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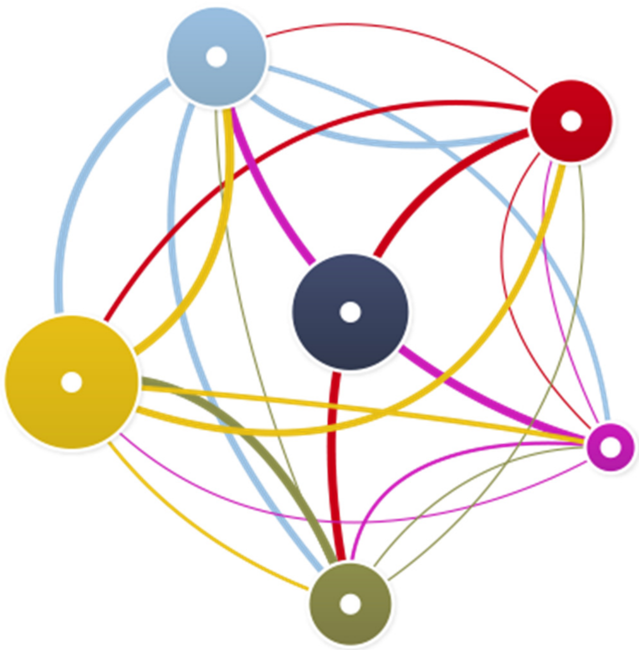

How does ICT facilitate the communication in design teams?

Master's Thesis in the Master's Programme Design and Construction Project Management

OGNJEN DELIPARA
OLEKSANDRA FROLOVA

Department of Civil and Environmental Engineering
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Department of Civil and Environmental Engineering
Division of Construction Management
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

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ABSTRACT

The construction industry has a need of improvement of productivity and efficiency on all stages of a projects life-cycle. An improvement of the communication in a project may evidently enhance and result in improved productivity and efficiency. This case study focuses on the design phase, which is, as many researches show, the fundamental stage where a lot of mistakes can be predicted and avoided. Many of the defects causing re-work in the construction phase can be derived to errors and defects originated in the design phase, which are consequently caused by communicational issues. Moreover, knowledge transfers through communication plays a significant role in such organisations, it is important, that this process is performed well and fast and nowadays it can be considerably improved with the help of utilizing building information modelling (BIM) and other ICT tools. The main aim of this research is to identify how knowledge transfers through communication are currently performed in a multidisciplinary design team with the help of BIM and other ICT tools and how it further can be improved in the future.

The case study was performed in the department of Civil Engineering of a Swedish consultancy firm. The findings show that BIM is one of the main communicational tools in the design team. However, BIM is currently not developed enough to provide all possible opportunities and advantages toward a better performance. There are a number of hindrances that need to be considered, which also were identified in this research. Due to the fact that the case company originally is an oil and gas company and succeed in using different ICT tools, also some benefits were identified in order to apply these experiences in construction projects.

Key words: communication, knowledge transfer, information and communication technology, building information modelling

Hur underlättar IKT-verktyg kommunikationen i ett projekteringsteam?

Examensarbete inom masterprogrammet Design and Construction Project Management

OGNJEN DELIPARA
OLEKSANDRA FROLOVA
Institutionen för bygg- och miljöteknik
Avdelningen för Construction Management
Chalmers tekniska högskola

SAMMANFATTNING

Byggsektorn är i ett behov av förbättringar gällande produktivitet och effektivitet i alla faser av ett projekts livscykel. En förbättring av kommunikationen i ett projekt kan bevisligen förbättra och resultera i förbättrad produktivitet och effektivitet. En av många anledningar till att kommunikationen i byggsektorn är begränsad beror till en viss del på att det är många multidisciplinära aktörer med olika bakgrund involverade i byggprocessen, speciellt projekteringsfasen. De många problem, defekter, omarbeten och efterarbetningar, som uppstår under konstruktionsfasen härrör från misstag, felaktigheter och avvikelser med ursprung i projekteringsfasen av byggprojekt. Projekteringsteam i byggsektorn arbetar i en miljö som kännetecknas av ständiga förändringar i aktiviteter och processer som i sin tur reciprokalt och interaktivt utvecklas till ett komplicerat samspel med konkurrerande och motstridiga krafter.
Kunskapsöverföring genom kommunikation spelar en viktig roll för att en organisation ska fungera effektivt och det är av yttersta vikt att denna process fungerar väl. I dagsläget kan BIM (Byggnadsinformationsmodellering) och andra IKT-verktyg (information och kommunikation teknologier) avsevärt förbättra kommunikationen mellan multidisciplinära aktörer av ett team och i sin tur även kunskapsöverföringen.

Syftet med studien är att identifiera hur väl kunskapsöverföringen genomförs, med stöd av BIM och IKT-verktyg, i ett projekteringsteam. I tillägg undersöks möjligheterna för huruvida BIM och IKT-verktygen ytterligare kan förbättra kunskapsöverföringen i form av kommunikation i framtiden. Fallstudien utfördes i avdelningen för infrastruktur hos ett svenskt konsultbolag. Resultaten visade att BIM är ett av de främsta kommunikationsverktygen som används i projekteringsteamet. Dock är BIM inte tillräckligt utvecklat för att bidra med sin fullständiga kapacitet och tillhandahålla eventuella fördelaktiga egenskaper för ett ytterligare förbättrande av kunskapsöverföringen i projekteringsteamet. Andra faktorer som implicerar och påverkar den framtida utvecklingen av BIM har också beaktats i studien. I tillägg är företaget i grunden ett konsultföretag vars primära område är olja och gas, och där man framgångsrikt använder olika utvecklade IKT-metoder. Studien innefattar även en kortare analys motsvarande tillvägagångsätt i olja och gas avdelningen, där en del fördelar som kan appliceras i byggsektorn identifierades.

Nyckelord: kommunikation, kunskapsöverföring, information och kommunikation teknologier, byggnadsinformationsmodellering

Contents

Preface

The master's thesis was performed at the Department of Civil and Environmental Engineering, division Construction Management at Chalmers University of Technology, Sweden. The study was performed in close relation to the Think Tank BIM & Management which is a close cooperation between Chalmers University, Construction Management and the Centre for Management in the Build Environment.

The thesis has been carried out under supervision of Petra Bosch and Susanne Van Raalte. The research was performed in the Swedish department of Civil Engineering at Reinertsen, a Norwegian oil and gas company and it was started in January and was finished in September of 2015. Interviews with the different specialists from the Norwegian company were the main data source in this thesis.

We are really grateful for all help during our research. We would like to say big thank you, Susanne Van Raalte for your support with relevant information in all our steps and giving us a place in the office in Gothenburg. Thank you very much, Petra Bosch, for your supervision and helping us with everything. We are really grateful for all specialists who agreed to give us interview, which contributed a lot with the practical insights for the thesis. We would like to thank the Swedish Institute who supported Oleksandra Frolova during her time of her studies at Chalmers University of Technology with a Visby scholarship.

Göteborg September 2015

Ognjen Delipara and Oleksandra Frolova

Notations

BIM	Building Information Model or Building Information Modelling
CAD	Computer Aided Design
CE	Concurrent Engineering
ICT	Information and Communication Technology
2D	Two dimensions: x and y
3D	Three dimensions: x, y and z

1 Introduction

In this chapter the background and the objectives of the master's thesis are presented. The main researched question and delimitation of research are discussed further in the chapter. Furthermore, the structure of the master's thesis is described briefly per chapter.

1.1 Background

According to Dainty et al. (2006), the communication in the construction industry is somewhat constrained, mainly because of factors regarding communication issues linking to the involvement of several multidisciplinary and fragmented participants.

Many of the defects causing re-work in the construction phase can be derived to errors and defects originated in the design phase, which consequently are caused by such communicational issues.

The construction industry is one of the lowest regarding the annual rate of increasing productivity and performance (Bröchner and Olofsson, 2012). Because of this, the construction industry is therefore generally perceived as an antiquated industry and rather slow in adapting new technologies compared to other industries such as for example the manufacturing industry (Nof, 2009). Hence, the communication issues are acknowledged as one of the factors related to the construction industry's generally modest performance (Dainty et al., 2006).

Communicational issues in construction arise mostly from the specifics of a project team. Viewing it from a perspective of the design phase, project teams in the construction industry, specifically in the design phase, operate in an environment that is highly dynamical, fragmented and characterized by continuous changes, activities, processes and progresses which in turn interactively embroil competing and conflicting forces (Bowen and Edwards, 1996). The construction design team consists of participants from the different fields and disciplines, and often has contrary interests and can perceive information from opposite points of view (Dainty et al., 2006). All these factors cause communicational problems and need additional solutions to make the process of interaction and communication exchange easier. One of the additional tools which can improve the process of communication is ICT.

In literature ICT has been seen as supporting performance. ICT stands for information communication technologies, and are technical and computerized tools used to facilitate the interaction between people through unified communication (Dainty et al., 2006).

Information and communication technologies have a substantial impact on project performance and are very dominant in the design phase, shaping a large number of production functions and activities. This implies that ICTs have a significant impact in the design phase in the construction industry (Dainty et al., 2006).

ICT tools have the potential to improve the interdisciplinary communication within the design team. However, in order to make this happen, it is of importance to effectively use the ICT-tools in order to increase and improve the performance in the construction industry (Lam et al., 2010).

The most common tool which is now widely used in construction is building information modelling. BIM as a concept embraces a range of characteristics, which can be described as an intelligent project representation and database, communicational tool and a set of policies for better interaction and project performance (Aranda-Mena et al., 2009). As a powerful ICT tool BIM provides a lot of opportunity for the collaboration in the design team, but still the process of the BIM implementation is quite challenging (Aranda-Mena et al., 2009).

Still introducing new facilitating ICT-tools in a design process may consequently create new communicational problems. Although the construction industry may have gained tremendous benefits from the development and implementation of BIM and ICTs, it is at the same time the cause of various practical issues deeply rooted in sharing of information and knowledge between different disciplines in a design team. One example in the construction industry is the practical issues related to interoperability between different types of software that different disciplines use during construction design (Giel and Issa, 2013). In addition to the practical and technical problems, the changes generated by implementing BIM and ICT tools may result in resistance against the implementation and use. The process to adopt new technical computerized ICT-tools, software's and working structures vary and how people work with digital computerized tools also varies. People that are comfortable and successful in their traditional way of conducting their work may approach the continuous development of new ICT tools with resistance.

With the purpose for increased integration of the design team and sharing knowledge and information between all participants from the early phase of the project, there are attempts to apply concurrent engineering methods in construction. Concurrent engineering method allows people to work in parallel sessions and get access to all information at the same time (Khalfan and Raja, 2012). It is used as a supporting method for the BIM and other ICT tools, but it is still has a lot to improve for successful implementation in construction projects.

So it can be seen as much problems as an opportunities with the implementation as well as use of BIM and ICT tools for the improvement of communication in a design team. The hindrances described above are related to knowledge boundaries, which according to Carlile (2002) appear in an organisation, when the knowledge itself is the source of prevention, and a barrier inhibiting knowledge sharing.

It is important to clearly identify those boundaries, which arise in a design team during the development of a construction project and attempt to analyse the consequences which aspects create these boundaries with the purpose to improve communication through the BIM and other ICT tools in design team.

1.2 Objectives

The main aim of the report is to explore how the communication is performed in the multidisciplinary design team during the construction project with the help of BIM and other ICT tools. The objective is to identify the role which BIM and other ICT tools play in knowledge transfer during the design stage of construction project, and suggest how this process can be improved in the future.

1.3 Research questions

The study is attempting to answer the following research questions:

1. How is knowledge transfer through communication currently performed with the help of BIM and other ICTs in design teams in engineering construction projects?
2. How can knowledge transfer through communication be improved through the use of BIM in design teams?

The theoretical starting point is to study BIM and other tools as boundary objects and boundary spanners that can support knowledge in design teams.

1.4 Delimitations

This thesis focuses primarily on communication issues during the design phase of the construction project with the use of BIM and other ICT tools through the theoretical lenses of boundary objects and spanners. The research is based on a single case study in the department of Civil Engineering of the case company.

1.5 Thesis outline

The thesis consists of seven chapters. Chapter two presents the theoretical framework in relation to the research question with the analysis of previous research of the relevant topics. The third chapter describes the methodology that was used in the master's thesis. Chapter four discusses the results from the case study, which become the basis of the discussion chapter number five, in which the case study data is related to the theoretical framework. Chapter six presents conclusion of the research and suggests improvements which can be made in the future.

2 Theoretical framework

In order to introduce a theoretical framework to the subject, this chapter is divided into three parts. The first part defines knowledge and further presents the chosen definition of interactive knowledge perspectives used in this thesis. The second part introduces the concurrent engineering method as an approach that is in conjunction with working methods supported by ICT tools, as BIM, in order to improve the information and knowledge sharing between the participants of the design team. The section also presents the original concept and definition of BIM as a main ICT tool which is widely used in construction industry and may facilitate communication in our context.

2.1 Concepts of knowledge

In order to understand how knowledge transfer through communication with the help of BIM is performed in the design team it of importance to identify which obstacles and hindrances are present in a multidisciplinary design team environment. By recognizing, identifying and making clear which communicational obstacles, in the form of knowledge boundaries, inhibit communicational knowledge transfer, an understanding of how knowledge transfer is performed through communication is developed.

