners. The knowledge in practice was shared with the team members through visualisation, sketches, and markings in the 2D and 3D representations especially in the integrated design meetings. The more integrated design workdays supported cooperation and interaction through a combination of various sets of visual communication means.

4.5 Facilitation of the knowledge network

In case 1 a specific facilitator took the job to set up a supporting environment for the team, while in project 2, 3, and 6B this was performed by the PL. In team 5, the ICT coordinator was facilitating the meetings and took over the roles of the PL to some extent. Especially in the more integrated design meetings this facilitating role became more apparent.

A senior project manager mentioned that:

> "*The project manager is the facilitator ('getting the coffee'), facilitating the workflow and to ensure the knowledge and information distribution within the project team*" (firm interview of case 6).

In the clash detection meetings in which a 3D model was presented, the PL shared some of the coordination tasks with the 3D-model coordinator (case 4 and 5). However, in case of technical problems (case 5), navigation problems (case 3B and 5), or confusion and miscommunication (case 3B and 5) between disciplines, the project leader applied a supporting and facilitating role and kept close range on where they were in the 3D model (case 3B) or decided upon different strategies to go through the model (case 5). In especially the more integrated design meetings, the project leaders made sure that all disciplines were heard and committed during the work. They did this through asking questions, confirming, or giving specific tasks and actions to all knowledge disciplines.

In the design events the communication behaviour of the project leader can be perceived as facilitating communication between the different team players and disciplines. The project leader facilitates by reducing the noise and misconception interfering with the message. From our observations we found miscommunications during the verbal as well as during visual communication. In these events the project leader took a more active role, bridging the interaction between different disciplines. In addition, the involved parties reverted to using an established framework, a common ground, like drawings or a particular language (in cases 4 and 6 the participants reverted to English when there were misinterpretations) to reduce the misconception and resolve the issue.

5 Discussion

In all industries there are issues associated with the extraction, distribution and application of embedded knowledge. However, project-based industries are especially vulnerable due to their inherent deadline focused work process, which rarely enables a suitable and stable environment for knowledge work across structural and organisational boundaries. Therefore, this research aims to explore how sharing and generating practice based and distributed knowledge occurs through interaction in interorganisational projects and how this is managed. This study contributes to project management literature concerning managing distributed and embedded knowledge in projects in three ways: visualizing actual project interaction; managing through multiple forms of visual communication means and perceiving the project leader as a boundary spanner for distributed and embedded knowledge in interorganisational projects. These three contributions are discussed in more detail below.

One of the contributions of this research is the visualisation of the interaction distribution of the knowledge network of which the design team consists. With help of a visual interaction pattern of different types of meetings, we gain insight in the actual interaction during design meetings and in different contexts (traditional versus integrated contexts). The interaction patterns present a distinction between different set-ups for design teams, i.e. a traditional versus a more integrated way of working. The integrated way of work displays a higher interaction and overall commitment, which can provide opportunities to deal with the common problem in construction design teams of miscommunication and misinterpretations. Furhtermore, the integrated way of work also focuses on supporting a space in which participants can interact and share knowledge (cf. Earl, 2001). These findings are in line with literature discussing extreme collaboration (Garcia et al., 2004) and concurrent design (Anumba et al., 2002; Kamara et al., 2002), but give further insight in the actual interaction distribution. Furthermore, the interaction distribution lifts up the importance of different roles in the design teams. The findings contrast earlier literature, which states that only particular roles interact during construction design meetings (Foley and Macmillan, 2005; Moore and Dainty, 1999).