2.1.1 Knowledge

The precise meaning of knowledge is philosophically multi-paradigmatic and quite ambiguous to interpret and grasp (Newell et al., 2009). Different interpretations and theories of knowledge run counter to each other (Tsoukas and Vladimirou, 2001).

Cook and Brown (1999) presented a basic summary and a well-structured elemental explanation of their interpretation of knowledge, where they distinctively and epistemologically derived it into two fundamentals: knowledge as a possession and knowledge as a practice.

Knowledge as a possession is basically characterised of stressing the cognitive features and capacities of knowledge by relating to it as a resource in the human mind, which may be developed and used to improve work (Newell et al., 2009).

According to the knowledge as a possession theory, the knowledge pyramid (see figure 1) explains the notion of knowledge in the context of a hierarchical structure. By studying the pyramid (see Figure 1) bottom-up, data represents simply basic discrete and objective facts. Information is represented by data, which is systematized and put into a context. Moreover, knowledge is referred to as data and information that is culturally, individually and subjectively perceived through previous experiences and perceptions, which now gives insight and understanding into something. Finally wisdom is represented by knowledge placed in frameworks (Jennex, 2009). In this hierarchy, knowledge is allowed to be possessed by individuals. This implies that knowledge is a mental process acquired by individuals and that it may be accumulated, stored and converted (Newell et al., 2009).

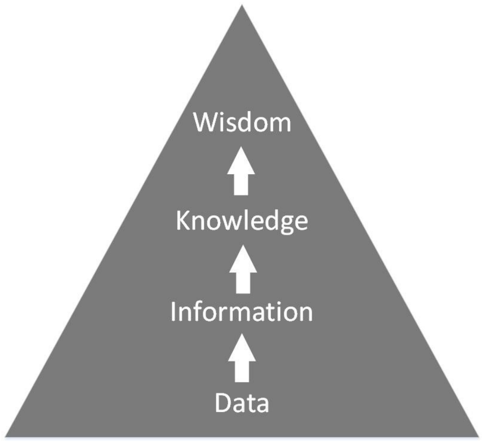

Figure 1 Illustration of the knowledge pyramid (Jennex, 2009).

On the other hand, knowledge as practice is characterized by the fact that knowledge is always rooted in the context of interaction and that it is situated in systems of on-going intrinsic social situations and practices relationally mediated by tools and objects, referred to as artefacts (Newell et al., 2009). Moreover, the knowledge as practice view argues that knowledge is frequently repeated, reproduced, constructed and negotiated which consequently implies it is dynamic, contextual and provisional (Gherardi and Nicolini, 2000).

Out of the knowledge as a practice view, which focuses particularly on knowledge and action, a complementary view referred to as knowledge of processes evolved. The "process" view emphasizes the social and organisational aspects of knowledge, claiming that it is highly imbued by social, contextual and political mediations. This implies it is subjected to ambiguous multi-faced interpretations and meanings, simultaneously as it is dynamical in highly contextual aspects, which indicates that accepted interpretations and meanings may change as the structure of involved actors and context change (Newell et al., 2009).

2.1.1.1 Explicit and tacit knowledge

Knowledge may be differentiated into two types: explicit and tacit (Nonaka et al., 2000; Newell et al., 2009; Clegg et al., 2011).

- Explicit knowledge is knowledge that can be expressed, articulated and reflected on, usually in form of formal and systematic language. Explicit knowledge can be elaborated, recorded and shared in form of data, scientific formulas, specifications and manuals. This enables it to be relatively easy processed transmitted and stored, allowing others to learn it.
- Tacit knowledge on the other hand, is highly embedded in activities, actions, procedures, routines, commitments, values, ideas and emotions. Because of this, tacit knowledge cannot necessarily be articulated and communicated to others, stored, processed and transmitted easily. Moreover, it is hard to formalize and simultaneously highly imbued by personal interpretations and insights in combination with subjective intuitions.

However, it is of importance to emphasize that explicit and tacit knowledge are not mutually exclusive, they are on the other hand complementary and crucially vital to each other.

2.1.1.2 The SECI-model

Moreover, Nonaka et al. (2000) suggested that knowledge is continuously generated and formed through dynamical intersections and interactions of explicit and tacit knowledge (see Figure 2) braked down into four dimensions of knowledge alternation and creation.

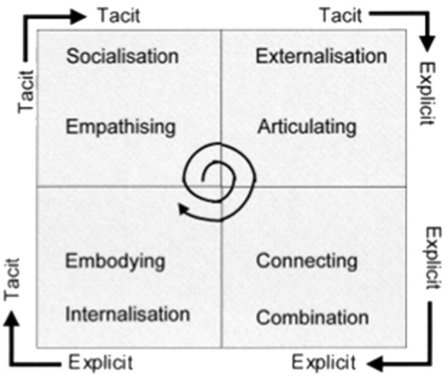

Figure 2 SECI-model (Nonaka et al., 2000).

Furthermore, according to Clegg et al. (2011), Newell et al. (2009) and Nonaka et al. (2000), information is tangible and exists in media and in networks, which implies it may be communicated and transferred independently. When enabling information into a context, a shared space for emerging relationships, exchanging experiences and reflections allows the information to be interpreted into the context, the information becomes knowledge and this knowledge consequently becomes intangible.

The SECI-model consists of (Clegg et al., 2011; Newell et al., 2009; Nonaka et al., 2000):

- Socialization (tacit to tacit), represents the interaction of individuals with individuals, enabling dialogue and reflection of own and others experiences. In this Originating space, individuals should develop empathising abilities, in order to enable the sharing of experiences and mental models, which is crucial to socialization. This square is represented by face-to-face connections; it is here where knowledge creation and sharing may be initiated. Socialization represents the informal interaction and exchange of shared issues.
- Externalization (tacit to explicit) refers to the interaction in more formal and structurally constructed articulating spaces, where creative and essential dialogues are conducted and facilitated simultaneously as ideas are challenged, reflected and approached abductively. This phase involves designers in project teams, which disposes and plan how to undertake a joint task, issue or problem.

- Combination (explicit to explicit) is represented in the form of people combining ideas, which are already well known. The space of systematizing facilitates knowledge creating and sharing with the help of information communication technologies, ICT, which connects new knowledge with already known and current knowledge, and subsequently enables it to different levels of an organisation.
- Internalization (explicit to tacit) characterized by putting results into practice, in this case it is when the acquired knowledge becomes an accepted performing activity executed structurally and with repertoire. The embodying is the space where formal (explicit) knowledge are integrated in the participation of trainings or performed activities

2.1.2 Knowledge in companies and organisations

Organisational knowledge is a set of shared and developed understandings, values, norms, practices, routines, means and believes within a team or group of actors, which integrates artefacts and actors in order to forms the social capabilities of an organisation (Newell et al., 2009).

Knowledge work is defined (Newell et al., 2009) as activities and occupations in organisations highly imbued by theoretical knowledge, analytical skills combined with a set of creative and social competences. It is individuals who are highly educated and which apply their theoretical knowledge practices to recognize and elucidate issues. Knowledge work can be subdivided into professional work and contemporary work.

Knowledge can be distributed and adopted differently (Newell et al., 2009):

- Knowledge diffusion is characterised by distributing and spread knowledge to a larger group, more widely.
- Knowledge transfer is knowledge exchange but not always internalized, adopted and reused.
- Knowledge sharing is internalized knowledge exchange and absorbing.

2.1.2.1 Design Team

In order to understand what influences the problems construction design-teams face; both internally within the group and externally across projects, it is important to address the characteristics of teams, respectively projects.

A team is basically created for enabling and gathering complementary skills to complete required achievements and results that could not be accomplished by a project group consisting of a group of individuals (Dainty et al., 2006).

According to Newell et al. (2009), every member in a team must perceive themselves as a unit, work to a common goal and produce and contribute along it, simultaneously as communicating, sharing information and by influence and encourage each other.

This abovementioned core unit of working in teams is crucially connected to the performance of a team, in consonance to the rest of the industry. Senaratne and

Gunawardane (2015) cognate increased and improved team performance to an overall increased performance within an industry.

The design phase during construction projects is according to Bowen and Edwards (1996), the initial construction phase where the client is supposed to mediate their requirements and aims. In accordance to this, the design team, has to initially make a basic outcome which is meeting the client's objectives in the form of adequate plans subsequently meant to be completed in a particular set of activities to fully meet the requirements and needs.

The design team has a quite significant role and influence on project success in the construction industry. One substantial and crucial factor imbuing team performance, and consequently project success is actually team structure and constitution. Due to this, it is highly noteworthy to underline how the members of a team interact with each other, and how the different roles within a design team are performed (Senaratne and Gunawardane, 2015).

The special characteristic of construction design teams that significantly affects the performance and interaction between the members of design team is its temporary nature (Dainty et al., 2006). The temporary nature of construction projects hindrances long-term orientation of forming design team. Its structure is quite fragmented, a lot of participants are usually involved, which cause a lot of conflicts and misunderstandings. Ad-hoc approaches are also prevalent in those types of teams (Dainty et al., 2006).

Projects on the other hand, consist of a group of individuals, that have no fixed membership and where the work is often temporary, fluid, interrupted and distributed. The corresponding definition of a project's is to bring together individuals from different backgrounds to collectively achieve common objectives. From a knowledge management perspective, a project must aim to work as a team in order to be efficient and reciprocal in order to overcome knowledge boundaries (Newell et al., 2009).

In any industry, which is characteristically constituted and imbued of activities of a team-based manner, it is crucial that the work is performed by synergistically uniting team members' knowledge's, skills and expertise in order to enabling efficacious and successful project results and outcomes (Dainty et al., 2006).

In the manufacturing-, finance- and sales-industry, teams tend to be developed through interactions and dialogues, which are prolonged over several of years, and sometimes extend over entire carriers, as an enabling context, evolving mutual responsibility and team commitment, constructing trust and decreasing fear of conflict. This evolvement is crucial in order to consecutively and progressively improve and develop mutual accountability, synergy and responsibility, both individually and within the team, which enables the team to work and meet their goals and missions successfully (Dainty et al., 2006; Knight, 2008; Newell et al., 2009).

However, according to Knight (2008) the design and construction teams tend to be of an ad-hoc character, this indicates and entails that there is not much time to develop, construct and enable evolvement of relations influenced by appropriate interactions and consequently mutually accountable teams with effective and synergetic communication, meeting required goals and achieving good results.

According to Dainty et al. (2006), one of the most crucial factors of achieving mutual accountability is having a transparent and effective communication climate enabling and facilitating the sharing of knowledge within the design team, by exchanging knowledge, ideas and information in a collaborative workplace environment. This further underlines the importance of externalization and enabling the context of transparent dialogues within a design team (Nonaka et al., 2000).

In addition, the knowledge creation model, the SECI-model, highly includes and expresses social processes of dialogue and interaction as a fundamentality. In the article Newell et al. (2009) it is argued that the three of the four basic progressions of the SECI-model; the socialization, the externalization and the combination square; involve social interaction and emphasise the importance of constructive communication. Further, it becomes important to enable the context in the form of physical and virtual spaces where this team interaction may occur. These spaces are relevant in order to develop an evolved shared mental space in the form of mutual shared experiences, emotions and ideas, but also mutual accountability of the teams work.

The teamwork involves rich personal interaction, where knowledge creation of ingrained tacit knowledge in the form of mutual understandings may only be achieved through shared experiences over a prolonged time period (Nonaka et al., 2000). In order to appropriately share the tacit knowledge in teams of temporary nature, it is important to enable a space where the experiences can be shared over time. This evidently further confirms the importance and need of a physical space, as well as the need of a communicative ICT space that can support these interactions (Newell et al., 2009).

However, enabling these physical spaces are not always adequately possible, due to factors as time, and different geographical issues. ICTs may facilitate the knowledge sharing and knowledge creating, however, it is of importance that the involved team members understand how and why different ICT tools can and should be used effectively as possible (Newell et al., 2009).

2.1.2.2 Knowledge boundaries

The process of acquisition and applying specific information, which facilitates our understanding of knowledge, may actually inhibit and be a barrier to knowledge sharing (Carlile, 2002; Newell et al., 2009). This implies that knowledge can itself be a hindrance of knowledge sharing across multidisciplinary teams (Carlile, 2002). Knowledge sharing hindrances and interferences are according to Carlile (2002), referred to as knowledge boundaries (Newell et al., 2009).

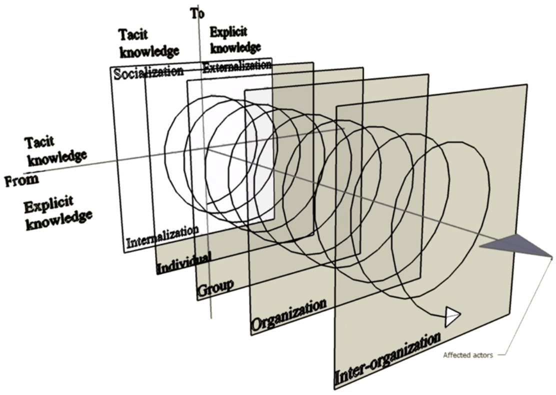

Figure 3 Ontologically enlarged SECI-model.

The spiral represented in Fig.3 illuminates how the interaction between tacit and explicit knowledge in the SECI-model are ontologically enlarged when moving through the different conversions and levels. Knowledge generated through the models may initiate and cause a new spiral of knowledge alternation and creation vertically and horizontally across for example teams or organisations. It is a dynamically and continuously developed process primarily enhancing the individual aspects, and then growing when it interacts and moves through different communities, groups, teams etc.. The knowledge may go beyond and overstep boundaries, such for example sectional, departmental, divisional and organisational (Nonaka et al., 2000).

Knowledge boundaries are when the knowledge itself is the source of prevention, and a barrier inhibiting knowledge sharing. It is the boundaries on a knowledgeable level related to professional and contemporary knowledge work (Newell et al., 2009). For example in the construction industry, between craftsmen and the design managers, where the craftsmen`s knowledge is adaptive within a fairly detailed and technical sphere in contrast to a design managers' knowledge that mainly concerns managerial knowledge involving coordination and planning, out of a wide comprehensive, and not detailed spectrum. The two professionals may speak about the same thing; however, they can only refer to the subjected things or the concept from their own spectrum of background and perspectives. The design manager may perhaps not understand why a certain detail incorporated in the craftsman's scope of work may not be finished faster because of a lack of knowledge in the craftsmen occupation and conversely.

Knowledge boundaries are subdivided into three categorizations (see Figure 4):

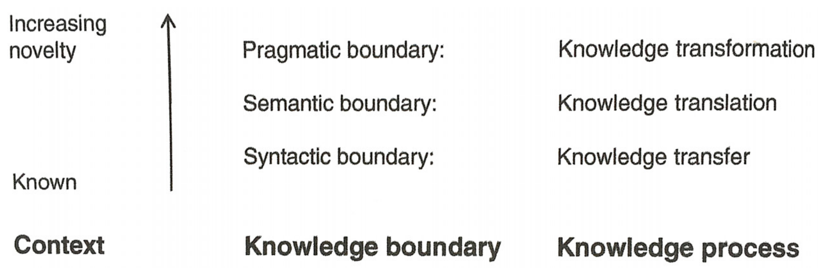

Figure 4 Framework of managing knowledge across boundaries (Newell et al., 2009).

Syntactic boundaries highlight differentiations across groups with different backgrounds in terms of communication and the context is of a known characteristic (Newell et al., 2009; Carlile, 2002). To overcome syntactic boundaries the knowledge is best shared through knowledge transfers. For example, a syntactic boundary can be represented in an international project, where different units of measurements are used. To overcome this syntactical boundary it is enough to agree on using the same unit of measurement. In this case, meters will be used instead of inches, so it is enough to transfer the unit

A **semantic boundary** concerns differences in understandings, interpretations and perspectives between different actors (Newell et al., 2009). Semantic boundaries highlights the fact that even if events and situations with a common frame or common language are currently existing, interpretations may often result in different understandings, which can impede and increase the ambiguity of communicating and collaborating between the actors (Carlile, 2002).

A **pragmatic boundary** is identified when the boundary create differences in interests between parties involved in a collaborative process (Newell et al., 2009; Carlile, 2002). Pragmatic boundaries can be problematic since even if the actors try to understand and see the problem from the other´s perspective, they may still disagree upon a solution because of resistance to change their practices, which is strongly considered as the "right" way of performing or thinking, and in which they are comfortable.

Knowledge transfer is considered as an important part of communication in design teams. The information exchange is desired to be more transparent and steadfast inside the team due to the fact that the better knowledge transfer can significantly improve project performance (Newell et al., 2009).

From the literature and research done in this field, we know that the main problem which hinders effective knowledge transfer is knowledge boundaries between specialists, representatives of different disciplines or different levels of organisation (syntactic, semantic or pragmatic boundaries) (Carlile, 2002). The ICT tools are seen as an effective way to overcome this boundaries with the providing a lot of opportunities for communication and information exchange. But as can be seen from the research and practice, at the same time ICT can hinder communication because of putting additional efforts on participants of design team and cause of new problems and efforts, so to create new boundaries. It is important to identify the boundaries which appear, find causes of these boundaries and suggest how to overcome them with the purpose to improve knowledge transfer with the help of BIM and other ICT tools to support communication in design team.

2.1.2.3 Boundary object

However, by enabling the usage of a common frame or syntax of reference for communicating across different fragmentized knowledge-groups, such as different disciplines or specialists within a design team, may facilitate and help the sharing of knowledge across these knowledge domains. This common frame or syntax, which helps different groups overcome knowledge boundaries and share knowledge across the boundaries are referred to as a boundary objects (Carlile, 2002). Boundary objects can be both of a concrete character, such as blueprints, drawings and prototypes, or of a more abstract one, such as visions and symbols.

An artefact is a tool or object, which facilitates and helps the mediation of certain messages connecting different groups, which are usually divided by certain knowledge boundaries. Boundary objects are such artefacts (Newell et al., 2009). Such abovementioned tools, items and artefacts that facilitate and enable the bridging of boundaries can also be technological (Yeow, 2014). ICT, is one of the many technologies referred to as fulfilling the need of a boundary object. ICT allows team participants to simultaneously and in parallel work in multiple teams and projects, by, among other things, to some level facilitating the performance of multiple tasks from a separate location overcoming certain boundaries.

Moreover, their performance is integrated in the specific situation of the specific time and space of use. This implies that they are restrictedly important and beneficial only when integrating and linking interdisciplinary work, by enabling a shared mutual common identity and model, transversely through normally fragmented disciplinary fields (Fellows and Liu, 2012).

In addition, physical and visual illuminations can be interpreted as boundary objects, especially in the construction industry (Newell et al., 2009). They play the role as a common syntax, and boundary object by enabling a shared language in form of, for example a blue print, consequently interact between professions and knowledge workers that are intrinsically separated by knowledge boundaries. This furthermore also implies that BIM, also fulfils the function of a boundary object by visually bridging different knowledge disciplines.

Moreover, according to Yeow (2014) project goals can in some cases philosophically also fulfil the requirement of serving as a boundary object, mainly because the goals may provide brief motivational orientation. However, in which manner the project is carried out does not relate to the project goal. This implies that management and managers also can be bridging boundaries.

2.1.2.4 Boundary spanners

Boundary spanners are individuals operating across one or more boundaries (Fellows and Liu, 2012). The main function and key objective of a boundary spanner is to be the spider in the web of organisations, maintaining and developing relationships simultaneously as facilitating communication transverse and between project groups, functional departments and divisions. (Newell et al., 2009). However, according to Bosch-Sijtsema and Henriksson (2014) the act of successful boundary spanning also includes the incorporating of adequate knowledge by connecting all involved participants simultaneously as setting up encouragingly proactive working sessions providing assistance in order to further binding and spanning across different disciplines and hierarchically.

Moreover, Bosch-Sijtsema and Henriksson (2014) further state that a boundary spanner in the context of a design team may be a team participant, for example a project manager, who improves the communication and therefore the knowledge sharing by connecting intrinsically diverse disciplines. In addition, the bigger the constellation of a design team is, the bigger is the need to allocate and disseminate the boundary spanning.

2.2 Concurrent engineering and BIM

Nowadays ICT tools facilitate knowledge sharing in the design team. BIM as a main ICT tool is used in construction and provides a lot of opportunities for communication and information exchange in the design team. It represents a complex concept which help to gather people and information in order to improve the quality of project execution. There is an attempt to apply concurrent engineering methods in construction with the purpose to reach higher integration between different knowledge fields and the methods and approaches are supported by the use of BIM and other ICT tools.

2.2.1 Concurrent engineering

As in many industries, including construction, there are attempts made to adapt to its highly competitive business environment. A lot of efforts are made to increase effectiveness and efficiency. The improvements regarding different collaboration aspects in the construction industry stimulate the development of new approaches to management of processes (Khalfan and Raja, 2012). One of the concepts, which are lately used more and more in the construction industry is concurrent engineering. It is originated from the manufactory and aerospace industry, and has two main principles: integration and concurrency (Zidane et al., 2015).

Concurrent engineering can be described as a comprehensive approach which primarily overlaps the activities that are usually performed in sequence and bases decision making processes on conclusions from all specialists involved, at the same time as focusing on achieving, meeting and creating a final end product equivalent to the customers' demands, requirements and objectives (Clausing, 1994).

The traditional approach in the construction industry is also characterized as a sequential process, especially in the design phase, which starts with the client setting their unique requirements. After that, it subsequently flows from the architect, to the different engineering teams and after to construction executors, where the physical production starts. These processes are highly fragmented and have a lot of disadvantages related to issues involving communication, repetitiveness of processes and unnecessary activities. According to Khalfan and Raja (2012), the process of conventional way of performing the initial phases of construction projects can be described as an "over the wall" approach, see Figure 5. When information transfers through the chain, and last department can reach it just in the final step.

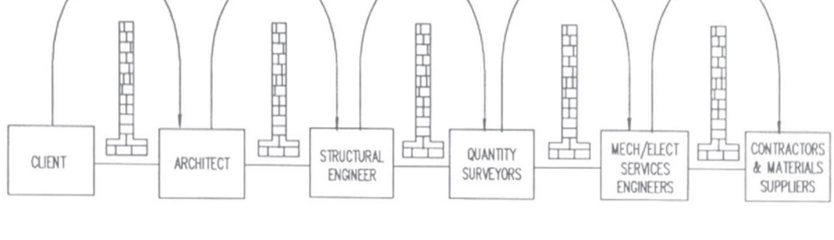

Figure 5 "Over the wall"-approach (Khalfan and Raja, 2012).

Due to the fact that nowadays construction projects become more and more complex, it is necessary to apply an integrated approach, where all participants can reach information from the early steps of design, and access it through the whole project life-cycle, see Figure 6. Concurrent engineering methods may provide a lot of opportunities, providing advantageous communication tools, making processes more transparent and helping to reduce unnecessary activities and costs (Khalfan and Raja, 2012).

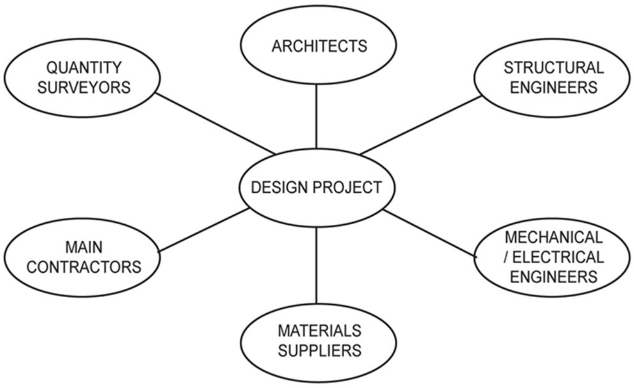

Figure 6 Integrated approach (Khalfan and Raja, 2012).

The advantage of Concurrent engineering is that it mainly focuses on the design phase, trying to improve all stages of the downstream processes. Significant amount of project costs can be decided and reduced during the planning and design phase. To achieve this goal, the integration of concurrent engineering methods is needed since the very early phases of design; it is of importance to bring all participants together and embrace all functional aspects involved as early as possible. Moreover, the integration and proper organisation of people, work processes and technologies are crucial in order to perform and meet the above mentioned goals (Zidane et al., 2015).

The main concept of such integrated collaborations implies that interaction of multidisciplinary specialists is performed concurrent (Anumba et al., 2000). The concurrent interaction from the earlier steps of the project process allows the participants to exchange knowledge, reach necessary information, discuss and solve difficulties faster and more efficient (Zidane et al., 2015). However, it is not easy to bring all the involved participants together in construction projects, as clients, contractors, suppliers etc. due to the conventional type of contract collaborations such as bidding in the beginning of a project (Zidane et al., 2015).

Conversely, concurrent engineering in the construction sector are sometimes referred to as concurrent construction, which is used to explain situations when all project activities all phases of construction, the design, construction and operational phases are joined, merged and concurrently designed. This may occur when achieving the full maturity of BIM, when executing Integrated Project Deliveries during the sequence when all phases are involved. This in order to effectively maximize the value of objective functions simultaneously as proactively adjusting constructability, operability and safety (Succar, 2009).

2.2.2 Building information modelling

In order to comprehend how communication through the use of BIM in a design phase can be improved, it is of importance to identify the extent to which BIM is applied today in the company. This is done by classifying which stage of maturity level of BIM is currently performed and to which extent it can be developed, in order to reach higher stages of BIM maturity levels.

2.2.2.1 BIM concept

There are a lot of views on BIM as a concept and how it should be developed in the future. Some of them consider BIM like a developed 3D tool for a construction specialist, some see it like a long-term concept of collaboration in project or organisation, but all of them can be divided on two general views on future development of the BIM concept (Aranda-Mena et al., 2009). The first one is complex and abstract, which has a research and philosophic orientation, taking into account many sides and characteristics of BIM. This perspective discusses how BIM should be develop in the future and which aspects should be developed to support all opportunities of BIM, which are widely described in scientific literature and has long-term orientation (Giel and Issa, 2013). The second is more linked to nowadays reality, the practical side of BIM implementation and more related to solving problems with existing tools, which is provided by different BIM-guideline literature (Giel and Issa, 2013).