A second insight is the fact that the observed design teams used various means of interaction in order to manage information and embedded knowledge sharing in a project. The combination of multiple interaction forms was found to be important in order to share situated and practice knowledge of the different project network partners. Project management literature suggests that interaction is one of the primary factors for ensuring project success, which connects to the previous findings (Dainty et al., 2006). Especially the use of visual communication was used to facilitate communication, decisions, reduce confusion, and to expose and share embedded knowledge, which is confirmed in literature (Boland et al., 2007; Henderson, 1991; Ewenstein and Whyte, 2007; Nicolini, 2007). This relates to work in which visual means are the locus of practice situated and generated knowledge (Boland et al., 2007; Henderson 1991). The visual means could be perceived as a boundary object in distributed knowledge projects, providing opportunities and space to utilize different sets of interaction and visual communication means (Gal et al., 2008). The combination of different forms of interaction can provide insights for the project-based industry to support a variety of interaction forms including human-to-human communication supported by visual communication means during design through work processes, methods, tools, and workspace. In addition, it was found that the variety of visual communication means reduced the risk of confusion as it provided additional frameworks to develop a shared understanding.

A final contribution discusses how to manage a project consisting of distributed and embedded knowledge. In order to cooperate, manage and share knowledge in such a project, interaction plays an important role (Hislop, 2005). For managing the thransfer and creation of embedded and distributed knowledge, the research proposes a number of findings in which the project leader can be perceived as a boundary crossing role: in terms of (a) integrating information through interaction; (b) bridging towards all stakeholders; (c) setting up and ensuring a supporting and stable work environment for the project team, (d) bridging interaction through using multiple communication means, (e) facilitation of the distributed knowledge network. The interactions during the meetings show clear signs of the project leader taking a boundary spanner role (Brion et al., 2012; Aldrich and Herker, 1977; Levina and Vaast, 2005). These findings confirm earlier studies focusing on different types of boundary spanning activities (Brion et al., 2008). The project leader as boundary spanner acted as a knowledge hub, distributing the in-house experience as well as informing the team of knowledge and information from external sources. During the design meetings several different frames of reference and previous working experiences are encountered (Torrington and Hall, 1998) that sometimes make it more difficult to be open for communication. However, the project leader can bridge these boundaries of different interpretations, experiences, ways of working, and experiences by listening and proposing suggestions for collaboration and interaction. In this way the project leader is perceived as a boundary spanner in bridging interaction across knowledge disciplines, organisations, working cultures and between diverse team players (Brion et al., 2012; Di Marco et al., 2010). The more integrated design meetings not only showed the project leader as a boundary spanner, but also lifted up different project partners as new boundary spanners in particular topics or spanning particular boundaries towards the external network or mother firms for integrating information and bridghing towards certain stakeholders. Furhtermore, in the larger project 5 with geographical locations it became clear that multiple local project leaders took a more local project leader boundary spanning role. In such a way the integrated design approach as well as geographical distribution of a design project support a more distributed type of leadership during the meetings (Fitzsimons, et al., 2011). However, these distributed types of leadership only provided boundary spanning in particular activities (i.e., integrating information and bridging towards certain stakeholders), the project leader was still the boundary spanner for all the other elements discussed in this paper. The design teams that were studied were relatively small and therefore the boundary spanning role of the project leader might have been more clear. However, for larger design projects, boundary spanning might need to become more shared and distributed

6 Conclusion

This study contributes to project management literature concerning managing distributed and embedded knowledge in interorganisational projects in three ways: visualizing actual project interaction; managing through multiple forms of interaction and perceiving the project leader as a boundary spanner supporting transfer and creation of distributed and embedded knowledge.

First, the appraoch to visualize interaction patterns gives an insight in the *actual* interaction in different types of construction project design meetings. Second, management of distributed and embedded knowledge in a project is enhanced when project members use a combination of multiple forms of interaction. Third, the project leader is perceived as a boundary spanner in terms of integrating information, bridging towards all stakeholders, setting up and ensuring a supporting and stable work environment, bridging interaction through multiple communication means, and facilitating the knowledge community.

The practical contribution of this research is primarily into supporting how interorganisational project teams can use multiple means of communication to enhance interaction and sharing of embedded and distributed knowledge. Furthermore, gaining insight in the role of the project leader as a boundary spanner can support project leaders as well as project teams in how to bridge between different project partners and stakeholders. The insights of the research could improve the efficiency of project meetings but also the interpersonal communication within the project team.

Future research is needed in order to create a better insight in the interaction of a knowledge community working in projects. Important would be to enrich this study with longitudinal observations on interaction patterns as well as include interaction that happens outside of phyiscal meetings of design teams during the whole design process. Furthermore, future work could relate this study to multiple industries as well as the development of the changing role of the project leader when design teams work in more integrated processes. If additional industries were to be observed patterns could be established and potentially synergy effects could be found across the different industries work processes.

Acknowledgement: We are grateful for the financial support of the following funding agencies for this study: The Swedish Research Council for Environment, Agricultural

Sciences and Spatial Planning (FORMAS), the Development Fund of the Swedish Construction Industry (SBUF) and the Centre for Management of the Built Environment (CMB).

7 References:

Akkerman, S. F., Bakker, A. 2011. Boundary Crossing and Boundary Objects. Review of Educational Research, 81, 2, 132–169.

Aldrich, H., Herker, D. 1977. Boundary Spanning Roles and Organization Structure. The Academy of Management Review, 2, 2, 217–230.

Anumba, C.J., Baugh, C., Khalfan, M.M.A. 2002. Organizational structures to support concurrent engineering in construction. Industrial Management Data Systems, 102, 5, 260-270.

Axley, S.R. 1984. Managerial and Organizational Communication in Terms of the Conduit Metaphor. The Academy of Management Review, 9, 3, 428-437.

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., 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.

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

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

Currie, G., White, L. 2012. Inter-professional barriers and knowledge brokering in an organizational context: the case of healthcare. Organization Studies, 33, 10, 1333-1361.

Dainty, A.R.J., Moore, D., Murray, M. 2006. Communication in construction: Theory and Practice. Taylor and Francis, Oxford.

Davenport, T.H., Jarvenpaa, S.L., Beers, M.C. 1996. Improving knowledge work processes. Sloan Management Review, 37, 53-65.

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), 123–132.

Earl, M. (2001). Knowledge Management Strategies: Toward a Taxonomy. [Article]. Journal of Management Information Systems, 18(1), 215-233.

Eisenhardt, K.M. 1989. Building theories from case study research. Academy of Management Review 14, 4, 532–550.

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

Eriksson, P.,E. 2013. Exploration and exploitation in project-based organizations: Development and diffusion of knowledge at different organizational levels in construction companies. International Journal of Project Management, 31, 3, 333-341

Farenga, S. J., Joyce, B.A., Wilkens, R., Ness, D. 2003. Teaching observation: Gathering baseline data. Science Scope, 26, 6, 56.

Foley, J., Macmillan, S. 2005. Patterns of interaction in construction team meetings. Co-design, 1, 1, 19-37.

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

Fruchterman, T.M.J., Reingold, E.M. 1991. Graph Drawing by Force-directed Placement. Software - Practice and Experience, 21, 11, 1129-1164.

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

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.

Hoe, S. L. 2006. The boundary spanner's role in organizational learning: unleashing untapped potential. Development and Learning in Organizations, 20, 5, 9–11.

Jaradat, S., Whyte, J., Luck, R. 2013. Professionalism in digitally mediated project work. Building Research 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

Kamara, M., Anumba, C.J., Evbuomwan, N.F.O. 2002. The suitability of current briefing practices in construction within a concurrent engineering framework. International Journal of Project Management, 19, 337-351.

Katz, R., Tushman, M. 1979. Communication patterns, project performance, and task characteristics: An empirical evaluation and integration in an R&D setting. Organizational Behavior and Human Performance, 23, 2, 139–162.

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

McDonald, S., 2005. Studying actions in context: a qualitative shadowing method for organizational research. Qualitative Research, 5, 4, 455-473.