There are also different viewpoints on BIM from the prospective of different participants involved in the construction process (Aranda-Mena et al., 2009). On the one hand, BIM can be seen as an advanced software application or documentation exchange platform, but on the other hand from the more complex understanding, BIM can be seen as a complex collaborative tool and concept which provides new opportunities for developing construction project.

One of the most common and demonstrative concepts considers BIM as a multi-dimensional model, where a 3D model represent all possible geometry characteristics of the project and other dimensions complete it with other related information (such as time and cost), which allow to follow virtually each phase of building lifecycle (Lee et al., 2005), see Figure 7.

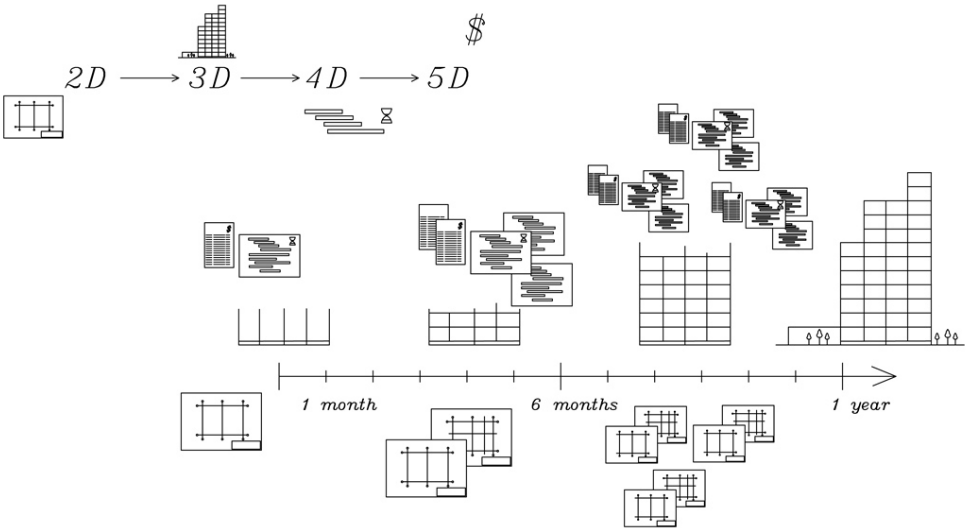

Figure 7 BIM concept.

2.2.2.2 BIM maturity levels

According to Succar (2009) BIM can be implemented in different stages, which correspond to three levels of maturity.

Collaboration on the first stage is executed with the help of a 3D model, which consists mostly of general geometry, see Figure 8 (Succar, 2009). It is represented by the transformation of 2D materials to 3D, which include basic architectural information mostly in CAD format (Khosrowshahi and Arayici, 2009). It makes communication between stakeholders easier, but it is still difficult between disciplines. The organisational behaviour stays the same, but at the same time the semantic nature of the model in this stage stimulates faster interaction between phases of construction project life-cycle (Succar, 2009).

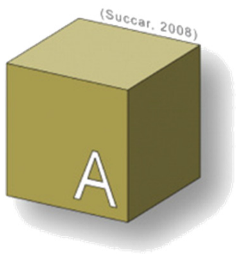

Figure 8 First stage of BIM maturity: object-based, including models (Succar, 2009: 364).

The second stage involves the integration process, which with the help of different collaborative tools and software helps to improve communication between all disciplines and project participants involved (Succar, 2009). The level of model development allows interaction between one or two project phases and connect two different disciplines. Also interchange exists between 3D models and time and cost estimation information (see Figure 9).

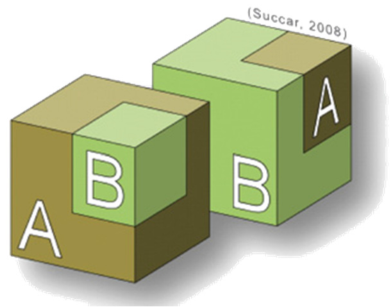

Figure 9 Second maturity of BIM: model-based, including collaboration across labour disciplines (Succar, 2009: 364).

The third stage represents the whole BIM philosophical concept. The fully-integrated model allows interdisciplinary and real-time collaboration during the full project life-cycle, see Figure 10. The phases are overlapping and it is possible to reach all information about the project (Succar, 2009). At this level of maturity the model works as nD model, where, for instance, fourth and fifth dimensions are set as time and cost, and allow concurrent collaboration of all operation during the design, construction and other phases of project (Lee et al., 2005). This level of BIM demands a change of all aspects and ways of working, such as contractual relationship, share of risk and responsibilities, tools and software. New approaches of collaboration in construction projects must be applied to make it work, such as integration project delivery, concurrent engineering, some aspects of LEAN in construction, green policies, cost estimation and other aspects of business knowledge available (Succar, 2009).

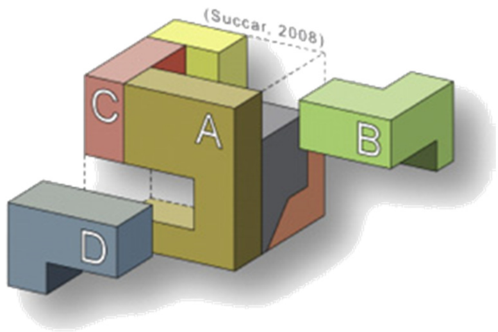

Figure 10 Third maturity of BIM: network-based where integration between disciplines occur, integrated project deliveries (Succar, 2009: 365).

Khosrowshahi and Arayici (2009) research shows that in most countries BIM is developed on the first level of maturity, just a few countries have reached the second level and nowadays it seems impossible to properly apply BIM at the third level due to the nature of the contemporary construction business environment.

2.2.2.3 Hindrances to BIM implementation

According to Eastman et al. (2008) there are a lot of obstacles to implementing BIM, which can be divided on process and technology barriers.

In general, the business environment and construction market are not ready nowadays to apply the full-working concept of BIM. But there a lot of attempts to apply some aspects of it. Most of the companies strive to avoid the use of BIM trying to save financial resources in the early stages of the project. Attempts to apply BIM usually appear when project scope is decided, financed and design is already complete. It demands more efforts from the project team and often meets resistance from its members (Eastman et al., 2008).

BIM-application demands a lot of investment and efforts to learning processes, which also take a lot of time and financial resources. Such efforts should be properly provided for by the project owner (Eastman et al., 2008).

Another big challenge for implementing BIM is that all participants of the project should be involved in collaboration as early as possible, and it is not an easy task to motivate them from the very beginning. Also a lot of legal barriers exist for applying BIM, starting from the form in which documentation should be exchanged and ending with risk allocation and sharing responsibilities. It will be difficult to transfer to the next stages of BIM, until the legal documents and contractual relationship are improved (Eastman et al., 2008).

Another side of hindrances exist are technological difficulties. IT tools and technology are not ready enough to integrate collaboration of all disciplines. There are a lot of opportunities of model development and collaborative tools exist to work and exchange information between one-two disciplines. However, the fully integrated BIM concept cannot be applied until integrated working environments are created with the help of servers, which allow easy documentation in different formats exchange and new management protocols. It explains situations in which nowadays the BIM concept is realized more like developed clash-detection tool, but not like a fully-integrated collaborative mode (Eastman et al., 2008).

Another technological problem with the BIM implementation is related to standards adaptation. There exist a lot of BIM Standards, but still they are not used in practice (Eastman et al., 2008). Participants of design teams work with the familiar formats and software, which in the end are difficult to transform and exchange through the model. To reach meaningful interoperability in the model is one of the challenging task with the BIM application. The concept of one model where everybody can access needed information in real time is difficult to reach in reality. A lot of effort need to be done to create common standards for easier information exchange between all applications (Bernstein and Pittman, 2004).

3 Methodology

The methodology of research are built on the four main steps. First, the literature review was conducted in order to get better understanding of the research field. The theoretical framework were developed with the purpose to identify and give better description of the main research field. This research aims to identify how communication facilitated by ICTs, focusing on knowledge transfers, are presently performed and which benefits the ICTs and BIM actually provide, and may further provide. The research is narrowed down to focus on a design team and the structural multi-disciplinary and inter-communicational environment and processes within it.

Second, the study was performed as single case study at the case company, a Scandinavian consultancy company, which is mainly executing engineering construction projects on the land department. The report is structured by using the case study to reveal the performance of knowledge transfers through communication in a design team, with the use of BIM, during the execution of engineering construction project. To better grasp the subject, a series of interviews with the specialists from different levels of project organisation were conducted. In order to complement the results and answer the research question, interviews with some representatives of the oil and gas department were conducted.

Third, the data gathered from the industry were analysed and discussed through the theoretical framework.

And last, conclusion was made and suggestion for future improvement were recommended.

3.1 Research design

The choice of research design sets a main direction for data collection and analysis. It narrow down the framework for analysing and generalizing the data: finding connections between variables, helps to generalize and understand data collected from the group of individuals interconnections (Bryman and Bell, 2015).

3.1.1 Abductive approach

The investigation adapted and carried out an abductive approach. An abductive approach is characterized by continuous reciprocal reflectiveness where for example the case is initially introduced; primarily it is similarly to an inductive approach, but apply more integrated process of analysing the data, which came from understanding the scientific practice, were researchers should go back and forward all time in order to get outcome which reflects reality the best (Dubois and Gadde, 2002). Thereafter, sets of different theoretical frameworks were principally looked at, mainly from an inspiring perspective. From here, a fairly holistic and comprehensive analysis was conducted simultaneously as it was continuously reflected upon which set of the theoretical frameworks it suits the best (Dubois and Gadde, 2002). Finally, a complete theoretical framework may be defined, corresponding to previous stages of the process.

3.1.2 Single case study

The case study provides an opportunity to discover a research field in the context of the real situation. It is important to clearly identify the focus of a case study in the particular field and decide if it is rational to use a single or multiple case studies. It is reasonable to use a single case study when the research question is specific and need to be studied in unique environment or within the specific team. Single studies show better results when the quality of data gathered is more important than quality of repetitive studies. But at the same time it is sometimes difficult to keep the process in track during the case study, so it should be properly structured in order to have right direction of research (Bryman and Bell, 2003).

The single case study was chosen for the research with the purpose to get particular information about research questions in the framework of one organisation and with the focus on communication in design team, which use in their practice BIM and other ICT tools.

3.2 Literature review

A literature review was executed in order to fully grasp and get initial and deeper understanding of what is already and currently known in the field of our research. In addition, it complementarily facilitates and enables which theories are suitable and moreover this consequently increases the level of legitimization of our research (Bryman and Bell, 2003). Based on the literature review, the theoretical framework consisted of the following elements.

In order to understand how knowledge transfers through communication with the help of BIM are performed in the design team it of immense importance to identify which obstacles and hindrances are present in a multidisciplinary design team environment. By recognizing, identifying and making clear which communicational obstacles, in form of knowledge boundaries, inhibit communicational knowledge transfer, we gain an understanding of how communication is currently performed.

Furthermore, in order to comprehend how communication through the use of BIM in a design phase can be improved, it is of importance to identify the extent to which BIM is applied today in the company. This is done by classifying which stage of maturity level of BIM is currently performed and to which extent it can be developed, in order to reach higher stages of BIM maturity levels.

3.3 Data collection

The semi-structured interviews were performed for the data-collection in the research. According to Bryman and Bell (2003) the semi-structured interview provides more flexibility of the process. The semi-structured approach for the interviews have the same general guide for all interviews, but allow additional questions or changing the orders of discussed questions. It provides more options and advantages to get all possible information about a research field during the interview than the structured interviews with 'yes or no' questions, but still semi-structured interviews should be planned well and questions need to be clearly set.

In order to collect information and give the practical insight for research, seven interviews with specialists from the case company were performed. In order to provide an objective view on the use of BIM and other ICT tools, the following pre-criteria were set: interviewees had to be selected from the different levels of organisational chart, they had to represent different disciplines, and they should be familiar with the concept of BIM. Two interviews were performed with the specialists from the oil and gas department, so information could be analysed and compared to what we received from construction industry.

Each interview took approximately one hour. The notes were made during the interview and some of them were audio-recorded with the previous permission from interviewees. The semi-structured interviews consist of the questions around implementing BIM and ICT tools in organisation, which are divided into six groups. The first group of questions introduces interviewees and theirs roles and responsibilities in organisation. The second group consists of questions regarding definition and perception of BIM and ICT by specialists. The third group is about communication and how BIM and ICT tools support the design phase of construction projects. The fourth group of questions related to design team and meetings. The fifth group is about BIM and ICT tools implication and challenges connected to it. The sixth and last group consists of question which can give view on the future of BIM and other ICT tools. It gives information how specialists see the future of such tools and how it can be improved for their work in future.

3.4 Data analysis

The data collected through the interviews were audio-recorded or written down. The audio-recorded material was also written down later. Some interviews had to be translated from the Swedish language to English. After each interview was structured with the same order in order to compare answers from the different interviewees. This first analysis of data become the basis for the result chapter of this report. The information about research field were written down with the purpose to get impression of practical outcome about research field. The results were considered through the theoretical framework for the discussion of the research. And finally, conclusion were made to provide objective answers on research questions.