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

Moore, D.R., Dainty, A.R.J., 1999. Integrated project teams' performance in managing unexpected change events. Team performance management, 5, 7, 212-222

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

Organ, D. W. 1971. Linking pins between organizations and environment: Individuals do the interacting. Business Horizons, 14, 6, 73–80.

Peng, Y., Sutanto, J., 2012. Facilitating Knowledge Sharing Through a Boundary Spanner. IEEE Transactions on Professional Communication, 55, 2, 142–155.

Pyöriä, P. 2005. The concept of knowledge work revisited. Journal of Knowledge Management, 9, 116-127.

Prencipe, A., Tell, F. 2001. Inter-project Learning: Processes and Outcomes of Knowledge Codification in Project-Based Firms. Research Policy, 30,9, 1373–1394.

Ramírez, Y. W., Nembhard, D. A. 2004. Measuring knowledge worker productivity: A taxonomy. Journal of Intellectual Capital, 5, 602-928.

Schultze, U. 2000. A confessional account of an ethnography about knowledge work. MIS Quarterly, 24, 3-41.

Shantz, A., Wright, K., Latham, G., 2011. Networking with boundary spanners: A quasi-case study on why women are less likely to be offered an engineering role. Equality, Diversity and Inclusion: An International Journal, 30, 3, 217–232.

Senescu, R.R., Aranda-Mena, G., Haymaker, J., 2013. Relationships between project complexity and communication. Journal of Management in Engineering, 29, 183-197.

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.

Szulanski, G. 1996. Exploring internal stickiness: impediments to the transfer of best practice within the firm. Strategic Management Journal, 17, 27-43.

Torrington, D., Hall, L., 1998. Human resource management, 4th edition, Prentice Hall, London.

Tsoukas, H., 1996. The Firm as a Distributed Knowledge System: A Constructionist Approach. Strategic Management Journal, 17, 11-25.

Von Hippel, E. 1998. Economics of product development by users: the impact of sticky local information. Management Science, 44, 5, 629-644.

Wikforss Ö., Löfgren, A. (2007). Rethinking communication in construction. Journal of Information Technology in Construction, 12, 337-346.

Table 1: Data collection with the different case studies.

Case	Type of collaboration	Duration collaboration event	Additional interviews (project and firm level)
1	Integrated design work day	6 h	3 project, 3 firm
2	Integrated design work day	5 h	2 project, 1 firm
3A	Integrated design work day	5h	3 project, 1 firm
3B	Integrated design work day and 3D clash detection	5h	
4A	Geographically distributed traditional design meeting	1.30h	4 project, 5 firm
4B	Geographically distributed traditional 3D clash detection	1.30h	
5	Geographically distributed Traditional 3D clash detection	2h	3 project, 3 firm
6A	Traditional design meeting Oil & Gas: rough estimation	2 h	2 Project, 3 firm
6B	Concurrent Oil & Gas	2 h	
Total		**30 hours**	**31 interviews**

Table 2: Description of the case studies team members

Case	Type of collaboration	Size of team	Contractor members	External / distributed members
1	Integrated design work day	14	6	8 (incl. PL) external
2	Integrated design work day	10	7	3 external
3A	Integrated design work day	11	6	5 external
3B	Integrated design work day and 3D clash detection	8	4	4 external
4A	Geographically distributed traditional design meeting	5	4	1 (other location)
4B	Geographically distributed traditional 3D clash detection	8	7	1 (other location)
5	Geographically distributed Traditional 3D clash detection	13	1	4 in location2 2 in location3 6 (incl. PL) in location4
6A	Traditional meeting Oil & Gas: rough estimation	15	12	3 external and in location2
6B	Concurrent meeting Oil & Gas	9	9	

Figure 1: Interaction distribution of integrated and/or concurrent construction design projects (case 1, 2, 3A and 3B).

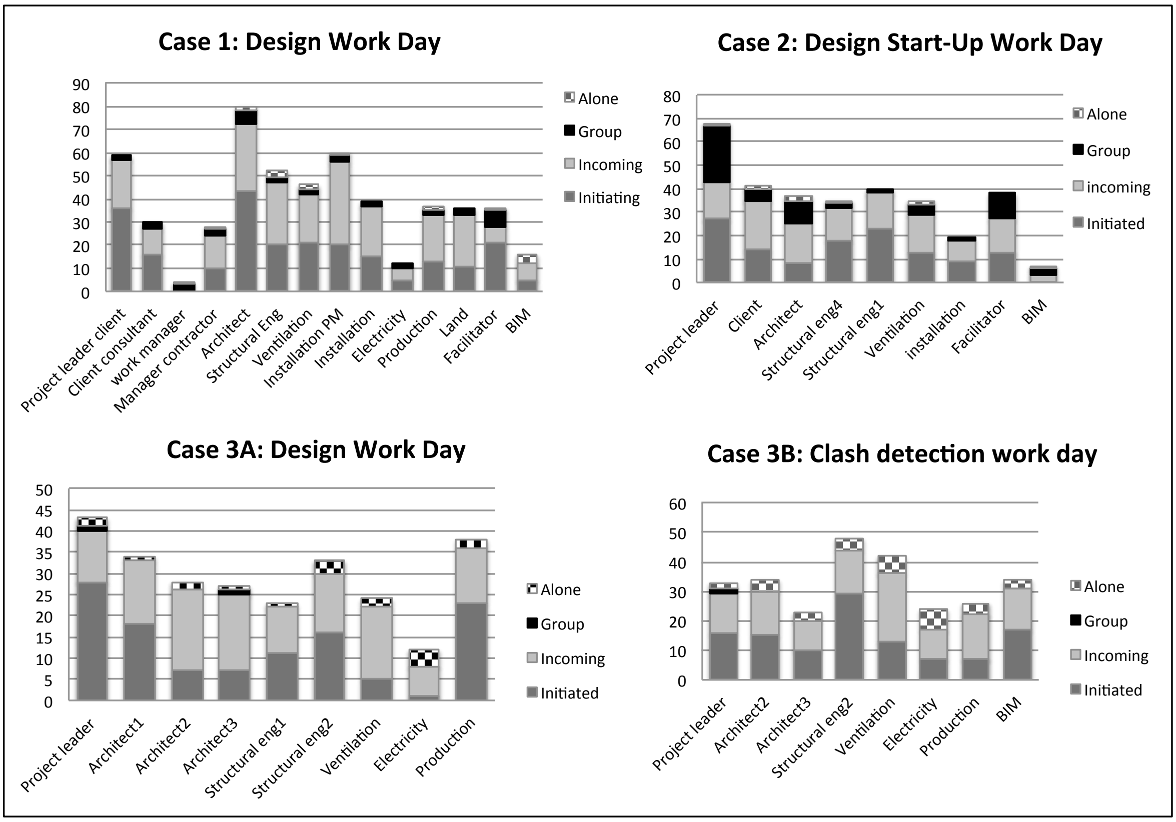

Figure 2: Interaction distribution in traditional design project meetings (case 4A, 4B, 5, and 6) of the construction and oil and gas industry.