4 Results

The chapter presents results from the case study and information gathered from the interview with the specialists from the company. The structure of the company design team is described in the chapter and outcome from the interviews data presented in order to provide understanding how communication in design team is currently performed in the company, which opportunities the ICT tools provides for this process and how it supports knowledge transfer between the different participants of design team.

4.1 The case study

The case company is a technical consultancy firm originated from Norway and the oil and gas industry, but today they specialize in several different technical areas, such as infrastructure and construction. It is a family owned company and has the strongest presence in Scandinavia and its vicinity with about approximately 2700 employees, and their main office is located in Trondheim, Norway.

The teams, which work with the construction projects usually consist of specialists from different disciplines. There are a lot of different projects running simultaneously and in parallel at the company. In order to handle the collaboration between wide ranges of different disciplines in a multi-project environment, the company is currently implementing a concurrent engineering design method, both on the off-shore oil and gas department and on the Land side. However, the Oil and Gas department have developed a dynamic concurrent design method with appurtenant software and ICT-tools, which the Land department tries to implement as well. For this purpose, the Land department will adopt and implement Building Information Modelling, BIM, as the main ICT-tool process, in order to achieve these goals. What is characteristic for BIM is that the associated tools allow involvement of all participants from the early phases of a construction project. In addition it allows work in parallel on different parts of a project simultaneously as it facilitates communication through the use of innovative ICT methods (Reinertsen, 2015).

4.1.1 Design teams

The disciplines that are involved in the design team are considerably depending on which specific project is subjected and how large-scaled it is. However, usually all disciplines are somehow involved in most projects. The different disciplines involved in the design phase of infrastructure projects can generally be categorized in:

- Road
- Construction
- Water and sewer
- Landscape
- Electro
- Geo-technique
- External Environment (Norwegian)

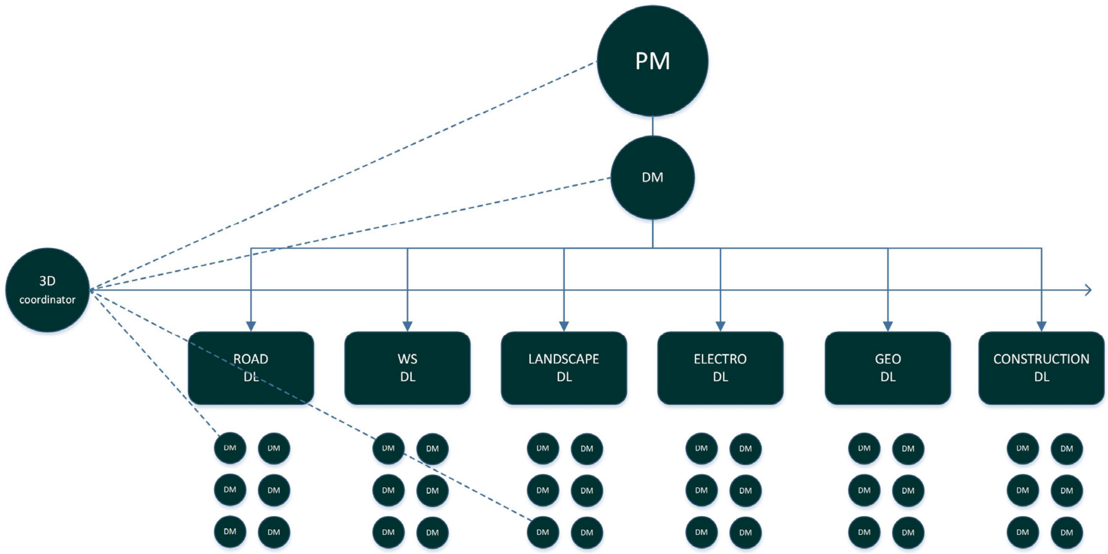

Figure 11 Organisational design chart.

In addition, some projects require knowledge that is abundantly specialized and which may not be performed by the in-house resource work force due to lack of specialization, like for example landscape architects or geo-technicians. In these situations, external consultants are hired to perform the special tasks due to the lack of resource on the in-house front. However, it is in most cases preferable to use in-house staff, because their working and reasoning methods and structures are often already pervaded and corresponding to the rest of the company's.

Currently, there is an up-going trend regarding certain contract-forms, which is more and more commonly worked towards, which are turnkey-contracts. This implies that the design team may only have one channel of communication with the contractor/client.

Usually during the competitive procurement and acquisition process, in the tendering offer it is commonly already decided, designed and pre-mediated who will be responsible for how the design team will carry out the work. The tendering designation appoints the head Project Manager (PM), the Design Manager (DM) and the main responsible for each different specific discipline-team. This latter function is addressed as the discipline leader (DL) role.

The Design Manager role, are sometimes also referred to as an engineering manager, is often possessed by a person with a technical background often originated from a discipline group in the design team.

The main idea is that the Design Manager and the different discipline leaders assigns the specific member from the own discipline group according to the experience and knowledge corresponding to what have to be done in the specific project. However, usually, there is not much room for selection and the resources, which are available, are often the ones that will be selected. The discipline members that are appointed to work in the specific project, will also be presented in the procurement process, similarly to a team-formation or a presentation of a team, with their profiles and earlier experiences clearly stated.

The discipline leaders role during the executive part of the design phase is mainly to coordinate, monitor and follow up the work in the discipline team, which generically consists of approximately 10 persons, simultaneously as acting as a communicative link with the other disciplines leaders' in order to follow up the design work.

4.2 Results from the interviews

In order to reflect the outcome from the interviews and address it in relation to the research questions, the main aspects of communication are taken up, such as meetings in design team, knowledge boundaries in organisation, use of BIM and other ICT tools.

4.2.1 Meetings in the design team

The amount of meetings in the design team varies, and highly depends on which project, the client and who the Project Manager is. Most often it is the project manager who evaluates when it is good to have meetings and how often.

Many meetings require that people from different offices and disciplines have to gather and meet up. However, because of the quite dispersed location of the discipline members and the design team, it can be very time consuming and expensive to travel around and always make sure everybody meet up on the same location, so a lot of meetings are conducted as video-meetings through computerized video-meeting systems.

The video-meeting systems are purpose-designed computer based enterprise software used by companies in order to satisfy the need of communication, integration and information sharing between members. According to the interviewees, the video-meeting systems are a fairly good solution overcoming geographical boundaries and when having members of a design team on split locations. The software enables multiple members discussing and working together and simultaneously with their models on split and mutual screens even though they are dispersedly located. Within the consultant firm, there were initially issues with the time of update of actions for the recipients when working together on common screens. Due to the recent technical improvements, the updates currently perform relatively well to real time.

However, the video-meetings cannot fully correspond to face-to-face meetings according to some of the interviewees. The interviewees claim it is not always that everybody perceives and understands what was exactly discussed and decided during video-meetings. So in addition, not to neglect this information to be lost, it is important to document what was said and decided during the meeting, in order to make sure that everybody understood the meetings objectives. The meeting protocols are sent out (through e-mail) to all disciplines to transmit and mediate the mutually written information. The e-mail traffic generally tends to be considerably extensive, resulting in the need of prioritizing which e-mails to manage and deal with, especially by some of the middle managers in the design team. In addition to this, the objectives discussed in the meeting are also documented on a server, and are available whenever somebody may need it.

The larger a meeting is, the more important issues are discussed and the more different disciplines are involved, the bigger is the need to write down and document it and share it, according to the interviewees.

From our interviews we found that within the design team, there are different types of meetings:

- Project meetings, with client, discussion of contractual and economical issues.
- Design Review meetings, including the discipline leaders, the 3D-coordinator and the design manager. This fills the function as a design coordination meeting, where the aspects of technical, safety and quality issues are reviewed. These meetings include the action of clash-detection between the different disciplines 3D-models and also confirmation that 2D and 3D models correspond to each other. The design review meetings are often conducted in relation to deliveries, which, depending of project, generally occur at 50%, 80% and 100% of project completion.
- Discipline meeting, which are meetings between the different disciplines leaders, where issues on a trans-discipline level are discussed. They occur approximately once a week.
- Internal meetings, within each discipline group, which are more of an informal character.

In addition, the design teams have concurrent work sessions, which are one of the effective multi-disciplinary work approaches according to most interviewees. Either the design team, from different disciplines work together in the same room on the same location or, if they are located on split locations, they work through video-meeting systems, where they can work on shared computer screens. Interviewees stated that design review and concurrent meetings both had a positive domino effect on integrating different inherently dispersed discipline groups and were an ice-breaker in further discussion between all involved participants of all kind of issues. But still the concurrent working sessions can be time-consuming and when working on split locations on shared computer screens, interviewees sometimes perceive this as slow and with hacks because of connectivity issues.

In general, in an early stage of a collaborative project, all members from different disciplines, which are located on several different offices, meet up on kind of big start-up meeting, enabling all members involved in the design team to meet physically and to mutually understand and connect to the project. The meeting and communication thereafter are mainly performed through phone, mail and to some extent video-meetings.

The longer into a project it is, the less need for meetings. However, the rate of meetings can increase if there is a need for it closely to deliveries.

Meetings play an important role in the performance of design team. It sets up main objectives of the project and provide all participants with understanding of main steps of the project performance. Due to the nature of the design team and complexity of construction projects, the communication and information exchange is quite challenging process. The way how meeting are performed and which outcome each member can get from it, directly affect project performance and success. Meetings in the design team, where the most of participants involved, is a real source of information, it stimulates problem solving and decision making. But still, as case study shown, there are a lot of difficulties with the information exchange during the design meetings in the company. Misunderstandings, lack of collaboration and integration and other factors can slow down knowledge transfer between team members and create boundaries. The set up of different types of meetings helps the firm to overcome these boundaries with providing opportunities to share information between different levels of organisation or specific groups, as for example discipline meetings. Design review meetings provide participants with artefacts, such as drawings or project documentation, so they can come to common understanding and find solutions. In the case company the 3D model supports a common understanding for all meeting participants, but still, according to interviewees, it need to be significantly improved in order to reach a higher level of integration and collaboration between different disciplines.

4.2.2 Knowledge boundaries in design team

As was stated before, design teams have a complex multidisciplinary structure. In the case company a design team is big, consists of different departments, has a complex hierarchical structure and faces additional challenges. For instance, working with the few big-scale projects in parallel or in geographically spread locations is one of these additional challenges. All these obstacles can cause communication problems between participants of the design team. Interview results shown there are a few types of such hindrances that slow the information exchange and knowledge transfer between participants. These hindrances can be seen as knowledge boundaries.

The knowledge boundaries that were identified are illuminated as the dotted red lines in the Figure 12.

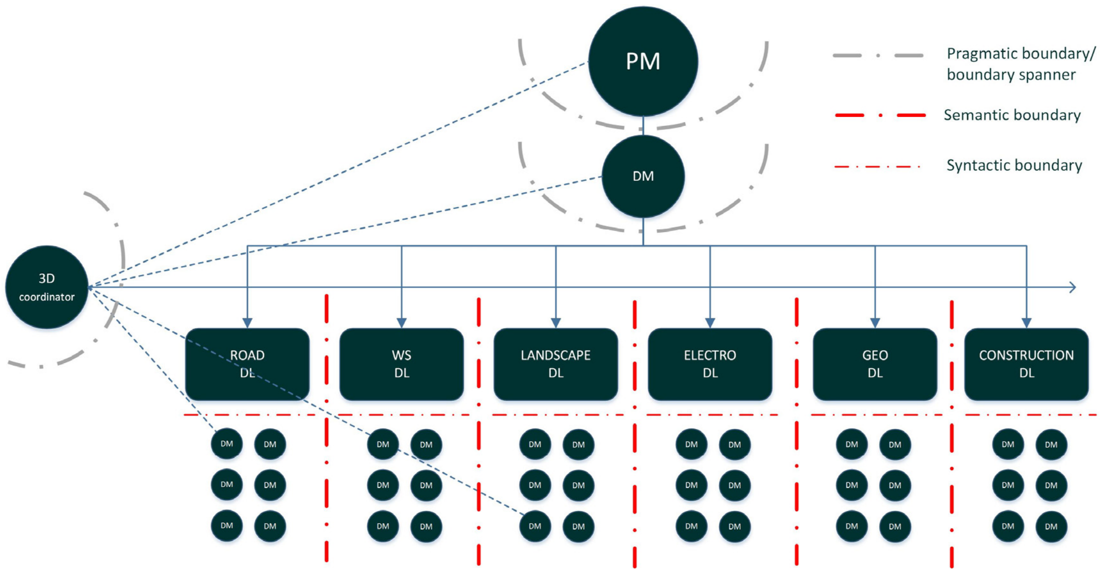

Figure 12 Knowledge boundaries in organisation.

The red thinner line shows syntactic boundaries, which appears between specialists from one discipline group, that have the same background, but still have difficulties to perceive and interpret information in the same way. As was seen from the interviews, these challenges are seen as misunderstanding between people, who work on the same projects and perform the same disciplinary part of it. Usually such misunderstanding appears due to a lack of information at the moment of performance needed or delay of such information, lack of integration between different parts etc.