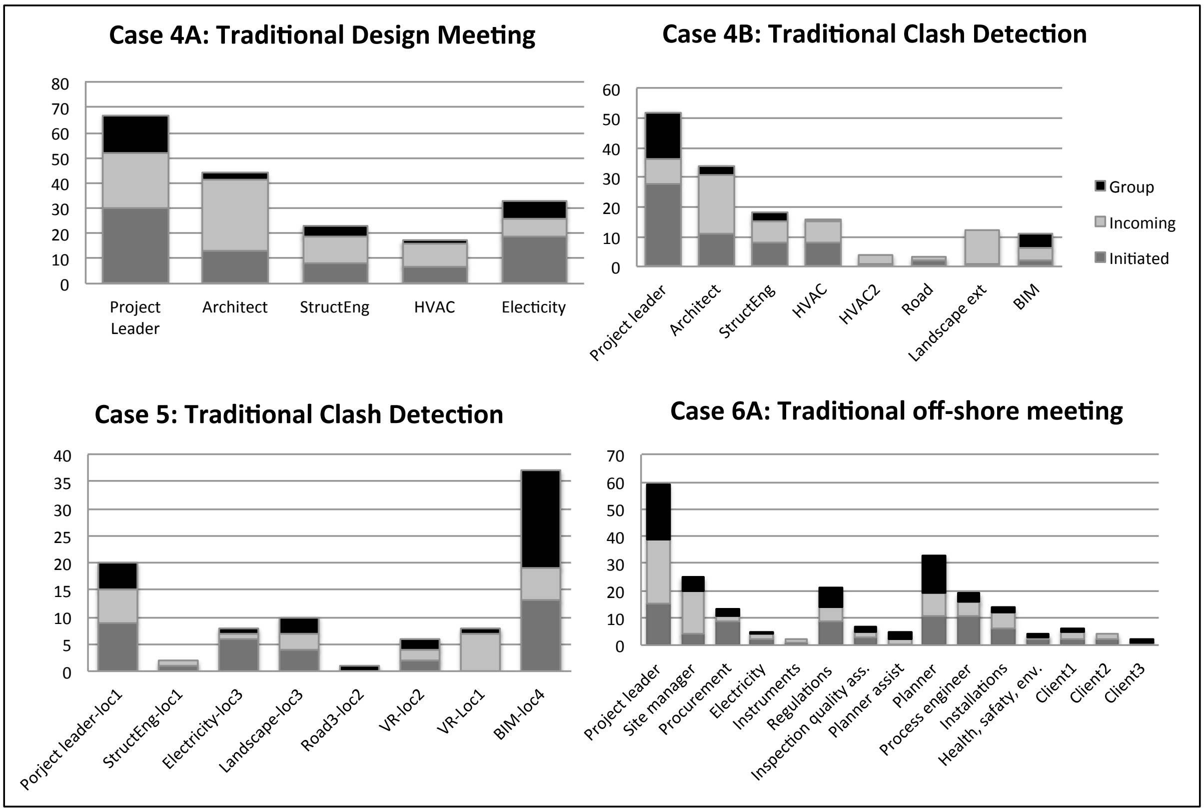

Figure 3: Interaction distribution in traditional and concurrent design project meetings (case 6A and 6B) of oil and gas industry.

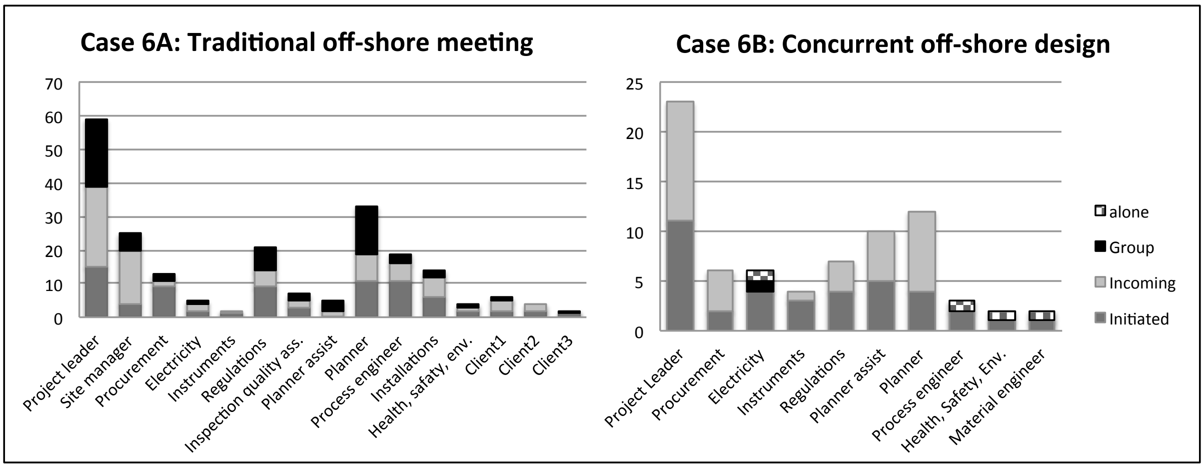

Figure 4: Visual Interaction Network of Integrated and/or concurrent ways of work of Case 1, 2, 3, and 6B based on Fruchtermann Reingold layout.

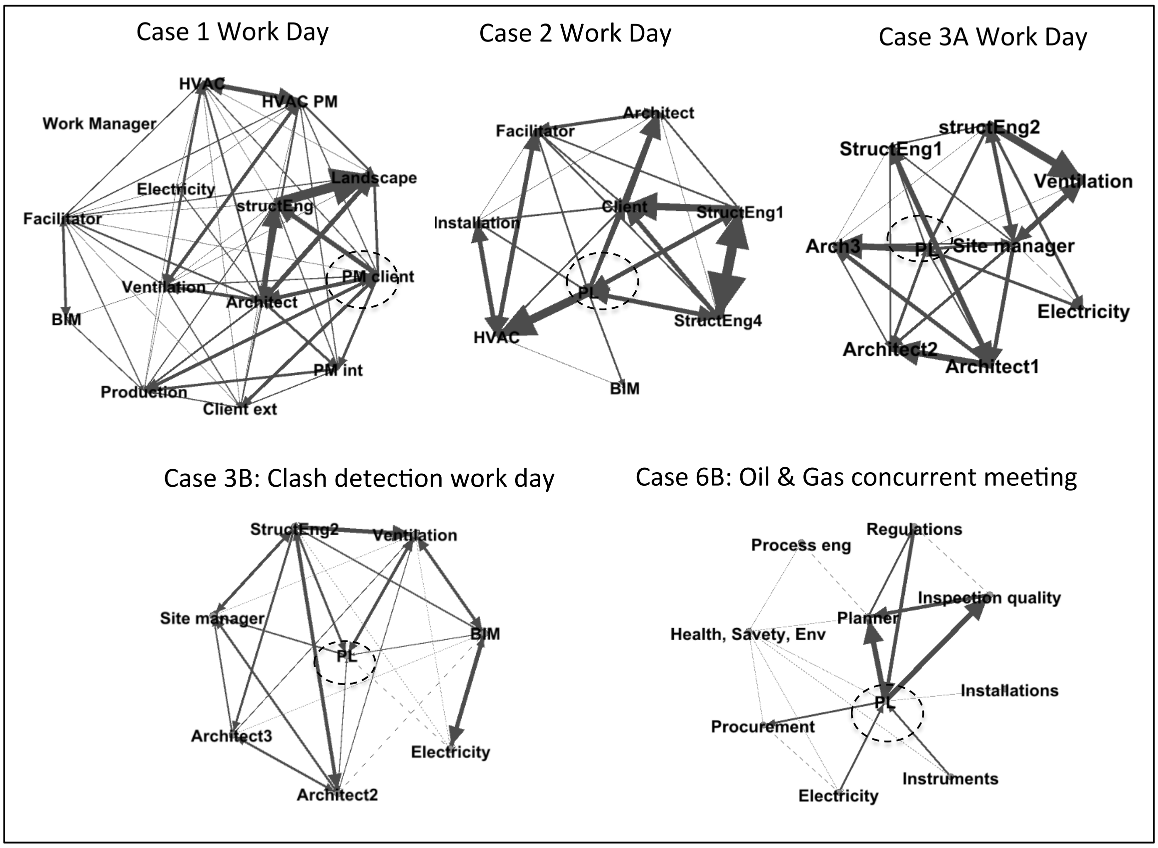

Figure 5: Visual Interaction Network of Traditional Design meetings of case 4A, 4B, 5, and 6A based on Fruchtermann Reingold layout.