The thick red line presents the semantic boundaries, which are the most common in the case organisation, and are common in the industry. It appears between different disciplines, which work on the same projects due to the fact, that perception of information is different and is highly depended on background and experience of each of the team members. At the case company it can be difficult sometimes to put information together for different departments. It happens because all departments for a long time work in their own environment, and try to put together the results of their work only in some periods of time. The integrated result of their work is impossible to see in real-time during the whole period of the project. Also different disciplines have their own specific knowledge, experience and way of working, which is not easy to understand for other disciplines.

The grey lines show pragmatic boundaries between different levels of the organisation. It can appear, for example, between project manager, design manager and discipline leaders due to the differences of seeing the main goals and objectives of the project and interpretation of information according to their own responsibilities.

Based on the abovementioned description of the design team, the observations in compliment to the interviews revealed that there are actually innately two different governing fragmentations of the design team, which is shown in the Figure 13:

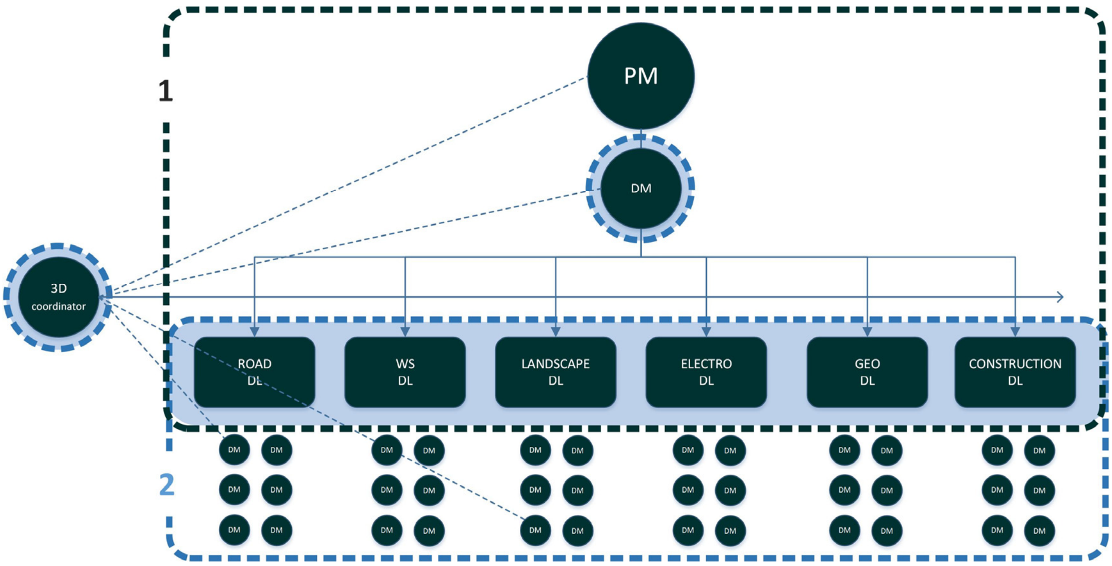

Figure 13 The illumination of the innately two different governing fragmentations of the design team: 1) Decision-making and 2) Execution.

1. The project manager, the design manager and the discipline leaders are the ones that communicate with the client and they are the ones that decide and are responsible for the design, how everything will be executed and how things will work in the design team. They are the **decision-making design-team** that designs how the design team it is going to work.
2. Different members from each different discipline group that are working on the same project are members of the design team that carry out, execute and

do the actual work, which will be delivered and which the disciplines leaders and project manager designed and decided in accordance to fulfil the client's requirements. They are here addressed as the **executive design-team**.

The observations additionally allowed an identification of pragmatic boundaries whose emergence is decisively originated from this design-team constellation above. However, it was also stated that some of the discipline leaders and design managers (that usually have a previous background as discipline members and/or discipline leaders) had the function as a boundary spanning entity.

Specifically, the implementation of new ICT-tools, in this case the implementation of 3D-models within the design team met resistance. In the situation of resistance against implementation of 3D-model usage, the 3D-coordinator plays a role as a boundary spanner. With the help of additional tools and methods available, the 3D-coordinator is trying to provide participants from different levels with the common understanding, so it will be easier to overcome boundaries that arise between them.

4.2.3 BIM, ICT and communication

BIM is described as a 3D-model, which is used as a technical virtual tool for design and construction. According to interviewees, currently BIM is solely used as 3D-models in order to conduct collision controls and to see if there are any unnecessary extensions in the design. The applications of BIM are limited to exclusively detect collisions of volume, masses and geometry and for visualization purposes. The clash detection features minimize the risk of collisions when constructing on the construction site and the visualisation is of advantage in presenting purposes, mainly used by the client. However, the future perspective is that the BIM 3D-model should consist of integrated models of 4D, which represents costs, and of 5D, which symbolizes time.

From a communicational perspective, the BIM models in the shape of 3D-models provide communicational advantages. According to interviewees, when conducting model-meetings, everything revolves around positioning and putting together an interdisciplinary mutual merged 3D-model with clash and collision controls. The clash detection model-meetings consequently result in started discussions of other important subjects, issues and problems.

The 3D model helps to visualize and put together project information from all disciplines. It consists mostly of general geometry, which helps to see general collisions in different parts of a project. The information is gathered in in the model in one certain format while the each of specialist works in their own model in other format, so most information including drawings properties cannot be transfer to the main model, just general geometry information.

According to the interviewees, the 3D model works as a communication tool during the project meetings, where clashes and collisions are discussed and written down. When clashes are identified, each discipline goes back to their desk and their drawing. In drawings they fix and change the problem, convert the drawing to a 3D-model and the 3D-coordinator put everything together in the main 3D-model, to detect new collisions, see Figure 14. This process is continuously on-going back and forward until there are no more collisions. Sometimes they do deliveries with collisions, because the drawings are still the most important. Also a general 3D model is available on the server, so everybody can see what should be fixed.

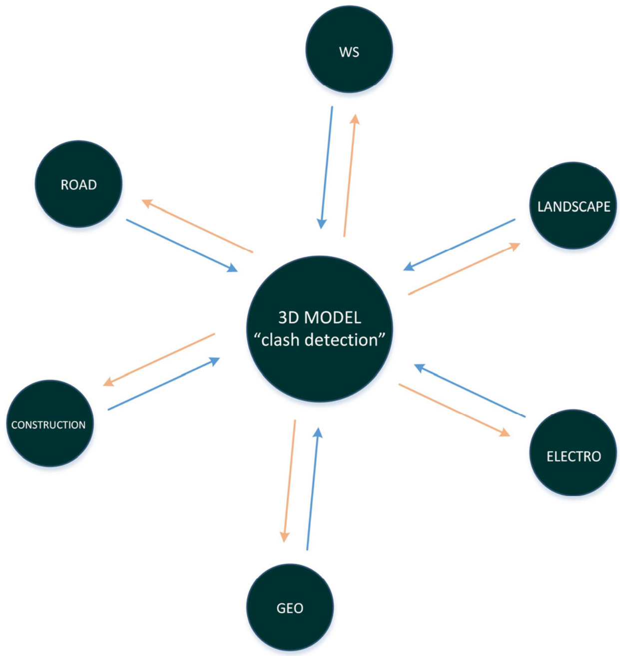

Figure 14 3D coordination from the case study (based on the interview data).

As it was concluded from the interviews, the process is perceived as quite inefficient and interviewees see a need for automating the process. Today there are attempts within use of beta version of Novapoint DCM model to make possible collaboration real-time and make model meeting more concurrent in the future.

4.2.4 Implication of BIM

The BIM processes enables problem-solving on a different dimension which was not available before. According to interviewees, BIM primarily enables a mutual platform where different disciplines, regardless of locations, can support work in real time and continuously see what the other design team members do, according to a concurrent design method. This is the aim of BIM and this is the main advantage. However, it is not fully implemented yet.

Today, out of a practical point of view, the main focus is on finishing 2D drawings, which are currently always prioritized. The 3D-models are created from the conducted 2D drawings. The aim of the case study in the future is to let BIM evolve and be implemented, with a simultaneous improvement of software and technologies to the extent that the 3D-model will be the number one prioritized main model. From the main 3D-model, it will be possible to take out 2D-drawings, fairly in opposite of how it is done today. In addition, this will further enable a better integrated and performed concurrent method by allowing all specialists and disciplines work in one model simultaneously.

According to the interviewees, the disadvantageous impacts of implementing BIM in the design team are that it provided a higher workload for everybody. Traditionally, it was sufficiently enough to produce and deliver a 2D-drawing. Today, the client most often also requires a corresponding 3D-model to the 2D drawings, which they did not require before. Everything has to be produced in the same timeframe as before. The 3D-models have to be fairly detailed, which requires more time to do and more work and the producers of the drawings have to take additional time to learn the 3D software. Everything has to be done in the same time-frame as before, however, without any additional motivational incentives to correspond to the higher workload. This implies the process of implementing BIM may initially be quite time-consuming and the implementation process may be subjected to resistance to some certain level. There are some indications that the resistance appears to be of a higher degree for people that have a higher level of experience from the former traditional way of working.

According to the interviewees, the increased needs of conducting correct and detailed 3D-models that in detail correspond to the 2D-drawings have resulted in additional responsibilities in comparison to how it traditionally was. Today, the drawings have to be more accurate than before, only because they constitute of the fundamental geometrical basis for the 3D-model. Before, when only delivering drawings, a 2D drawing could be less detailed, where some detail issues could simply and easily be solved by craftsmen on the construction site.

Holistically, the implementation of BIM, as an advantageous technological tool, is expedient on all phases and levels of a construction project. Defects, collisions and conflicts that traditionally were first detected on site during construction, causing sudden and unexpected unforeseen cost and time overruns are with the help of 3D-models already detected and corrected in the design phase, which may decrease the detections of conflicts and corrections on site and consequently it may save unnecessary cost and time overruns. However, according to interviewees, one consequence and impact of this holistically advantageous progressing development of BIM is that the specific discipline team members involved in the design work are increasingly deluged by new additional workloads, in the same frame of time and remuneration as before, implying that the discipline member are not individually benefitting from this general benefits that BIM provides.

To the extend which it is used today it is possible to detect conflicts and clashes. BIM provides 3D software models, which can be done very detailed, and it can be very time consuming to do all the 3D details.

4.2.5 Experience of ICT implication from oil and gas (BIZ-model)

The department of oil and gas industry at the case company uses a BIZ model for the collaboration through the design phase (see Figure 15). BIZ is a powerful tool for collaboration, which represents 3D models where all information from different disciplines is gathered. It consist of drawings, specifications, schedules etc. Moreover it helps members from different disciplines to collaborate and get all needed information easy and fast. If members from one discipline need any information from another discipline they can get it from the BIZ. In this case s/he needs to contact the information systems group, which works as a coordinator and has access to the main model. And in turn the information systems group should contact responsible person of each discipline, to demand information through the BIZ model. The system works as an engineering protocol and provides all opportunities for real-time two-side collaboration of a design team.

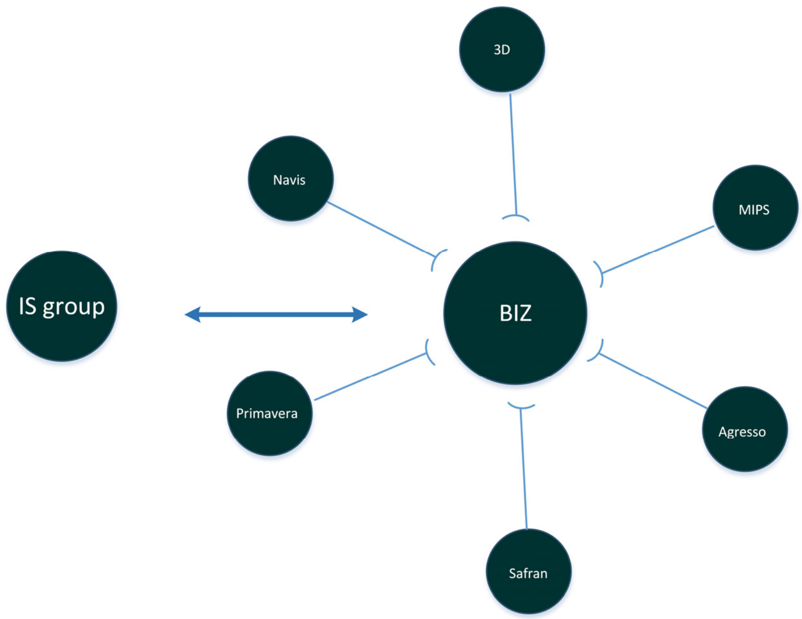

Figure 15 BIZ-model (based on interview data).

5 Discussion

Chapter 5 consist of discussion and analysis of the empirical results within the theoretical framework with the purpose to answer main research questions.

5.1 Knowledge transfer through the communication in design team

According to Newell et al. (2009), individuals undertake work roles, that are different in hierarchies, responsibilities but most certainly in knowledge and proficiency. On top of this, the individuals are influenced by different interests and governed by different political itineraries. These diverse discrepancies set the inherent foundation of knowledge boundaries and their intrinsic nature imply the difficulties that comes with when dealing with knowledge boundaries. In addition to this, the design-team has a complex multidisciplinary structure where it operates in a quite competitive environment, which makes collaboration between participants more difficult (Dainty et al., 2006).

5.1.1 Syntactic boundaries

Within each discipline group there are theoretically syntactic boundaries (Newell et al., 2009). In every discipline group, each group creates their own unique language in order to homogenize and enable simplification of their internal interactions. By identifying each other's differences and creating a shared language, it is possible to break down and overcome a syntactic boundary and enable knowledge to be transferred (Newell et al., 2009).

From the observations and the interviews, syntactic boundaries were identified in the interactions within discipline groups where members where located on dispersed and split locations.

For example, the members of a certain discipline group sitting in the Gothenburg office and the members of the corresponding discipline group settled down in a office in a location in Norway are exposed to syntactic boundaries. The geographical separation in split locations may be one of many causes for dis-unifications of a syntactic character (Newell et al., 2009; Yeow, 2014).

However, by enabling ICT-tools in form of videoconference systems, which is identified as ICT as a boundary object (Yeow, 2014), it is possible to overcome syntactic boundaries by creating a common language for transferring knowledge with the help of ICT-tools (Newell et al., 2009). The video-meetings are a rather effective way of preventing the arising risk of syntactic boundaries and dis-unification between colleagues that are geographically located in different offices in split locations.

5.1.2 Semantic boundaries

Semantic boundaries (Newell et al., 2009) were identified between the different discipline groups. Semantic boundaries highlight the differences in specialized conventional interpretations and meanings between different discipline members in a design team. Each discipline member is often highly specialized within their own discipline, causing fragmentations. To overcome a semantic boundary it is not sufficiently enough to transform the knowledge through connecting over a common syntax as it is in a syntactic boundary, because the degree of novelty is significantly increased within semantic boundaries (Carlile, 2002).

In this case, the knowledge cannot be transferred because of ambiguities. It needs to be translated (Carlile, 2002; Newell et al., 2009) which consequently can enable new and shared meanings so that the different discipline members can be able to identify and appreciate the differences in knowledge by taking on the perspective of the other discipline. This may allow a reciprocal sharing of knowledge between different discipline groups.

Currently, out of a structural point of view, by focusing on the operating inter-disciplinary working structures, the knowledge boundaries are initially and inherently not confronted although they exist. This is made by coordinating the main work of a project, and dividing it up to each relevant discipline. Each discipline can thereafter do their work and then the work is put together, different discipline members are avoided to interact and confront other discipline members, in their own developing work. This interactive confrontation is usually made first during the put together of moments.

However, the implementation of concurrent work sessions, and design review meetings, enables the different disciplines to interact, both physically and virtually.

By confronting the semantic boundaries, the differences in knowledge will most probably generate a conflict of ideas (Newell et al., 2009). However, this conflict may be advantageous and will mostly influence creative thinking.

Another way of confronting semantic boundaries are the usage of visual representations as boundary objects (Newell et al., 2009), in form of for example blueprints and especially in this case: 3D-models and BIM. The 3D-models obviously work as a platform for facilitating communication, and knowledge sharing across different disciplines and therefore bridging semantic boundaries.

5.1.3 Pragmatic boundaries

Firstly, the design team may innately be divided into a decision-making management oriented team consisting of the project manager, the design manager and the discipline-leaders and in to an executing engineering and technically devoted team; consisting of the discipline group members and in some extent of the discipline leaders.

This is where the pragmatic boundaries may exist in this case study. The pragmatic boundaries are generated by differences in interests between participants involved in a collaborative effort, in this case, the design team (Newell et al., 2009). However, according to Carlile (2002) disparities in knowledge are not necessarily always dissimilarities subjected in interpretations, the article argues that the boundary may be knowledge connected to practice as well.

To overcome pragmatic boundaries it is not sufficiently enough to translate knowledge and understand the other parts' perspective (Carlile, 2002), there will still be contradictions, conflicts, disagreements and no solution, because the participants do not want to change their own practice. When the conversion from a semantic to a pragmatic boundary occurs, the task novelty and the dependency increase and therefore also the uncertainties (Newell et al., 2009). The members have different invested interests and incentives, which can cause a conflict, which consequently may negatively undermine certain participants.

In the state of a pragmatic boundary, knowledge has to be transformed (Carlile, 2002) in order to support the specialists to translate each other's knowledge and practice and to transform their own practice as a result (Newell et al., 2009). In addition, stated by Carlile (2002), this alternated transformed knowledge that settles the bridging of a boundary can innately and subsequently be derived to new knowledge. This implies that this new knowledge alternated to overcome a pragmatic boundary may be regarded as a foundation of generating new innovative solutions. However, this paradoxically result in new knowledge

In some situations incentives may play an important role (Newell et al., 2009) to encourage the transformation because this may motivate members to agree upon the counterparty changes and adapt it to their practices.

The project manager and the discipline members may theoretically be subjected to pragmatic boundaries. The project manager is administratively minded, with a focus on satisfying the client in the frame of time, cost and quality, implying that there is no consensus for more detailed technical and practical practices, which are executed by the members of the executing engineering and technically devoted design team. The executing design team on the other hand only see the solutions in the scope of their specialization.

A good example of a pragmatic boundary that was identified, or the situation was recognized to be a consequence of a pragmatic boundary (Newell et al., 2009), were the case of the resistance against implementation of 3D-models within specialists in the discipline groups and people with experience of performing their work differently, because of increased workloads and responsibilities.

For example, discipline group members or discipline leaders opposing new effective implementations that subsequently increases their group and individual workloads and the responsibilities of their own, as well as their subordinates work, may oppose everything that the actual boundary spanner (Bosch-Sijtsema and Henriksson, 2014; Newell et al., 2009) proposes and suggests connected to BIM or concurrent engineering novelties, this because of the discontents that these actions are resulted in. In order to avoid resistance and opposite contradictions, according to the interviewees the boundary spanners sometimes have to use substitute expressions of BIM or Concurrent design to avoid negative response and resistance from subjected participants.

Nevertheless, incentives may play an important role to overcome, or facilitate the attempt to reduce pragmatic boundaries in form of resistance, dissatisfactions and discontents amongst the ones that has a reluctant view on, in this case, BIM and concurrent design.

Perhaps by encouraging quality of for example 3D-models, by providing an adequate act or incentive that will encourage someone to do partially accept the new implementations will perhaps be a measure that may facilitate, obviate or to overcome the pragmatic boundary.

5.1.4 Boundary spanner

In this case the 3D-coordinator and the discipline leaders, and the design manager, may, depending on which individual and which background may have the function as boundary spanners (Newell et al., 2009) because they “have a foot” in both the administrative and technical world, filling the function as a mediator and a bridge between the different sides of the pragmatic boundary. The attributed boundary spanners in this case are underlined with blue back colour in fig.13. However, the project manager may also play a crucial role of boundary spanning, by supporting and unifying the two conceptually separated design-teams in order to overcome boundaries (Bosch-Sijtsema and Henriksson, 2014).

From the observations and interviews it was understood that the discipline leaders and the design managers have both technical backgrounds and are familiar with the work of the discipline members, simultaneously as they have to answer and respond to the design manager and the project manager. In addition, the 3D-coordinator also fills the function as a boundary-spanner, by facilitating the work involving 3D-models, which is in fact identified as a boundary object (Newell et al., 2009; Yeow, 2014).

At the same time, the structural role of the boundary spanners, in this case the 3D-coordinator, the discipline leaders and/or the technical managers, may inherently and paradoxically be the cause of pragmatic boundary irregularities, as in abovementioned pragmatic boundary situation of implementing new ways of working. This situation can be explained with the effect, when new innovative knowledge that was generated to bridging a boundary, like for example when transforming knowledge to overcome a pragmatic boundary (Carlile, 2002; Newell et al., 2009), may paradoxically result in new learning boundaries.

The learning boundary becomes an additional challenge, which boundary spanners should deal with in the organisation. According to Newell et al. (2009), the more knowledge boundaries that are solved and have been overcome within a design team on a specific project, the more new shared practices are generated within these specific participants and specific project and the greater will the learning boundaries between the specific project and the rest of the design organisation. The new-shared practices are now knowledge different from elsewhere.

5.2 3D-model as an boundary object and communication tool

Boundary object help to create a shared meaning and common sense between the different disciplines, so all participants can meet in the same point of understanding (Carlile, 2002). As was said before, it can be seen as a tool, which helps to connect different groups of people with providing a shared meaning and common syntax (Newell et al., 2009). It can be used as a tool for representation, learning and transforming knowledge in order to overcome hindrances which create certain boundaries (Carlile, 2002). In this case, the video-meeting systems serve as a boundary object (Yeow, 2014).

Moreover, a 3D-model as an advanced visualisation tool can help to improve interaction between members of design team (Bosch-Sijtsema and Henriksson, 2014). From a technical perspective, the 3D-model, as a way of visual representation of information, has the function of a boundary object (Newell et al., 2009).

The Figure 16 shows the collaboration process between different disciplines in design team with the help of 3D-model. Red lines represent the semantic boundaries, which, as was told before, reflect difficulties in understanding between the members of different discipline groups (Newell et al., 2009).

Figure 16 3D-model as a boundary object.

According to Carlile (2002), the boundary object should facilitate common language inside the design team. The 3D model provides this opportunity as a system, which gathers information from all disciplines and presents it in the form of 3D visualisation, which can be easily understand for all participants. In order to overcome semantic boundaries, it is important to provide a better understanding of information which differs between disciplines (Carlile, 2002). Usually, according to the interviews, the 2D-drawings causes the most of misunderstanding between disciplines, so 3D information is more helpful in this case. But still, there are difficulties existing with the transformation process.

The drawings, that each discipline team member performs, are later shaped into a 3D-format, which is then up-loaded on the 3D-model. As was said before, a lot of information is lost during this process, and it cause collisions and misunderstanding.

According to interviewees, the 3D model is a powerful tool which provides a lot of opportunities for improving project performance, especially in the part of multidisciplinary collaboration, but how it is still very limited today. The disciplines can only put in information but not extract any information.

The 3D-model still needs additional tools to fill the functions of having full interoperability (Bernstein and Pittman, 2004) and having all the disciplines working together in one model simultaneously. This is mainly a technical issue, but it does imply that BIM have the possibilities to improve the communication in the design team even more. There is still lack of integration, which, according to Bosch-Sijtsema and Henriksson (2002), can support better collaboration.

In order to fully understand how the communication is performed it is important to emphasize how the design team is structured organisationally, and which implications each specific role has for the functions of the design team. It is important to know that communication success is highly dependent on the roles in design team (Bosch-Sijtsema and Henriksson, 2014). And hence this will tell where the knowledge boundaries are located and how the knowledge transfer through communication is performed.

5.3 BIM development and application of concurrent engineering in construction

The case company is trying to apply a concurrent engineering (CE) method in construction projects as an advance approach, which supports communication between participants of a design team. As was stated before, there are a lot of attempts to improve project delivery in construction within the schedule and shorten processes duration, both in design and production phase (Khalfan and Raja, 2012). Concurrent engineering methods can help a lot with this due to their basic concepts: integrating the processes and making participants work in parallel and concurrently (Zidane et al., 2015). Also concurrent methods provide benefits due to a better involvement of all participants and improvement of decision-making process, which is important for good communication and knowledge transfer in the design team. The method is used for the oil and gas industry and it shows good results in project delivery process, but it is still has a lot of challenges with the application it in construction (Zidane et al., 2015). There are characteristics within industry, which are important to understand for implementing this method in construction. The first are the difficulties with involving all stakeholders from the early steps of the project, which is crucial for integration as a part of concurrent method (Zidane et al., 2015). The second is related to the nature of contractual relationships, which is built mostly on bidding, and results in the situation, when clients, that are usually not part of industry, select contractors and suppliers according to the lowest bid. This results in the situation, where all participants are involved in the different steps of timeline (Knight, 2008). The last characteristic is fragmented nature of the construction industry, which makes challenging attempts to involve the range of different participants at the same time from the early steps (Zidane et al., 2015).

There is also another technical problem, which hinders the implementation of CE methods in the construction design process. According to Anumba et al. (2000), the successful implementation of the CE method in construction has a need for an efficient communication system, which supports collaborative work of different participants. Parallel and concurrent work demands powerful tools which support communication and documentation exchange during the design phase (Khalfan and Raja, 2012). IT should be easy to upload and get any information about the project during the whole project life-cycle. As was stated before, BIM tools play this role, but this is still is not developed enough to provide all necessary possibilities as an integrated system (Khosrowshahi and Arayici, 2009).

Nowadays BIM works as a virtual 3D model, advanced visualization and collision control instrument, but is not yet applied as a complex database or integrated system.

This stage of BIM development corresponds to the first level of BIM maturity, where in the same time there are attempts to make it work on the second level, so it will support multidisciplinary collaboration more (Succar, 2009).

The use of integrated approaches, as the CE method, together with the support of ICT tools can significantly improve problem-solving and knowledge transfer processes in between members of interdisciplinary design-tem (Bosch-Sijtsema and Henriksson, 2014). In this case BIM has big potential in the development of construction projects, especially in the design phase, but, as was concluded from the case study, it still needs big efforts and investments from all participants of design team. It means, that today BIM creates as much benefits as a problems. Due to the fact, that technology and contractual forms are not developed enough, specialists have higher workload and should put additional efforts to make it work proper (Knight, 2008).

However, it is no doubt that BIM has a big future in supporting communication and knowledge transfer in a construction design team. As was seen from the interviews, specialists have a really optimistic view on the future of BIM and they are ready to investigate in BIM development process. For this purpose new roles and responsibilities should be implemented in organisation, organisational structure and strategy should be rethink according to new opportunities which technologies provide. At the same time a big shift should also be done in governmental process and contractual relationships in construction.

6 Conclusion and recommendations

The main aim of the thesis was to discover how the communication in multidisciplinary design-teams are performed, with the help of BIM and other ICT-tools, how it supports the knowledge transfer processes and which intrinsic hindrances exist in this environment.

The role and implication of BIM and other ICT tools were studied in detail with emphasis put on implementing and further improving BIM and the ICT-tools with perspective on how to further improve knowledge transfers in the design team.

In order to investigate this aim, a literature review was performed with the purpose to provide better understanding of the theoretical research in this field. Thenceforth a case study was done in order to get practical insight for the research questions.

This chapter presents the conclusion, which answers the research question raised in the beginning of the report. Moreover, the chapter also presents recommendations for a future research in the field of the study.

6.1 Conclusion

Research question 1 - How is knowledge transfer through communication currently performed with the help of BIM and other ICTs in design teams in engineering construction projects?

To fundamentally understand how knowledge transfers through communication with the help of BIM and other ICT tools applied in the design team, it is of immense importance to recognize which obstacles and hindrances innately exist within a multidisciplinary design teamwork environment. By identifying and recognizing the communicational hindrances and obstacles, in the form of knowledge boundaries, and how they subsequently hinder communicational knowledge transfers, gives an understanding and reveals the status of how the knowledge transfers are performed currently.

Due to the nature of the design team, which is characterized by complex interactively embroiled hierarchical structures involving a range of multi-disciplinary parties, three types of boundaries were identified as the main hindrances to knowledge transfer between participants of design-teams: syntactic, semantic and pragmatic boundaries.

Each of the boundaries has its own origin and specific, which is important to understand in order to apply right approach to overcome it.

The case company is in a phase of continuously implementing concurrent engineering methods to the engineering construction projects which in turn are supported by BIM and other ICT tools. The 3D model is seen as an advantageous boundary object, which is used as a supportive tool during the concurrent meetings and helps members of different disciplines, groups and levels of organisation to bridge boundaries and most importantly, facilitate the communication between design-team participants help them overcome knowledge boundaries and enable knowledge sharing.

But as was concluded from the interviews, particularly BIM is today not fully utilized in relation to its potential advantageous use, due to a lot of different reasons. In order to be fully utilized and to take advantage of all beneficial features it may provide, BIM further still needs to be developed, utilized and integrated in the processes, not only in the design phase, but also in all succeeding phases.

Furthermore, in order to facilitate the use of BIM and other ICT-tools in the organisation, specific strategically boundary spanning roles should be set, which have the function and ability to connect participants across boundaries and through hindrances, as is the role of for example the 3D coordinator in the case company.

A boundary spanner, in this case the 3D-coordinator, plays an important role in the crucial collaboration processes of the design team and is seen as a advantageous asset by most team participants and in the organisation.

In this case, the role of the 3D coordinator did not only support communication processes with the use of ICT tools, such as 3D model, which in fact is a boundary object. In addition the 3D coordinator also worked to overcome resistance against the implementations and use of new methods and tools, and therefore played a strategic role as well.

Research question 2 - How can knowledge transfer through communication be improved through the use of BIM in design teams?

In order to comprehend how communication through the use of BIM in a design phase can be improved, it is of importance to identify the extent to which BIM is applied today in the company. This is done by classifying which stage of maturity level of BIM is currently performed and to which extent it can be developed, in order to reach higher stages of BIM maturity levels.

The BIM and ICT-tools, which are used today, are powerful tools, which provide a lot of beneficial advantages and opportunities for facilitating communication between the dispersed members of the multi-disciplinary design team.

At the case company, BIM is currently used as a tool, which supports visualisation, 3D coordination and collision control functions.

The fact that BIM facilitates communication in this case implies that knowledge transfers are also implicitly facilitated, however there are still a lot of hindrances, which prevent further development of BIM within the company, one of the reasons is derived to the lack of integration.

BIM, how it is developed in the company today corresponds to the first level of maturity, which can be useful internally within each discipline-group of the design team, but still has a lot of difficulties with multidisciplinary collaboration.

Due to the fact that most challenges appear to primarily be related to semantic and pragmatic knowledge boundaries within the design team and the design phase, BIM should preferably be incorporated to the second level of maturity, in order to correspondingly facilitate the bridging of knowledge boundaries which are shown as multidisciplinary misunderstandings.

The tools of BIM are however not fully utilized in its complete capacity. The further development of BIM is inhibited by several factors, such as by software interoperability issues, contractual forms, lack of specific organisational strategies etc. However, we recognize that the implementation of BIM have to be developed in the developing pace corresponding to the rest of the construction industry.

This paradigmatically implies that the higher level of BIM maturity achieved within a design team, the better will the performed communication within the multidisciplinary participants be.

6.2 Recommendations for future research

During the investigation and study of this thesis, a great number of interesting sub-subjects were faced. However, these were not aligned within the scope of this study, and are therefore subjected as recommendations for future research.

- The experience from oil and gas industry revealed that good communication with the help of ICT-tools may actually be reached in the design team, however with the help of adequate strategic support from the organisation. As was said before, the key success factors in the oil and gas projects are: (a) earliest involvement of all stakeholders, especially it is quite important that the client is from the industry, and is motivated in collaboration from the very beginning; (b) more proper contractual forms and agreements should be reached between all actors, so it is easier to meet all requirements and timeframes, and to reach integration; (c) advanced development of ICT tools, so it is easier to fast get input and output for all specialist; (d) clear roles and responsibilities of design team members and also new roles in design team which can support better ICT communication. Based on these findings, for future research we recommend a study of to which extent the success factors from oil and gas (a),(b),(c),(d), are present in the design-phase or design-teams work in the construction industry, and if not, how to approach a implementation of the success factors.
- In order to overcome pragmatic boundaries, in form of resistance against new implementations in an organisation, it is suggested that incentives may play an important role of overcoming such boundaries. For future research we recommend an investigation and study of how, and which specific incentives may play a role in order to overcoming pragmatic boundaries in the context of resistance within participants against new implementations, such as BIM within construction project design-teams.
- In order to implement further levels of maturity regarding BIM, the existent ways of working should be rethought in organisation. The clear responsibilities as well as new specific roles in the design team should be set and new appropriate contractual schemes should be implemented in order to provide better integration between all participants and thereafter improve communication with the help of BIM.

7 References

Anumba, C. J., Bouchlaghem, N. M., Whyte, J. and Duke, A. (2000): Perspectives on an integrated construction project model. *International Journal of Cooperative Information Systems*, Vol. 9, No. 3, September 2000, pp. 283-313.

Aranda-Mena, G., Crawford, J., Chevez, A. and Froese, T. (2009): Building information modelling demystified: does it make business sense to adopt BIM?. *International Journal of Managing Projects in Business*, Vol. 2, No. 3, June 2009, pp. 419-434.

Bernstein, P. G. and Pittman, J. H. (2004): Barriers to the adoption of Building Information Modelling in the building industry. *Autodesk building solutions*, November 2004, pp. 1-14.

Bosch-Sijtsema, P. M. and Henriksson, L. H. (2014): Managing projects with distributed and embedded knowledge through interactions. *International Journal of Project Management*, Vol. 32, No. 8, November 2014, pp. 1432-1444.

Bowen, P. A. and Edwards, P. J. (1996): Interpersonal communication in cost planning during the building design phase. *Construction Management & Economics*, Vol. 14 No. 5, September 1996, pp. 395-404.

Bröchner, J. and Olofsson, T. (2012): Construction productivity measures for innovation projects. *Journal of Construction Engineering and Management*, Vol. 138, No.5, May 2012, pp. 670-677.

Bryman, A. and Bell, E. (2003): *Business research methods (1st edition)*. Oxford University Press, Oxford, 2003, 608 pp.

Bryman, A. and Bell, E. (2015): *Business research methods (4th edition)*. Oxford University Press, Oxford, 2015, 778 pp.

Carlile, P. R. (2002): A pragmatic view of knowledge and boundaries: Boundary objects in new product development. *Organization science*, Vol. 13, No. 4, July 2002, pp. 442-455.

Clausing, D. (1994): *Total quality development: A step-by-step guide to world-class concurrent engineering*. ASME Press, New York, 1994, 506 pp.

Clegg, S., Kornberger, M., Pitsis, T. (2011): *Managing & Organizations: An introduction to theory & practice (3rd edition)*. SAGE Publications Ltd., London, United Kingdom, 2011, 682 pp.

Cook, S. D. and Brown, J. S. (1999): Bridging epistemologies: The generative dance between organizational knowledge and organizational knowing. *Organization science*, Vol. 10, No. 4, August 1999, pp. 381-400.

Dainty, A., Moore D., Murray, M. (2006): *Communication in construction: Theory and practice*. Taylor & Francis, London, United Kingdom, 2006, 263 pp.

Dubois, A. and Gadde, L. E. (2002): Systematic combining: an abductive approach to case research. *Journal of business research*, Vol. 55, No. 7, July 2002, pp. 553-560.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2008): *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*. Wiley Publishing, New Jersey, 2008, 504 pp.

Fellows, R. and Liu, A. M. (2012): Managing organizational interfaces in engineering construction projects: addressing fragmentation and boundary issues across multiple interfaces. *Construction Management and Economics*, Vol. 30, No. 8, August 2012, pp. 653-671.

Giel, B. and Issa, R. (2013): Quality and maturity of BIM implementation within the AECO industry. *Applied Mechanics and Materials*, Vols. 438-439, October 2013, pp. 1621-1627.

Gherardi, S. and Nicolini, D. (2000): To transfer is to transform: The circulation of safety knowledge. *Organization*, Vol. 7, No. 2, May 2000, pp. 329-348.

Jennex, M. E. (2009): Re-visiting the knowledge pyramid. *System Sciences, 2009. HICSS'09. 42nd Hawaii International Conference*, January 2009, pp. 1-7.

Khalfan, M. and Raja, N. (2012): Improving construction process through integration and concurrent engineering. *Australasian Journal of Construction Economics and Building*, Vol. 5, No. 1, November 2012, pp. 58-66.

Khosrowshahi, F. and Arayici, Y. (2012): Roadmap for implementation of BIM in the UK construction industry. *Engineering, Construction and Architectural Management*, Vol. 19, No. 6, November 2012, pp. 610-635.

Knight, M. D. (2008): Teams, contracts & BIM. *Ashrae Journal*, Vol. 50, No. 9, September 2008, pp.72-80.

Lam, P. T. I., Wong, F. W. H. and Tse, K. T. C. (2010): Effectiveness of ICT for construction information exchange among multidisciplinary project teams. Journal of Computing in Civil Engineering, Vol. 24, No. 4, July 2010, pp. 365-376.

Lee, A., Wu, S., Marshall-Ponting, A. J., Aouad, G., Cooper, R., Tah, J. H. M. and Barrett, P. S. (2005): *nD Modelling Roadmap: A Vision for nDEnabled Construction*. University of Salford, Salford, United Kingdom, 2005, 106 pp.

Newell, S., Robertson, M., Scarbrough, H., and Swan, J. (2009): *Managing Knowledge, Work and Innovation (2nd edition)*. Palgrave Macmillan, Hampshire, 2009, 277 pp.

Nof, S. Y. (2009): *Springer handbook of automation*. Springer Science & Business Media, Leipzig, Germany, 2009, 1840 pp.

Nonaka, I., Toyama, R., and Konno, N. (2000): SECI, ba and leadership: A unified model of dynamic knowledge creation. *Long Range Planning*, Vol. 33 No. 1, February 2000, pp. 5-34.

Quantumblack (2012): *Organisation. Transforming the capabilities of firms to bloom in the new world of data*. Retrieved August 9, 2015, from http://www.quantumblack.com/organisation-transforming-the-culture-of-firms-to-bloom-in-the-new-world-of-data/

Reinertsen (2015): *Our approach*. Retrieved June 1, 2015, from http://www.reinertsen.se/vart-arbetsstt.

Senaratne, S. and Gunawardane, S. (2015): Application of team role theory to construction design teams. *Architectural Engineering and Design Management*, Vol. 11, No. 1, January 2015, pp. 1-20.

Succar, B. (2009): Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in construction*, Vol. 18. No. 3, May 2009, pp. 357-375.

Tsoukas, H. and Vladimirou, E. (2001): What is organizational knowledge?. *Journal of management studies*, Vol. 38, No. 7, November 2001, pp. 973-993.

Yeow, J. (2014): Boundary management in an ICT-enabled project-based organising context. *New Technology, Work and Employment*, Vol. 29, No. 3, November 2014, pp. 237-252.

Zidane, Y. J., Stordal, K. B., Johansen, A. and Van Raalte, S. (2015): Barriers and Challenges in Employing of Concurrent Engineering within the Norwegian Construction Projects. *Procedia Economics and Finance*, 2015, Vol. 21, pp. 494-501.